Geology and Mineral Resources of the Hardin and Brussels Quadrangles (in Illinois)

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ABSTRACT

The Hardin and Brussels quadrangles lie in west-central Illinois on the northeast flank of the Ozark uplift and near the juncture of Mississippi and Illinois Rivers. Their area includes part of one of the sharpest zones of rock deformation in Illinois—the Cap au Grès faulted flexure, which separates the broad asymmetric Lincoln anticline and the Troy-Brussels syncline. The anticlinal uplift brings to the surface many early, middle, and late Paleozoic formations; two Pleistocene ice sheets advanced into but not across the area; and the two large rivers are bordered by a series of persistent terraces. The geology of this small area is thus in many respects a key to the interpretation of the stratigraphy, structure, physiography, and economic geology of a much larger region.

Rock formations.—The formations exposed are listed in the stratigraphic table on page 12. Faunal lists of Ordovician, Silurian, Devonian, Mississippian, Pennsylvanian, and Pleistocene fossils identified by specialists are given in separate tables.

Most of the Ordovician formations are exposed in only a small part of the area, but the Maquoketa shale is exposed more widely and thickens northeastward.

The Silurian rocks thicken northward, eastward, and southward from a central area. North of this central area they are chiefly very pure limestone; south of it they are all one uniform type of dolomite that is thought to be the result of subsequent alteration.

The Devonian rocks overlap the Silurian formations northward and southward from a central area of maximum thickness. At their southern margin the Devonian rocks are represented by a thin fossiliferous sandstone that shows an exceptionally perfect enlargement of all quartz grains.

The two lowermost Mississippian formations are restricted to the northeastern part of the area and are overlapped southwestward by the higher formations. All the formations of the Kinderhook group except the Chouteau limestone thicken northeastward down the flanks of the present Lincoln anticline, thereby recording—with the confirmation afforded by faunal differences on the two sides—the early growth of this fold. The Hannibal shale grades laterally southward as well as stratigraphically upward into the Chouteau limestone. This gradation, together with the excellent preservation of thin laminations in the Hannibal and the irregular bedding in the Chouteau, seems to indicate that the Chouteau limestone was deposited on a shallow bank formed by the rising anticline.

A short distance from the eastern margin of the area and along the line of the Cap au Grès flexure, the lower part of the Osage group of Mississippian rocks appears to grade laterally into the Fern Glen formation. Early movements along the flexure are shown by a slight angular unconformity at the base of the Osage group. A feature of special interest is the occurrence of two distinct types of chert in the Burlington limestone: common sharply outlined nodules and thick beds of irregularly silicified limestone.

The Meramec group of Mississippian formations thickens eastward down the trough of the Troy-Brussels syncline. Especially noteworthy features of the rocks of this group are the characteristic mammillary geodes which show evidence of progressive silicification upon weathering; the beds of clastic, somewhat cross-bedded limestone and the peculiar limestone conglomerates in the St. Louis limestone; and the appearance in these beds for the first time of sand grains of igneous and metamorphic origin, indicating some unknown but probably significant paleogeographic changes at that time.

The Pennsylvanian strata thicken southwestward and lie with marked unconformity upon different Mississippian formations. In the Troy-Brussels syncline they rest on a very irregular surface trenched in the youngest Mississippian rocks, but scattered remnants show that they once overlapped extensively onto older Mississippian formations on the Lincoln anticline. This unconformity and the overlap show that the anticline was uplifted and stripped of at least 400 feet of beds before the Pennsylvanian was deposited. Features of special interest are the occurrence, in the syncline in the southern part of the area, of continuous beds of fire clay composed of coarsely crystalline beidellite with a few large sand grains of quartz and fresh feldspar, and, on the anticline to the north, scattered remnants of flint clay composed of fine-grained kaolin and halloysite.

No Mesozoic rocks are known in the region.

The Tertiary is represented by thin and scattered remnants of gravel, sand, and clay that lie in a long north-south zone upon the flat upland surface along Mississippi River. These beds, formerly known as the "Lafayette," are here renamed the Grover gravel. The deposits appear to become coarser-grained southward toward the Ozarks, but where they are best exposed, the direction of cross bedding indicates deposition by a southward-flowing stream. The gravel consists entirely of quartzose materials—chiefly chert but also some large boulders of quartzite and a few pebbles of silicified metamorphic rocks. The distinctly foreign materials may have been reworked from nearby outcrops of Pennsylvanian rocks instead of having been transported directly from more distant regions. The associated sand differs markedly from the gravel in that it shows no evidence of silicification and contains grains of fresher feldspar. The formation seems not to have been deposited by glaciers or the sea or as residual accumulations, but by streams. Yet, analogy with present rivers indicates that streams sloping gently enough to fashion the peneplained surface on which the gravel rests would be unable to transport such large boulders. This difficulty, together with the probability that the gravel was preserved by uplift soon after being deposited, suggests deposition by rejuvenated streams. Such rejuvenation seems best explained by a gentle uplift of the Ozarks.

Accumulations of residual chert and clay, locally as much as 40 feet thick and chiefly early Pleistocene and Tertiary in age, are widely distributed outside the glaciated areas.

The Pleistocene deposits of the area, some of which are highly fossiliferous, are varied and widespread. No evidence of Nebraskan till was recognized in or near the area of the two quadrangles, but it is known to occur only a short distance to the northeast. Deeply weathered stream gravels near Batchtown evidently were deposited in an old strike valley when Mississippi River was forced eastward out of its channel by a tongue of the Kansan ice sheet.

Till left by the Illinoian ice sheet covers an irregular bedrock surface east of Illinois River. Streams draining off a small unglaciated area east of Illinois River were ponded by the edge of the ice, and varves in the pond sediments record 800 or more years of deposition. The Brussels formation makes the conspicuous Brussels terrace and fills old valleys along the Mississippi and lower part of Illinois River to heights of about 100 feet above the present river level. At St. Louis, Mo., this

formation and the terrace formed by it end sharply against a till dam formed where the Illinoian ice sheet crowded westward across the river. Local details in the two quadrangles seem to show, however, tnat this formation is the result of slow alluvial aggradation rather than sudden ponding. Loess is the most widely exposed deposit in the area, for it mantles to a depth of many feet the uplands, the slopes, and all but the most recently formed valleys. It apparently was formed as glacial rock floor, carried southward and spread in wide mud flats by major rivers, and then blown to the uplands by wind.

Scattered pebbles on an intermediate, the Metz Creek, terrace near the mouth of Illinois River may possibly be deposits left by a river flood of Wisconsin age. The still younger Deer Plain formation makes the conspicuous Deer Plain terrace, which stands about 40 feet above the normal level of Mississippi River. This formation slopes northward up the Illinois Valley. the terrace surface slopes northward up the Illinois Valley. The evident deposition of the Deer Plain formation under conditions of a flooded Mississippi and a partially dammed Illinois River suggest a very late Wisconsin age, for it seems clear that this formation must be younger than any large late Wisconsin flood that may have been spilled southward through the Chicago Outlet and the Illinois Valley.

Comparison of the constituent rock materials and the heavy minerals in samples of the Deer Plain and Brussels formations shows only a few differences between the two that are significant. The apparent differences of composition seem much more closely related to the average grain size of the different samples than to their ages, the heavier rocks and minerals being most abundant in the predominantly finer grained samples. This relationship might be caused entirely by processes of transportation and sedimentation.

Calcareous tufa was found in several places, built up by present-day and ancient springs into cones a few feet to several hundred feet in diameter. The peculiar concentric and radial structure of this tufa is ascribed by David White to algal growths.

The Recent alluvium of the major rivers averages several miles in width and probably 50 to 75 feet in thickness. It attains fairly uniform maximum thicknesses of about 100 feet along Illinois River but appears to thicken very gradually upstream along the Mississippi. Actual exposures, soils, bottom samples, and drill records all indicate that silt and fine sand are the dominant constituents of this alluvium. Coarse gravel is very rare and its scarcity suggests that the pebbles and boulders being dumped into the rivers by steep tributaries and from undercut banks of Pleistocene gravel are undergoing rapid abrasion by passing sand and silt.

Physiography.—On the physiographic maps, the fairly large, deeply dissected, and driftless area which centers in Calhoun County, Ill., and Lincoln County, Mo., lies within the Till Plains and Dissected Till Plains sections of the Central Lowland province and just north of the margin of the Ozark Plateaus province. It is here proposed to designate this area as the Lincoln Hills section of the Ozark Plateaus province.

The uplands of the Hardin and Brussels quadrangles are remnants of a very flat and widespread surface that bevels across rock structure and carries old stream gravels and weathered residuum. This upland surface is here called the Calhoun peneplain and is believed to have been formed in Miocene or early Pliocene time. In a very broad way, but not in detail, this peneplain follows the basal contact of the Pennsylvania rocks, thereby suggesting that differences in rock hardness may have partially controlled the regional base level when the peneplain was being formed.

The distribution of the Grover gravel and an empirical classification of the dip, strike, and oblique valleys of the region suggest that the drainage pattern on the peneplain may have comprised the ancestral Mississippi and Illinois, two southward-flowing streams, joined by the ancestral Missouri, an eastward-flowing tributary, and continuing southward along the east flank of the Ozarks toward the head of the Mississippi embayment. Such a drainage pattern probably developed long after the supposed original radial drainage consequent to the post-Pennsylvanian uplift of the Ozarks. It may possibly have developed by headward erosion from the Mississippi embayment along strike valleys lateral to the earlier radial drainage off the Ozarks. A post peneplain diversion of the ancestral Mississippi by late Tertiary warping is postulated to account for the present river course past Alton, Ill., and St. Louis, Mo.

Two periods of rejuvenation and dissection followed the development of the Calhoun peneplain and preceded the first invasion of Pleistocene ice. The first period followed a renewed uplift and warping of the Lincoln anticline and gave rise to broad postmature valleys one to three hundred feet below the peneplain. The second followed either a vertical uplift without tilting or a climatic change and resulted in sharp trenching of the major valleys to at least their present depths.

This preglacial trenching evidently formed deep narrow valleys, but lateral planation by the rivers soon began to cut back the bluff walls. Evidence indicates that within these two quadrangles Illinois River has encroached chiefly on its western bank but that eastern walls of both the Mississippi and Illinois troughs have also receded considerable distances. The deepest scouring by the two major rivers probably occurred before the Illinoian glaciation and possibly at the time of this pre-Nebraskan trenching. During the dissection of the peneplain many tributary valleys developed headward along lines of weakness, following joint planes and outcrops of shale beds, exhuming pre-Pennsylvanian valleys, and making characteristic "stratum benches" at the outcrops of different flatlying resistant rocks.

The land surface was repeatedly modified during the numerous Pleistocene changes, and the major trenching of the area was followed by four or more periods of alluvial aggradation, each of a different type: three in the Pleistocene and one in Recent times.

The Kansan ice sheet left a monotonously flat till plain on the uplands of northern Missouri. Just west of the Hardin and Brussels quadrangles the margin of the ice was exceedingly lobate, even leaving nunataks near its edge. Apparently a tongue of this Kansan ice sheet extended across the Mississippi trough, damming the river and temporarily diverting it eastward through a strike valley here called the Batchtown Channel. The Illinoian till plain on the uplands east of Illinois River is less dissected than the Kansan till plain and, here and there on its surface, carries large drumloidal mounds. Both the Kansan and Illinoian till plains are almost solely the result of glacial deposition; there is little direct evidence of ice erosion in the area. Terminal moraines are absent at the former margins of both ice sheets.

The Brussels terrace, an aggradational or constructional land form composed of the Brussels formation, is widespread and conspicuous. It was built near the margin of the Illinoian ice sheet, yet it shows no evidence of any "peripheral bulge" caused by loading of the earth's crust with ice. The Metz Creek terrace is a relatively inconspicuous cut surface that stands somewhat lower. Along the margins of the two river flood plains are many alluvial fans that head at elevations approximately accordant with the Brussels or the Metz Creek levels. The Deer Plain terrace, another aggradational land form, is widespread along Mississippi River. Near the mouth of Macoupin Creek there is evidence of drainage modifications and many of the terrace levels there are not matched on opposite sides of the creek. The complex terrace system at this locality seems to be due largely to slow degradation as the creek swung from side to side in its valley.

Minor modifications of the topography since the Pleistocene have, on the uplands, consisted largely of exhuming small pre-Illinoian valleys and of sharp gullying of steep slopes within historic time. On the flood plains, both rivers have cut vertically and shifted laterally since the Deer Plain formation was deposited. Mississippi River still continues to shift its channel, leaving bars and swales on its flood plain, but the Illinois has maintained a remarkably stable course throughout historic time and built up well-defined natural levees.

Mississippi and Illinois Rivers in this area are not truly meandering streams; their irregularities of channel are largely the result of braiding. Alluvial islands are a conspicuous element in both rivers and in adjacent parts of Missouri River. These islands are most abundant and largest near the mouths of tributary streams, a fact which together with other evidence seems to show that the islands have grown from deposits brought in by side streams. This process of island growth is believed to account for the fact that Mississippi River crowds closely against the inside of its curved trough as it sweeps around the southern end of Calhoun County. The effect of this island growth upon a stream's regimen is an interesting problem both in theoretical physiography and in practical river engineering. Apparently the subdivision into two channels and the adoption of a more roundabout course does not decrease but actually somewhat increases the river's cutting and transporting power. Measurements of the channel dimensions above, opposite, and below the very stable islands in Illinois River suggest that this increased cutting power may result from the relative deepening of each of the two branches and from the increased area of erodible channel walls exposed to running water.

A table comparing the mean discharge, velocity, width, depth, suspended load, and slope of adjacent portions of Illinois, Mississippi, and Missouri Rivers shows that the Illinois and Missouri have very different regimens. The Illinois is characterized by a very flat slope, a low velocity, and a proportionately deep and narrow channel and the Missouri by exactly the opposite conditions. The channel of the Illinois is remarkably stable and the line of deepest water crowds not the outside but the inside of the bends.

An attempt to interpret the peculiar features of Illinois River leads to a general discussion of dynamic equilibrium in streams. The concept of graded stream slopes has long been familiar in geology and geography, but the analogous concept of adjusted-channel cross-sections is no less important. Because of friction with the channel walls, streams tend to establish the most nearly semicircular cross-sections possible. But, since natural streams flow in crooked channels between erodible banks, the cross-sections they can maintain are very much flatter than semicircles. The concepts of graded slopes and adjusted cross-sections may be combined in the generalization that cutting by a stream, either at its bottom or its sides, tends to reduce the velocity of flow and that deposition at either place tends to increase the velocity. This means that, for a given set of conditions of total load, grain size, and stream discharge imposed upon a stream, there is an inverse relation between slope and the depth-width ratio and that these two variables are determined not separately but jointly. In other words, the profile of a perfectly graded stream may vary irregularly from place to place, depending upon the shape of the channel cross-section. This interpretation of cross section adjustment seems to be confirmed by the published results of experimental work and by measurements of artificial canals and natural streams.

The concept of adjusted cross-sections thus offers a possible explanation of the deepening of certain rivers as they approach base level and of the sometimes obvious effect upon present stream profiles of the preexistent land surfaces. It also affords a basis for the interpretation of the peculiar features of Illinois River. The exceptionally flat gradient of the bedrock floor, which presumably was cut by some much larger glacial or preglacial river, together with the later condition of backwater from the Mississippi, has favored a maintenance of equilibrium in the present Illinois, not by building up a steeper slope but by establishing a deep and narrow channel.

Structure.—The Hardin and Brussels quadrangles include part of the Lincoln anticline, a broad asymmetrical fold that lies far down on the northeast flank of the Ozark dome. The southern limb of this anticline is marked by a narrow belt of steep dips and essentially vertical faults that here is called the Cap au Grès faulted flexure. South of this narrow flexure the beds again rise gently toward the Ozarks, thereby forming the broad asymmetrical Troy-Brussels syncline. The gentle dips on the north limb of the Lincoln anticline are interrupted by a more or less systematic pattern of minor folds, but no evidence of such minor folds was found south of the Cap au Grès flexure. Along most of the flexure the structural relief averages about 1,000 feet and the maximum dip is about 70°, but locally the uplift is greater and the beds are overturned. Although this narrow belt of disturbed rocks was interpreted by early geologists as one fault throughout its entire length, detailed mapping now shows that faulting is discontinuous and distinctly subordinate to flexing. In many places the faults in the Cap au Grès flexure are normal, but at some places they seem to be steep reverse faults. The evidence suggests that a fairly uniform monoclinal flexure was later broken by local strike faults that increased the structural relief of the deformed zone. Small transverse faults, along which the movement appears to have been chiefly horizontal, cut across the flexure.

Two of the principal conclusions of the report are that the deformation of the region continued intermittently through a long part of geologic time and that this long continued deformation followed a rather definite sequence of events. Preliminary movements in middle Paleozoic times culminated in a major deformation before the Pennsylvanian and waned with several later uplifts that may possibly be continuing at the present time. More specifically, stratigraphic evidence shows the repeated warping of the region in Silurian and Devonian times and the integration of smaller units into the Lincoln anticline and the Troy-Brussels syncline in the early Mississippian. The major folding, which occurred sometime between St. Louis and Pottsville deposition, took place under surprisingly shallow cover. Physiographic evidence shows that later recurrent movements took place not only before the Tertiary peneplain was completed but again before the Pleistocene ice sheets advanced into the region and that the displacements then were dominantly vertical. Earthquakes in historic time may possibly record a continuation of these movements.

Interpretation of the structural features is considered under three headings. First, the evidence clearly contradicts the belief that folding along the Cap au Grès flexure might have been the result of "drag" along normal faults and it seems instead to prove folding by horizontal compression.

Secondly, it is pointed out that the structural features of the area might possibly be accounted for by movements along a deep-seated reverse fault which did not reach the surface beds.

Thirdly, the probable significance of normal faults associated with compression folds involves a general consideration of the surface-volume relationships in a deformed block. The hypothesis is offered that tensional faults do not necessarily mean relaxation from earlier compression and a change to crustal extension, but that eventual stretching of surficial beds squeezed upward by continued compression is a mechanically simpler explanation and one that better fits the progressive structural history of the area.

Economic geology.—The development of mineral resources in the Hardin and Brussels quadrangles has been hindered by poor transportation facilities. A great variety and quantity of easily quarried limestones are available, and certain of the less common types not now being utilized might be of commercial value even under present conditions. Chemical analyses of typical limestones and dolomites from twelve formations and physical tests of seven of these samples are given.

The abundant supplies of cement materials in the area may some day prove valuable. Large quantities of shale are available, fire clay occurs widely in southern Calhoun County, and small but workable bodies of flint clay have been found on the uplands. Chemical analyses of three samples of shale and ceramic tests of three samples of fire play, two samples of shale, and one sample of flint clay are given.

One bed of workable coal occurs in the area. This bed attains a maximum thickness of 2½ feet and has been mined at many places for local use. An analysis is given of the coal from this bed.

Sand and gravel are widespread in the Hardin and Brussels quadrangles but, at the present time, the deposits of these materials are not being utilized. The St. Peter sandstone, quarried elsewhere in the Middle West, crops out at Cap au Grès. Sieve analyses and physical and molding sand tests are given of two gravel and three sand samples.

Soil is doubtless the most valuable mineral resource of the area, for the many orchards there depend largely for their success on the presence of thick deposits of wind-blown loess on the uplands. Ground-water supplies are little utilized at present, but they are probably adequate for all future needs.

Despite favorable structure, prospects seem very poor for commercial production of oil and gas because no indication of petroleum has been found in the entire section of rocks exposed in the area. However, thin beds of oil shale—the Decorah limestone—crop out in part of the area.

Very thin discontinuous beds of impure phosphate come to the surface locally, and very small quantities of metallic sulfides are found in some of the formations, but the presence of both phosphate and metals is of scientific rather than commercial interest.

GEOLOGY AND MINERAL RESOURCES OF THE HARDIN AND BRUSSELS QUADRANGLES (IN ILLINOIS)

By William W. Rubey

INTRODUCTION

The geology of the Hardin and Brussels quadrangles is of special interest for several reasons: (1) These quadrangles constitute one of the few places within the State of Illinois where many different kinds and considerable thicknesses of Paleozoic rocks come to the surface, so that the area is exceptionally favorable for their study. (2) One of the most intensely deformed zones of rock structure within the entire State lies in the Brussels quadrangle. (3) Two of the Pleistocene ice sheets advanced into but not across this area, thus affording excellent opportunities for studying marginal features of the ice and for comparing the effects in glaciated and unglaciated regions. (4) Two large rivers, the Mississippi and the Illinois, cross the quadrangles, and these have left there a record of their long and complex histories.

Exact knowledge of the geology of any region has two principal uses: It serves to place on record descriptions of those mineral resources having past, present, or potential commercial value, and it affords a guide to the successful exploitation of nearby areas. Not less important is its function of elucidating the many events that have taken place during the geologic history of the region, for by this means it advances the science of geology and stimulates and broadens the interests of all the people in the nature and history of the earth on which they live.

The investigation upon which this report is based was undertaken upon the intiative of the State Geological Survey of Illinois and under a cooperative arrangement with the United States Geological Survey. The investigation had a dual purpose: (1) To study the exposed rocks so that potentially valuable mineral resources within the area might be utilized effectively and so that the different rock layers drilled through in wells elsewhere in the State might more readily be recognized and (2) to record the interesting geologic history and make it more readily available for educational purposes.

The field work in the area was carried on by the writer during 8 months in the summer and fall of 1928 and the spring and summer of 1929, with the valuable assistance of J. R. Ball for 2 months in 1928. The mapping was done upon copies of the then unpublished topographic sheets of the Hardin and Brussels quadrangles, enlarged to a scale of 2 inches to the mile. Although rock exposure are more numerous in these two quadrangles than in most parts of Illinois, lateral tracing of the different rock units, in the strict sense of the term, is impossible for more than very short distances because of the thick mantle of Pleistocene loess.

This widespread mantle of Pleistocene loess raised thorny questions about the best method of cartographic representation for the geologic map. A map of actual rock outcrops in the Hardin and Brussels quadrangles, on the published scale of 1:62,500, would show only narrow bands of bare-rock exposure along the most precipitous bluffs and in the beds of the most steeply falling creeks, with small isolated patches scattered here and there on hillsides. Such an actual outcrop map would be exceedingly difficult to read and, in fact, it would grossly underestimate the amount of definite information that is readily available on distribution of bedrock formations that lie a few feet underground over large areas in the two quadrangles. Soils and loose fragments of rock disclose the nature of the underlying rock in many places and a thin mantle of loess merely blankets and does not obscure the topographic forms characteristic of different rock formations. Consequently, the areal distribution of rock formations can be shown with considerable accuracy where the rocks lie at or only a few feet below the surface of the ground.

But where the mantle of Pleistocene loess is many tens of feet thick, these clues as to the nature of the underlying bedrock are missing. In such places—usually on hilltops, ridges, and flat benchlands—the presence of certain rock formations immediately beneath the loess cannot safely be inferred from bedrock elevations at distant or even at nearby exposures. Rock formations younger than the highest ones exposed any-

Note.—This report was transmitted by the author in 1931, and after critical reading and suggestions by others it was revised and retransmitted to the State of Illinois for publication in 1936. Unfortunately publication was not possible, and circumstances do not now permit the revision necessary to bring the report up-to-date. To avoid further delay it is published in its present form.

where on a hillside may underlie the loess that caps the hill. Furthermore, even if it were certainly known that a particular rock formation underlies a cover of 60 to 80 feet of loess, it would be very misleading to indicate that rock formation on the geologic map. For to do so would mean, by any normal map interpretation, either that the formation there is 60 to 80 feet thicker than the evidence indicates or that the thickness is normal but that the rocks have been so deformed at that place as to raise them 60 to 80 feet above their normal position.

Between these two objectionable extremes of an almost uninterpretable outcrop map on the one hand and an unduly theoretical and misleading bedrock map on the other, some intermediate compromise had to be chosen. The compromise adopted for the geologic map of these quadrangles (pl. 1) is to show the pattern of underlying rock formations where surficial loess and soil are relatively thin and the loess pattern where surficial deposits completely obscure all topographic evidence of the underlying bedrock. The maximum thickness of loess omitted from the map by this convention is not certainly known; but from numerous local exposures it appears to be distinctly less than 20 feet, the contour interval of the topographic map, and probably is about 10 feet.

ACKNOWLEDGMENTS

The writer wishes to express his great indebtedness to the many geologists who by their discussions, suggestions, and criticisms during the field examination and the later office preparation have contributed largely to the final report. E. O. Ulrich and Edwin Kirk, of the Federal Geological Survey, studied the collections of fossils from the Ordovician rocks and advised in the interpretation of the stratigraphic relations of these rocks. T. E. Savage, of the University of Illinois, visited the writer in the field, examined the Silurian and Devonian fossils, and helped to interpret the rocks of those ages. J. M. Weller, Illinois Geological Survey, and R. C. Moore, Kansas Geological Survey, held field conferences with the writer on problems of the Mississippian rocks, and J. M. Weller, J. B. Knight, Jr., Yale University, and David White, Federal Geological Survey, conferred on problems of the Pennsylvanian rocks. J. M. Weller studied the collections of Mississippian and Pennsylvanian fossils. F. C. Baker, University of Illinois Museum, examined the Pleistocene fossils. After Dr. Baker's death, Dr. J. P. E. Morrison, of the U. S. National Museum, kindly completed the arrangement of Pleistocene fossils into taxonomic order and environmental groups. Field conferences with W. C. Mendenhall, Federal Geological Survey, on the physiographic history and with M. M. Leighton, Illinois Geological Survey, on the Pleistocene rocks, were exceedingly valuable. Similar conferences with F. E. Matthes, H. D. Miser, and G. R. Mansfield, of the United States Geological Survey, and Paul MacClintock, of Princeton University, contributed largely to the work. A brief field conference in western St. Louis County, Mo., with R. B. Cozzens, W. D. Shipton, and G. A. Quackenbush, of Washington University, afforded valuable information about the Tertiary gravels. J. E. Lamar, Illinois Geological Survey, visited the field and helped greatly in problems of economic geology. T. B. Root and Robert Gillson, Illinois Geological Survey, part of the time in company with Lamar and the writer and part of the time alone, collected numerous samples for analysis and laboratory testing.

The Lighthouse Service, Department of Commerce, made possible a very instructive trip on Mississippi River from Hamburg to Alton on its steamer *Wakerobin*. The United States Engineer Office, War Department, extended an opportunity, which unfortunately was lost because of conflicting arrangements, for a similar trip on the lower Illinois River, and the War Department also loaned copies of its very detailed surveys of Illinois River.

Samples were analyzed and tested in the laboratories of the Illinois Geological Survey, the State Highway Department of Illinois, and the Department of Ceramics of the University of Illinois. H. S. McQueen, of the Missouri Geological Survey, made laboratory examinations of samples from the oldest rocks exposed within the region. C. S. Ross, United States Geological Survey, gave advice in the petrographic examination of other samples by the writer, and G. H. Girty, United States Geological Survey, helped materially in the interpretation of diamond drill cores. W. O. Hazard, United States Geological Survey, took photographs of the rock samples. (See pls. 4, 6*A*, 7*A*, *B*, 8*B*, *C*, 12*A*.)

Many of the geologists mentioned above and several others read and helpfully criticized parts of the manuscript—specifically W. C. Alden, W. H. Bradley, M. R. Campbell, G. E. Ekblaw, James Gilluly, M. I. Goldman, D. F. Hewett, Edwin Kirk, J. E. Lamar, M. M. Leighton, J. H. Mackin, G. R. Mansfield, F. E. Matthes, H. D. Miser, T. E. Savage, E. O. Ulrich, J. M. Weller, J. S. Williams, and M. G. Wilmarth. Acknowledgments would be incomplete without a grateful mention of those of the writer's colleagues who by their interest in and generous discussion of the problems of this area have furnished ideas and thus influenced the final report. It would, in fact, be difficult to exaggerate the extent of the contributions by others to this work, and whatever of merit the report may contain should properly be credited to them. Nevertheless, the writer assumes full responsibility for all statements of fact and opinion that are not specifically referred to other individuals.

GEOGRAPHY

LOCATION

The Illinois part of the Hardin quadrangle is bounded on the north by Lat. 39°15′, on the east by Long. 90°30′, on the south by Lat. 39°00′, and on the west by the Missouri State line, which here follows the main channel of the Mississippi River. The Illinois part of the Brussels quadrangle is bounded on the north by the Hardin quadrangle, on the east by Long. 90°30′, and on the south and west by the State line or the channel of the Mississippi River. They are both partial quadrangles in that they include only those parts of the two 15-minute maps that lie within the limits of the State of Illinois. The two quadrangles lie along the west-central boundary of Illinois and cover approximately the southern two-thirds of Calhoun County, the western sixth of Jersey County, and the very southwestern corner of Greene County, Ill. (See index map, fig. 1.) The southeastern extremity of the area lies about 25 miles northwest of St. Louis, Mo., and 20 miles west of Alton, Ill., and the northeastern corner of the Hardin quadrangle lies about 55 miles southwest of Springfield, Ill.

The Brussels quadrangle is included in and makes up the northeastern part of the O'Fallon, Mo.-Ill., 30-minute quadrangle, a topographic map of which was published in 1903. Topographic maps are available of the Nebo, Pearl, Roodhouse, and St. Charles—originally called Bonfils—15-minute quadrangles, which lie immediately northwest, north, northeast, and southeast, respectively, of the Hardin and Brussels quadrangles.

In the two quadrangles are several towns, of which Hardin, the county seat of Calhoun County, with a population of 838 in 1940, is the largest. Hamburg, Batchtown, Brussels, and Fieldon follow in order of size, with populations of 300, 297, 275, and 217, respectively. Nutwood, Rosedale, Deer Plain, Meppen, and Michael are smaller villages that have not been incorporated.

Two systems of land nets or surveying districts are used in the Illinois part of the two quadrangles and a third system is used in the Missouri part. The townships and ranges east of Illinois River, in Jersey and Greene Counties, are referred to the third principal meridian and its base line and are numbered northward and westward. In Calhoun County, between Illinois and Mississippi Rivers, the land net is referred to the fourth principal meridian and its base line, and the townships and ranges are numbered southward and westward. West of the Mississippi River, in eastern Pike and Lincoln Counties and all of St. Charles County, Mo., the townships and ranges are referred to the fifth principal meridian and its base line and are numbered northward and eastward.

PHYSIOGRAPHIC SETTING

The area of the two quadrangles is shown on the map of the physical divisions of the United States [1] as lying along the western margin of the Till Plains section of the Central Lowland province of the Interior Plains division. The area is immediately adjoined on the west by the Dissected Till Plains section of the Central Lowland and it lies only a few miles north of the northeastern margin of the Springfield-Salem plateaus section of the Ozark Plateaus province of the Interior Highlands division. In the table accompanying this map the characteristics of the Till Plains section are given as "young till plans; morainic topography rare; no lakes," of the Dissected Till Plains section as "submaturely to maturely dissected till plains," and of the Springfield-Salem plateaus section as "submature to mature plateaus."

Much more extensive description and discussion of these physiographic provinces are given in a separate paper.[2] Under the heading, Till Plains Sections of the Central Lowland, it is stated [3] that "north of the Ozark Plateaus the western boundary is at the contact of the Illinoian and Kansan drift sheets" and that "the Dissected Till Plains, separated from the Ozark Province by Missouri River, are coextensive with the drift of the Kansan * * *." Under the heading, Ozark Plateaus, it is stated [4] that "a strip a few miles wide on the north side of Missouri River has a purely erosion topography no longer influenced by the wasted drift, although the position of Missouri River was essentially determined by the edge of the drift. In detailed work this may be considered as part of the Ozark Province, since its topography has more in common with the country to the south than to the north."

Judged by the criteria that have been cited for determining the boundaries between these three sections, it seems incorrect to include the unglaciated areas of Pike, Calhoun, and Jersey Counties, Ill., and Pike, Lincoln, St. Charles, and St. Louis Counties, Mo. (fig. 4), within the limits of either the eastern Till Plains section or the western Dissected Till Plains section. Moreover, in their geologic history and rock composition, in the general character and ruggedness of their topography, and in their effect upon human culture, the uplands of parts of Lincoln County, Mo., and Calhoun and Jersey Counties, Ill., are very similar to large parts of the Ozark region of southern Missouri.

The distinctive features of this region led one writer [5] in a description of the topographic districts of Missouri,

[1] Fenneman, N. M., Physical Divisions of the United States (map, with table of characteristics by N. M. Fenneman and D. W. Johnson): Assoc. Amer. Geographers, Annals, vol. 18, no. 4, pp 261–353, Map, 1928.

[2] Fenneman, N. M., Physiographic divisions of the United States: Annals Assoc. Amer. Geographers, vol. 18, pp. 261–353, 1928.

[3] Fenneman, N. M., op cit., pp. 316, 317.

[4] Fenneman, N. M., op cit., p. 326.

[5] Shepard, E. M., Underground waters of Missouri, their geology and utilization: U. S. Geol. Survey Water-Supply Paper 195, pp. 8, 10–11, 1907.

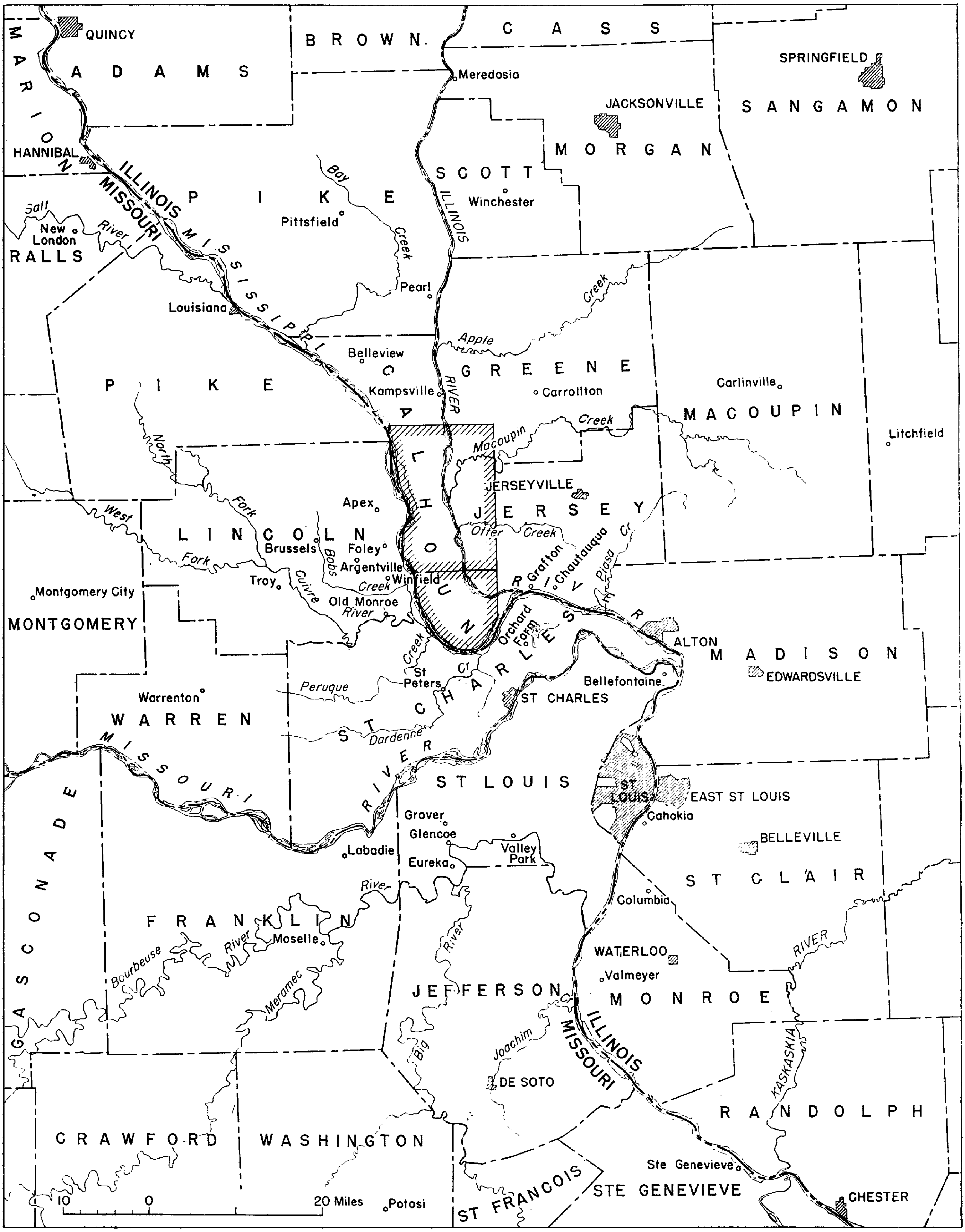

FIGURE 1.—Index map of parts of western Illinois and eastern Missouri showing location of Hardin and Brussels quadrangles in Illinois.

to recognize a zone along Mississippi River as a separate topographic unit, which he designated as the Lincoln Ridge district. Because of the longitudinal division of this area by Mississippi River, the local name Lincoln Hills seems a more appropriate designation than Shepard's name Lincoln Ridge; it seems useful to take cognizance of the distinctive features and geographic relationships of the region, and it is accordingly proposed that the name Lincoln Hills section of the Ozark Plateaus Province be applied to it.

Under this proposed system of nomenclature the area of the Hardin and Brussels quadrangles would lie chiefly within the Lincoln Hills section, and only the northeastern part of the Hardin quadrangle would lie within the Till Plains section.

RELIEF AND DRAINAGE

The maximum relief within the area of the two quadrangles is approximately 475 feet; two hill tops in sec. 2, T. 6 N., R. 13 W., rise to an elevation between 880 and 900 feet above sea level, and only 1½ miles to the south in the SE¼ sec. 14, T. 6 N., R. 13 W., the mean elevation of Illinois River is between 400 and 420 feet. If the bed of the river instead of the water surface is considered, the maximum relief is approximately 500 feet, for at two places within the area—opposite Gilbert Lake in the SE¼ sec. 15, T. 6 N., R. 13 W., and in Dark Chute in the SE¼ sec. 2, T. 10 S., R. 2 W.—there are permanent deeps in the Illinois River with bed elevations of somewhat less than 400 feet above sea level. The maximum local relief within the area of the two quadrangles is at the bluff in the NE¼ sec. 9, T. 6 N., R. 13 W., where, within a horizontal distance of approximately 800 feet, the surface rises from about 430 feet on the Illinois flood plain to about 830 feet on the bluffs overlooking the river. Along most of the bluffs throughout the quadrangles, however, the local relief is only 200 or 300 feet, and the average difference in elevation between the river flood plains and the upland divides is about 300 or 350 feet.

The area lies near the mouth of Illinois River and includes parts of Mississippi and Illinois Rivers. Nearly all the land surface slopes directly into one or the other of the two rivers or into small streams tributary to them. East of Illinois River, however, a part of the surface drains into Macoupin and Otter Creeks, two large tributaries of the Illinois that rise far east of the area.

The topography of the two quadrangles falls naturally into two main components—the uplands and the river flood plains. (See airplane photographs, pl. 15.) The flood plain of the Mississippi averages about 5 miles in width, that of the Illinois about 3 miles. Both flood plains are relatively flat. The valleys of many of the tributary streams are flat-bottomed and extend back into the general uplands as embayments of the flood plains. The upland of Calhoun County forms a long narrow "peninsula" between the Mississippi and Illinois flood plains. The uplands of Jersey and Greene Counties merge eastward into an extensive upland till plain which continues essentially unbroken over a large part of the State of Illinois. The uplands may be further subdivided into (1) undissected remnants of plateau or upland proper and (2) slopes from these plateau remnants down to the flood plains. In Calhoun County and the southwest corner of Jersey County the remnants of upland plateau are very small—nearly all the surface has been reduced to slopes—but in the northeast part of the Hardin quadrangle, wide areas of the Illinoian till plain still remain undissected. (See pl. 15 *A*, *C*.)

Throughout most of the area the uplands and the flood plains are separated by a line of abrupt bluffs or cliffs, but in parts of the region there are remnants of intermediate upland surfaces or terraces and at these places the bluffs are less conspicuous.

CLIMATE

The climate in the Hardin and Brussels quadrangles does not differ essentially from that which prevails throughout most of the central Mississippi valley region—cold winters and hot summers and a rainfall adequate for most agricultural purposes, although droughts are frequent late in summer. There are no Weather Bureau stations within the area, but records kept over a period of many years at the nearby stations of Louisiana,[6] Warrenton, St. Charles, and St. Louis, Mo.,[7] show that the mean annual temperature in this region is about 55° F. and the mean annual rainfall between 35 and 41 inches. Records covering a period of more than 30 years at Louisiana, Mo., show extreme temperature ranges from 105° above to 27° below zero and variations in the annual rainfall from 21.55 to 50.61 inches.

HISTORY OF HUMAN SETTLEMENT

The earliest records of human occupancy in this region have not yet been carefully studied. Less than 50 miles to the southeast, on the flood plain of the Mississippi opposite St. Louis, Mo., stands the group of Cahokia Mounds,[8] believed to mark the site of an ancient Mound Builder village. The group includes the famous Monk's Mound, said to be one of the largest artificial mounds in the world. It is not improbable, therefore, that Mound Builders may once have occupied parts of the area of the Hardin and Brussels quadrangles. In fact, some of the human skulls and other bones picked up by the writer from freshly

[6] Sweet, A. T., Hawker, H. W., Knobel, E. W., and Fehsenfelt, J. B., Soil survey of Lincoln County, Missouri: Field Operations Bur. Soils, 1917, pp. 1486–1487.

[7] Fippin, E. O., and Drake, J. A., Soil survey of the O'Fallon area, Missouri-Illinois: Field Operations Bur. Soils, 1904, p. 817.

[8] Moorehead, W. K., and Leighton, M. M., The Cahokia Mounds: Univ. Illinois Bull., vol. 21, 1923.

plowed fields, recently opened Indian mounds, and steep hillsides were determined by Curator F. C. Baker of the University of Illinois Museum as the bones of Mound Builders.

Old burial or perhaps signal mounds are abundant within the area. Nearly every hill or bluff that overlooks the river valleys has from 1 to 8 or 10 of these Indian mounds upon its highest point or points. Most of them are conical, less than 50 feet in diameter, and only 5 to 10 feet high, but a few are much larger and built in curved irregular patterns. Fragments of burned limestone are found near many of those artificial piles. The most conspicuous group of mounds seen near the area are upon the Illinois flood plain at the foot of the bluffs in the NE¼ sec. 27, T. 8 S., R. 2 W., 5 miles north of the Hardin quadrangle. Very few of the hundreds of mounds in this region have been left unmolested. Nearly all have been partially opened by local residents to obtain the bones, stone axes, pipes, arrowheads, beads, or pottery that they may contain.

It has been reported[9] that sculptured pictographs could be seen in a limestone cave in the river bluffs of Greene County, 25 or 30 miles above the mouth of Illinois River, and also that "some 25 or 30 miles above the mouth of the Illinois River, on the west bank of that stream, high up on the smooth face of an overhanging cliff, is another interesting pictograph sculptured deeply in the hard rock." Neither of these pictographs were seen by the writer.

It seems fairly certain that the region must long have been a favorite haunt of American Indians, for chipped flints, polished stone implements, and piles of clam shells are still common in many places. The early French explorers found the region inhabited chiefly by the Illinois tribe although, because of the convergence of three principal waterways, it was at times occupied by more western tribes.

Marquette and Joliet, on their voyage of discovery down Mississippi River in 1673, are the first white men known to have passed through the area. Thereafter the French dominated the region for about a century and colonies were established at Ste. Genevieve, St. Louis, St. Charles, and many other places along the Mississippi, Illinois, and Missouri Rivers.[10]

In 1762 and 1763, France ceded its lands west of the Mississippi River to Spain and those east of the river to England, and within the following 25 years many of the early French families withdrew to the west side of the river. In the 1790's, pioneers from Kentucky, Tennessee, Virginia, and from other of the more southern of the new American States and Territories, began to settle upon both the American and the Spanish sides of the river. "Louisiana" was returned to France in 1801, and 2 years later it came into the possession of the United States. In 1797, the famous Daniel Boone located his colony near the Missouri River about 15 miles southwest of the Brussels quadrangle. The invasions by the white people caused some hostilities with the Indian tribes native to the region, but colonization continued, Illinois and Missouri were admitted to statehood, and by 1830 the frontier had passed on westward.[11]

The early southern pioneers were hunters who chose to settle in the more heavily wooded lands along the rivers and smaller watercourses. However, the development of steam navigation upon the western Great Lakes in the early thirties opened up northern routes of immigration and then, within the next two decades, a great many farmers from the Northeastern States moved into the region and settled upon the agriculturally superior prairie lands passed up by the earlier frontiersmen. During the same period large numbers of German and some Belgian and Swiss immigrants came into the region, settling mainly in compact colonies along the bluffs and flood plains. The thrifty people brought in on these two later waves of immigration soon dominated large parts of the region, both in numbers and in prosperity. Many of the earlier woodsmen sold out their homesteads to the newcomers and moved on westward to the new frontier; others remained in more isolated areas and adapted themselvs to agricultural pursuits.

For a while most of the shipping of the region was upon the rivers. The first steamboat ascended the Mississippi River above St. Louis in 1817, and by 1830 there was regular boat service on the upper Mississippi, the lower Missouri, and the Illinois. With the growth of population the steamboat business prospered, towns sprang up along the rivers, and St. Louis and New Orleans became the great markets of the region. But with increasing demand for greater transportation facilities, railroads began to be laid down parallel to many of the major rivers, and with their completion in the early fifties, the steamboat commerce[12] declined abruptly. The main thoroughfares quickly shifted from the rivers, many new towns were built along the railroads upon the agricultural uplands, Chicago became one of the leading markets of the region, and the present economic era was established.

[9] McAdams, William, Records of ancient races in the Mississippi Valley, C. R. Barns Pub. Co., St. Louis, pp. 12–13, 27–29, 1887.

[10] For an account of early French activities in the region see Parkman, Francis, France and England in North America, Part 3, La Salle and the discovery of the Great West, 1907.

[11] For summaries of the early settlement of the region see Chittenden, H. M., The American fur trade of the Far West, vol. 1, pp. 71–82, 97–112, 1902. Fippin, E. O., and Drake, J. A., Soil survey of the O'Fallon area, Missouri-Illinois: Field Operations Bur. Soils, 1904, pp. 816–817. Barrows, H. H., Geography of the middle Illinois Valley: Illinois Geol. Survey Bull. 15, pp. 64–125, 1910. Sauer, C. O., Geography of the upper Illinois Valley and history of development: Illinois Geol. Survey Bull. 27, pp. 144–203, 1916. Sauer, C. O., The geography of the Ozark Highland of Missouri: Geog. Soc. Chicago Bull. 7, pp. 73–174, 1920.

[12] For a very readable account of conditions during the heyday of the steamboat period see, Life on the Mississippi, by Mark Twain (S. L. Clemens), one of the early steamboat pilots.

Many of the early stages in the development of the region have left their imprint in the geography and culture of the Hardin and Brussels quadrangles. This area, lying as it does along two large rivers, includes very little of the upper prairie land; thus, it retains far more than most areas of similar size the features that are reminiscent of the early history. A few families of French descent still live along Illinois River. Southern customs and traditions are widespread and many of the present inhabitants are descendants of the early German settlers. Hardin and Hamburg, the two largest towns in the area, are old river towns, built during the steamboat days and still handicapped by the change in mode of transportation.

Only small portions of the area—the upland till plain, the flat terrace surfaces, and parts of the flood plains—are suitable for grain farming. However, orchard husbandry has been highly developed on the bluffs and rugged uplands, and "Calhoun County apples" are well known in many parts of the Middle West. These orchards have been eminently successful, and the region has prospered not only because of the steep slopes, which afford excellent drainage, but also because of the thick mantle of rich loess soil with which the slopes are covered.

Marketing facilities are still inadequate. The only railroad within the two quadrangles is a spur line of the Chicago and Alton which extends down the east side of Illinois River to East Hardin; Calhoun County remains the one county in Illinois that does not have a railroad. Inasmuch as there were no bridges over either Illinois or Mississippi River when field work for this report was done in 1928 and 1929, nearly all produce was then transferred to market by boat, barge, or ferry. The only hard-surfaced road within the area was State Route 38 which, with the ferry at Hardin, connected Kampsville and Hardin with Fieldon, Jerseyville, Alton, East St. Louis, and St. Louis. Motor trucking to nearby railroad shipping points and directly to the larger markets was also done by way of ferries at Kampsville, Deer Plain, Golden Eagle, West Point, and Hamburg. However, a large part of the crops still went to market by river. During harvests, boats picked up shipments consigned to St. Louis, Hannibal, and Peoria at many landings along the two rivers.[13]

Large areas of the swampy lowlands along both rivers are held in their primitive state by gun clubs which are controlled largely by residents of St. Louis and Alton. These clubs are used generally throughout the year for recreation, but the principal sport is shooting waterfowl in fall and winter.

ROCK FORMATIONS

The rocks exposed in the Hardin and Brussels quadrangles are limestone, dolomite, shale, sandstone, and coal and consolidated silt, sand, gravel, and till. All were deposited as sediments from water, wind, or glaciers and are called sedimentary rocks in contrast to the crystalline rocks, which were formed by great heat or by intense pressure. Beneath these rocks that crop out at the surface are others that can be reached by deep drilling. Some of the deeper-lying rocks are sandstones, dolomites, and shales much like those exposed at the surface, but at still greater depths lie crystalline rocks of a sort now exposed only in distant regions.

The accompanying chart shows the rock formations of the area arranged in order of age, from oldest at the bottom to youngest at the top. The sedimentary rocks up to and including those of Mississippian age were laid down during many successive advances of the sea across the region. The Pennsylvanian strata were formed partly in sea water and partly upon the land. The much later Tertiary and Quaternary unconsolidated rocks were all formed upon land as stream, wind, or glacial deposits.

The rock formations of the two quadrangles are described in the following pages in the order of their age, the oldest first and the youngest last. The very oldest rocks—those not exposed in or near the area—are known only from incomplete records of deep drilling and from distant exposures. In the following descriptions of the rocks of the area, it seems advisable to separate sharply these rocks not exposed to study from those that can be examined in detail.

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[13] Lloyd, J. W., and Newell, H. M., Marketing Calhoun County apples: Univ. Ill. Agric. Exper. Sta., Bull. 312, pp. 563–612, 1928.

Chart of rock formations exposed in Hardin and Brussels quadrangles, Illinois

Era	System	Series	Stage or group	Formation and member	Thickness (feet)	Letter symbol on geologic map
Cenozoic	Quaternary	Recent		River alluvium [1]	0 to 125	Qr
		Recent and Pleistocene?		Calcareous tufa [1]	0 to 35	Qct
		Recent and Pleistocene [2]		Undifferentiated stream deposits, slope wash, and talus	0 to 25	Qu
		Pleistocene	Wisconsin stage	Deer Plain formation [1]	0 to 50	Qd
			Wisconsin (?) stage	Scattered pebbles [1]	0 to ½	
			Wisconsin (?), Peorian, and Sangamon stages	Loess	5 to 80	Ql
			Sangamon (?) and Illinoian stages	Brussels formation [1]	0 to 100	Qb
			Illinoian stage	Pond deposits marginal to the Illinoian ice [1]	0 to 70	Qp
				Till and stratified drift	0 to 100	Qt
			Yarmouth (?) stage	Hard pitted clay [1]	0 to 10	Qec
			Kansan stage	Gravel and till (?) near Batchtown [1]	0 to 45	Qk
	Tertiary and Quaternary [3]			Residual chert and clay [1]	0 to 40	
	Tertiary	Miocene (?)		Grover gravel	0 to 30	Tg
				—Unconformity—		
Paleozoic	Carboniferous	Pennsylvanian		McLeansboro formation	0 to 28	Pm
				Carbondale formation	65 to 90	Pc
				Pottsville formation	0 to 85	Pp
				—Unconformity—		
		Mississippian	Meramec group	St. Louis limestone	75 to 185	Ms
				—Unconformity (?)—		
				Spergen limestone	70	
				Warsaw formation	50 to 65	Mws
			Osage group	Keokuk limestone	65±	Mk
				Burlington limestone	140 to 200	
				Sedalia limestone		Msb
				—Unconformity—		
			Kinderhook group	Chouteau limestone	22 to 60	Mc
				Hannibal shale	30 to 100	Mh
				Glen Park formation	0 to 25	Mlg
				—Unconformity—		
				Louisiana limestone	0 to 6	
				—Unconformity—		
	Devonian	Upper		Cedar Valley limestone	0 to 40	Dc
				—Unconformity—		
	Silurian	Niagaran [4] (middle)		Joliet limestone	0 to 16	Sebj
				—Unconformity (?)—		
		Alexandrian [4] (lower)		Brassfield limestone	0 to 40	
				—Unconformity—		
				Edgewood limestone: Bowling Green (?) limestone member	10 to 50	
				Edgewood limestone: Noix oolite member		
				—Unconformity—		
	Ordovician	Upper		Maquoketa shale	100 to 200	Om
				—Unconformity—		
		Middle		Kimmswick limestone	70±	Ok
				Decorah limestone	5–10	Opd
				Plattin limestone	140–150±	
				—Unconformity (?)—		
		Lower		Joachim dolomite	80±	Oj
				St. Peter sandstone	150±	Os
				—Unconformity (?)—		
				Cotter (?) dolomite	8±	Oc
			Not exposed in Hardin and Brussels quadrangles			
	Cambrian					
Pre-Cambrian						

[1] Many of the Tertiary and Quaternary formations do not occur in actual contact with one another yet their relative ages are determined from physiographic relationships.

[2] The undifferentiated stream deposits, slope wash, and talus include some deposits as old as Illinoian and possibly even Kansan but they are thought to be chiefly of Recent age.

[3] The residual chert and clay are believed to include materials which range in the date of their formation from Tertiary to Recent but they are probably for the most part early Pleistocene in age.

[4] According to the classification used by the Illinois Geological Survey.

ROCKS NOT EXPOSED

PRE-CAMBRIAN

The oldest rocks known in the Mississippi Valley come to the surface in only a few places. In the St. Francois Mountains in the eastern part of the Ozark uplift, 70 miles or more south of the Hardin and Brussels quadrangles, granites and rhyolites, with subordinate amounts of diabase, tuff, and metamorphic rocks, occupy a surface area of about 1,200 square miles.[14] Much farther north, in Minnesota and Wisconsin, these and many other rock types of the same relative age crop out over large areas. Here and there in the intervening region, a few wells have penetrated deep enough to prove the presence of these rocks as the fundamental basement upon which all the later rocks have been built.

Within the Hardin and Brussels quadrangles no wells have been drilled to a sufficient depth to reach the pre-Cambrian rocks. However, a deep well in St. Louis, Mo., is reported to have struck these rocks at a depth of more than 3,800 feet.[15] The Little Silver well near St. Peters, in St. Charles County, Mo., 4 or 5 miles southwest of Golden Eagle, Calhoun County, Ill., failed to reach these rocks at a depth of more than 2,700 feet.

EARLY PALEOZOIC

Lying upon the pre-Cambrian rocks throughout the Mississippi Valley are many hundreds of feet of Cambrian and Ordovician sandstones, dolomites, and shales. None of the Cambrian and only the upper part of the Ordovician strata come to the surface in the Hardin and Brussels quadrangles, but their presence underground is demonstrated by deep wells drilled nearby. Of the formations that crop out within the two quadrangles, the oldest one that can readily be identified in well records is the St. Peter sandstone. In the Little Silver well near St. Peters, Mo., more than 1,700 feet of Cambrian and early Ordovician dolomites, sandstones, and shales that lie below the St. Peter sandstone were penetrated without reaching the underlying pre-Cambrian rocks. The deep well at St. Louis, Mo., showed more than 2,200 feet of these beds between the St. Peter sandstone and the basement of pre-Cambrian rocks.[16]

ROCKS EXPOSED

PALEOZOIC

The Paleozoic rocks exposed in the Hardin and Brussels quadrangles include representatives of the Ordovician, Silurian, Devonian, Mississippian, and Pennsylvanian systems. In general, these rocks make up a great unit, which consists dominantly of limestone in the upper and dolomite in the lower part and is broken at irregular intervals by four thick beds of shale and a few thick and thin beds of sandstone. Before erosion the total thickness of these rocks ranged from 1,100 to 1,750 feet and probably averaged about 1,400 feet. Of this thickness the Ordovician and Mississippian systems make up all but a small part.

The Paleozoic rocks of the area record a history of many gentle movements of the earth and repeated incursions of the sea. During the early part of the Paleozoic the region seems to have laid at times on the northeast flank of a low broad land area that probably corresponds with the present Ozark Highlands. This Ozark land area probably persisted during middle Paleozoic time, but there was gentle irregular warping within the Hardin and Brussels quadrangles. The irregular warping seems to have been integrated gradually into a local uplift, which was separated from the Ozark Highland by a local basin of deposition. During late Paleozoic these gradual movements culminated in sharp folding and since Paleozoic time the local uplift has grown slightly.

ORDOVICIAN

The Ordovician rocks that crop out within the area include the Cotter (?) dolomite, the St. Peter sandstone, the Joachim dolomite, the Plattin limestone, the Decorah limestone, the Kimmswick limestone, and the Maquoketa shale. Only a few feet of the Cotter (?) dolomite is exposed and its total thickness is not known. The aggregate thickness of the exposed Ordovician formations ranges from 550 to 700 feet.

Most of these formations are exposed in only a small part of the Hardin and Brussels quadrangles, and it is impossible to observe regional variations in their thicknesses. However, the Maquoketa shale, which is more widely exposed and more easily recognized in well records, clearly thins southwestward across the area toward the Ozark Highlands of Missouri.

During the field work on which this report is based, fossils were collected from the Plattin, Decorah, Kimmswick, and Maquoketa formations. Dr. E. O. Ulrich, of the United States Geological Survey, made several preliminary reports upon the stratisgraphic significance of these collections and Dr. Edwin Kirk, of the Survey, furnished the list of identifications. (See pp. 167–169.)

COTTER (?) DOLOMITE

The oldest rocks that come to the surface within the limits of the Hardin and Brussels quadrangles have been seen by only a few geologists. Keyes[17] mentions "a foot or two" of "magnesian limestone" exposed at the base of Cap au Grès bluff "in times of very low

[14] Wilson, M. E., The occurrence of oil and gas in Missouri. Mo. Bur. Geol. and Mines, vol. 16, 2d ser., pp. 34–35, 1922.

[15] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, p. 17, 1911.

[16] Fenneman, N. M., op. cit., pp. 16–17.

[17] Keyes, C. R., Some geological formations of the Cap-au-Grès uplift: Iowa Acad. Sci. Proc., vol. 5, p. 60, 1898.

water." Weller[18] reports "three or four feet" of "a gray or brownish buff, earthy magnesian limestone * * * exposed for only a few rods * * * along [the] base of the bluff about one-fourth mile above the mouth of Dogtown Creek." The following section was measured "about ¼ mile north of Dogtown Landing" by C. McMackin of the Illinois Geological Survey in the spring of 1934 at a time when Mississippi River was very low:

Top.	*Feet*
4. Sandstone, St. Peter, basal layer conglomeratic-------	
Unconformity.	
3. Dolomite, Cotter(?), thin-bedded, nonfossiliferous. Top bed, 1 foot thick, stands out as ledge------------	5½
Unconformity.	
2. Sandstone, fine-grained, thin-bedded, white----------	3
1. Covered---	8
Water level.	

This locality, in the SE¼ of sec. 30, T. 12 S., R. 2 W., is the highest part of the Lincoln anticline[19] in Calhoun County.

During the field seasons of 1928 and 1929, Mississippi River seems not to have fallen to a stage sufficiently low to expose these rocks. However, beds that very probably represent this formation crop out along the same fold 4 miles to the west-northwest, about 1 mile north of Winfield in Lincoln County, Mo. Here, at the mouth of Lick Spring Hollow, is an exposure of 28 feet of alternately massive and thin-bedded, pale buffy gray, fine-grained, argillaceous and sandy dolomite. The bedding is somewhat irregular and suggests contemporaneous brecciation. Several other outcrops of this formation within 2 or 3 miles of the one just mentioned have been described by other geologists.[20] Krey gives a detailed section of 47 feet of alternating dolomite, sandy and cherty limestone, and sandstone; he reports that the maximum thickness of the strata exposed in this area is about 130 feet.

In these, the oldest rocks exposed along the Lincoln anticline, no fossils have thus far been found. Rocks that occupy a similar stratigraphic position below the St. Peter sandstone have been called the Prairie du Chien group in northern Illinois, the Shakopee dolomite in Iowa and elsewhere, and the "Jefferson City group" in Missouri.[21] Keyes[22] applied a local name, "Winfield limestone," to these beds in Lincoln County, Mo., but Krey[23] adopted the term "Jefferson City group" for the exposures on both sides of Mississippi River along the Lincoln anticline. "Jefferson City group," as used by Dake and by Krey, includes the Jefferson City, the Cotter, and the Powell formations.

Inasmuch as nearly all the outcrops of these rocks along the Lincoln anticline lie in Lincoln County, Mo., it seems desirable to follow the terminology used by the Missouri Bureau of Geology and Mines. Accordingly, samples collected from the Lick Spring Hollow locality were sent to H. S. McQueen, Assistant State Geologist of Missouri, for study and identification by the method of insoluble residues.[24] Mr. McQueen kindly made the following report upon these samples:

Lick Spring Hollow, 50 feet northwest of Tiller's farmhouse, NW¼ sec. 13, T. 49 N., R. 2 E., Lincoln County, Mo.

I-99-a. Massive phase. Dolomite, light buff with fine gray bands, very fine grained. Insoluble residue consists of (a) extremely fine, subangular, frosted grains of sand and (b) considerable buff-colored silt with flakes of muscovite.

I-99-b. Thin-bedded phase. Dolomite, buff and gray in color, fine-grained, even more so than I-99-a. Insoluble residue shows: (a) fine, subangular frosted grains of sand; also light buff colored flakes of clay, (b) silt fraction very large as compared with I-99-a; sand, very fine grained but more argillaceous; somewhat plastic muscovite present in this fraction.

These small fragments of dolomite yield insoluble residues of varying amount, but of essentially the same characteristics, the broader features being considered. The heavy silt or argillaceous fractions, and the sand described are commonly found in the Cotter, and the specimens are from that formation. A study of sections of the pre-St. Peter rocks as presented in drill samples would indicate that the Cotter dolomite underlies the St. Peter sandstone throughout east-central Missouri.

As a result of this examination, the reported outcrop of these beds in Calhoun County is here tentatively referred to the Cotter dolomite. This formation, first described in Arkansas,[24a] has been definitely recognized as far north as Ste. Genevieve County, Mo.[25]

ST. PETER SANDSTONE

The oldest formation well exposed within the Hardin and Brussels quadrangles is the St. Peter sandstone. Its outcrop is a narrow band, barely more than 1 mile long, that makes the Cap au Grès or "sandstone headland" overlooking Mississippi River. At this outcrop the formation consists of approximately 150 feet of clean well-sorted quartz sandstone. However, well logs indicate that it thickens to 200 and 250 feet within less than 15 miles to the south and southeast.

Lithologic character.—At close range the sandstone seems massive and almost structureless, but from a

[18] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 221, 1907.

[19] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Missouri, to Nauvoo, Illinois: Illinois Geol. Survey Bull. 45, pp. 46–48, pl. 1, 1924.

[20] Potter, W. B., Geology of Lincoln County. Preliminary Report on the Iron Ores and Coal fields: Mo. Geol. Survey, pp. 223–224, 1873. Krey, Frank, op. cit., pp. 16–17, 1924.

[21] Dake, C. L., The problem of the St. Peter sandstone: Missouri School of Mines and Metallurgy Bull., vol. 6, no. 1, pp. 12, 65, 84, 1921.

[22] Keyes, C. R., op cit., p. 60.

[23] Krey, Frank, op. cit., p. 16.

[24] McQueen, H. S., Insoluble residues as a guide in stratigraphic studies: Missouri Bureau Geology and Mines, 56th Bienn. Rept., Appendix I, pp. 3–32, 1931.

[24a] Purdue, A. H., and Miser, H. D., Description of the Eureka Springs and Harrison quadrangles, Arkansas-Missouri: U. S. Geol. Survey Geol. Atlas, Eureka Springs-Harrison folio (no. 202), pp. 4–5, 1916.

[25] Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 22, pp. 81–84, 1928.

distance of a few score feet or more it is seen to be regularly and rather thinly bedded. (See pl. 3.) Here and there through the formation are cross-bedded layers and ripple-marked surfaces. The cross-bedded layers are rarely more than 1 foot thick and the oblique laminations generally but not invariably dip southward or westward. The ripple marks seem to be of the symmetrical or oscillation type.[26] The largest ones seen by the writer are in the lower part of the formation and trend about N. 80° W. They measure from 2 to 3 inches from crest to crest and are from 1/4 to 3/8 inch deep.

Where weathered, the sandstone is generally brownish gray, though in some places it is yellow or even distinctly red. On fresh fracture, however, it is commonly light tan and in some beds pure white.

Much of the sandstone is fairly hard where exposed to weathering but relatively friable and loose back a few inches from the outcrop. The harder portions seem to be cemented with iron oxides, silica, or calcite. In the northern part of the outcrop, where there are numerous small folds and minor faults, quartzitic seams cut across the sandstone in various directions. Here and there the sandstone is perceptibly calcareous, but no beds of limestone or dolomite, such as were reported [27] in the outcrops in Lincoln County, Mo., were seen in the entire exposure. Lamar [28] noted "nodules and bands of calcareous sandstone, particularly in the upper part of the exposure" at Cap au Grès, but he thought that this calcareous material was probably introduced by downward-percolating waters.

The sand grains themselves are small and exceptionally well sorted. In all parts of the formation examined, nearly all grains have diameters greater than 1/10 millimeter and less than 1/2 millimeter, with 1/4 millimeter the commonest diameter. Mechanical analyses of samples from this exposure [29] likewise show that this sandstone consists almost entirely of particles of the sizes commonly known as fine sand and medium sand.[30] These mechanical analyses also show that the samples of sandstone from this exposure are somewhat finer grained than most of the samples of St. Peter sandstone that have been studied.[31]

The sandstone consists [32] almost entirely of colorless quartz grains, the shapes of which range from nearly perfect spheres to apparently unabraded doubly-terminated quartz crystals. Many of the grains show some rounding and a large number are marked with broad shallow pits or impressions left by adjacent sand grains.[33] The more perfectly rounded grains have a "frosted" or "ground glass" surface, but the quartz crystals are clear and sparkling. Casual inspection indicates that the quartz crystals are more abundant and more perfectly formed on the hardened weathered surface than in the relatively friable fresh rock.

As has been pointed out previously [34] a large proportion of the unabraded quartz crystals in the sandstone at this locality are simply secondarily enlarged quartz grains. Although some of this enlargement clearly occurred before the final deposition of the sand grains, the freedom from abrasion of most of the crystals and the greater abundance of secondarily enlarged grains on weathered surfaces make it seem probable that most of the enlargement took place long after deposition.

Stratigraphic relations.—The contact of the St. Peter sandstone with the underlying Cotter (?) dolomite was not seen. However, available information suggests that here as in Missouri [35] the lower contact of the St. Peter may be an unconformable one. In a deep well drilled at Kampsville, Calhoun County, Ill., 7 feet of blue shale was reported below the St. Peter sandstone and in another well, 14 miles southeast of Cap au Grès, in sec. 26, T. 48 N., R. 5 E., St. Charles County, Mo., 19 feet of "blue mud" underlay the sandstone. As has been pointed out,[36] these beds below the sandstone may have originated as residuum from the solution of underlying dolomite and therefore indicate a period of weathering immediately before the deposition of the sandstone. In the lower part of the formation at the Cap au Grès exposure several unusual circular faults or joints were noted. The largest recognized is about 9 feet in diameter; it incloses two smaller, concentrically arranged circular faults. The fault or joint surfaces are nearly vertical, but they seem to dip slightly inward, probably converging to form a steep cone. In the middle and upper part of the formation, in the northern part of the Cap au Grès exposure, the regular northeastern dip of the beds is interrupted by a few minor faults and many small folds, in which the bedding dips from 5° to 10° in nearly every direction. Though both the conical faults in the lower part of the formation and the irregular dips in the upper part are susceptible to many different interpretations, it seems worth while to mention that both might have been caused by the collapse in the lower part and slumping in the upper part of partially consolidated sand into caverns previously devel-

[26] Kindle, E. M., Recent and fossil ripple mark; Canada Geol. Survey Mus. Bull. 25, pp. 23–29, 1917.

[27] Dake, C. L., op. cit. p. 17. Krey, Frank, op. cit., p. 18.

[28] Lamar, J. E., Geology and economic resources of the St. Peter sandstone of Illinois: Illinois State Geol. Survey Bull. 53, p. 50, 1928.

[29] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County, Illinois State Geol. Survey Rept. of Inv., 8 p. 20, 1926; Geology and economic resources of the St. Peter sandstone of Illinois, Illinois Geol. Survey Bull. 53, pp. 44–45, table facing p. 149, 1928.

[30] Wentworth, C. K., A scale of grade and class terms for clastic sediments: Jour. Geology, vol. 30, p. 384, 1922.

[31] Dake, op. cit., pl. 8, facing p. 162.

[32] For chemical analyses of the St. Peter sandstone of Lincoln County, Mo., see Dake, C. L., The sand and gravel resources of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 15, pp. 168–169, 1918.

[33] Lamar, J. E., Geology and economic resources of the St. Peter sandstone of Illinois: Illinois Geol. Survey Bull. 53. pp. 47–49, 1928.

[34] Lamar, J. E., op. cit., p. 49.

[35] Dake, C. L., The sand and gravel resources of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 15, pp. 109–111, 1918.

[36] Lamar, J. E., op. cit., p. 20.

oped in the underlying dolomite, as was reported in the St. Peter sandstone of the Eureka Springs and Harrison quadrangles,[37] Arkansas and Missouri.

The St. Peter sandstone apparently grades upward into the overlying Joachim dolomite.

Name.—No fossils, such as those found sparingly elsewhere [38] in the St. Peter sandstone, have been reported from the exposures in Calhoun County, Ill., or Lincoln County, Mo.

The name "St. Peter sandstone," first used for rocks in Minnesota,[39] was applied to the sandstone at Cap au Grès by Worthen.[40] Keyes [41] later proposed the local term "Cap-au-Grès" sandstone. Weller [42] and Shepard [43] adopted the name St. Peter for the Calhoun County, Ill., and the Lincoln County, Mo., outcrops, respectively. This usage has been followed by later writers, but Dake [44] and Krey [45] have called attention to the possibility that the St. Peter sandstone of this area may include in its lower part beds that are equivalent to the Everton limestone of Arkansas [46] and southern Missouri.[47] Inasmuch as no limestone or dolomite was found interbedded with the sandstone at Cap au Grès, the name St. Peter sandstone is retained in this report, although the possibility that the formation may include beds equivalent to the Everton is recognized.

JOACHIM DOLOMITE

Above the St. Peter sandstone lies the Joachim dolomite, a formation about 80 feet thick that is made up chiefly of brown dolomite. Its area of outcrop is less than 2 miles long and borders that of the St. Peter sandstone on the east and to the north.

Lithologic character.—Although massive beds several feet thick are conspicuous in this formation, thin-bedded layers only a few inches thick are common, especially in the lower and middle parts. The rock is commonly buff or brown on fresh fracture and weathers to a lighter brown mottled with small spots of yellowish gray. This dominant brown phase of the rock is minutely crystalline and notably porous. However, in the lower part of the formation are dark bluish gray fine-grained beds, the color of which seems to be caused by finely disseminated pyrite.

Here and there throughout the formation are thin argillaceous strata and beds of somewhat sandy dolomite. In its lowest few feet, the Joachim is distinctly sandy and some layers might be called dolomitic sandstone rather than sandy dolomite. Locally the top of the formation is marked by a bed of soft pale-buff dolomite or powder, nearly a foot thick, which may be partially decomposed dolomite. A thin section of this soft rock showed only very finely divided carbonates.

Two striking characteristics of the formation in this region are the pronounced bituminous odor given off by much of the porous brown dolomite when it is freshly broken and a distinctive nodular surface that the rock develops upon weathering.

A chemical analysis of a representative sample of Joachim dolomite, taken from the 50-foot face of the abandoned quarry in the NE¼SE¼ sec. 19, T. 12 S., R. 2 W., near the West Point Ferry landing, shows that dolomite, with an average molecular ratio, calcium to magnesium, of 6 to 4, makes up about 94.8 percent of the rock. The impurities are largely silica, which probably is present chiefly as scattered quartz grains. (*See* chemical analysis, p. 156.)

The 15 chemical analyses published in (pp. 156–158) this report have each been interpreted by the writer in terms of their probable mineral composition. A brief explanation of the method by which these interpretations were made seems worth while.

The factors, 1.785 and 2.091, from which the calcium and magnesium carbonate contents might theoretically be calculated, give estimates that are somewhat too high. In most of the group, the CO_2 calculated by this method exceeds the loss on ignition, by 1.3 percent in one analysis; the calculated total of all constituents commonly exceeds 100 percent, by 1.7 percent in one analysis; and these discrepancies within the different analyses are roughly proportional to the amount of carbonates present. This error, which, from inspection of the analyses and examinations of the rocks themselves, seems to be due largely to incomplete combustion, is to a certain extent compensated by the conventions that were followed in reporting the percentages of iron and sulfur. Nevertheless, it seemed desirable in estimating the probable mineral compositions from these analyses to reduce all excessive totals to 100 percent.

A more serious error is introduced by uncertainty about the chemical composition of the complex clay minerals which make up a large part of the more highly argillaceous samples. The proportions of the lime, magnesia, and silica that should be calculated as clay instead of as carbonates or quartz is very difficult to

[37] Purdue and Miser, op. cit., p. 7.

[38] Dake, C. L., The problem of the St. Peter sandstone: Univ. Missouri School of Mines and Metallurgy, vol. 6, no. 1, pp. 194–197, 1921. Lamar, J. E., Geology and economic resources of the St. Peter sandstone of Illinois: Illinois Geol. Survey Bull. 53, p. 36, 1928. Weller and St. Clair, op. cit., p. 98.

[39] Owen, D. D., Preliminary report of the Geological Survey of Wisconsin and Iowa, U. S. Gen. Land Office Rept.: 30th Cong., 1st sess., Sen. Ex. Doc. 2, p. 169, 1847.

[40] Worthen, A. H., Geology of Calhoun County: Illinois Geol. Survey vol. 4, pp. 3–4, 1870.

[41] Keyes, C. R., Some geological formations of the Cap-au-Grès uplift: Iowa Acad. Sci. Proc., vol. 5, p. 60, 1898.

[42] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, pp. 221–222, 1907.

[43] Shepard, E. M., Underground waters of Missouri, their geology and utilization: U. S. Geol. Survey Water-Supply Paper 195, pp. 16–17, 1907.

[44] Dake, C. L., The problem of the St. Peter sandstone, Univ. Missouri School of Mines and Metallurgy Bull., vol. 6, no. 1, pp. 15–26, 1921.

[45] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Missouri, to Nauvoo, Illinois: Illinois Geol. Survey Bull. 45, p. 17, 1924.

[46] Purdue and Miser, op. cit., pp. 5–7.

[47] Weller and St. Clair, op. cit., pp. 91–95.

estimate. However, only three of the samples analyzed for this report contain sufficient quantities of clay to cause serious errors here and the interpretations of their mineral compositions are stated only in such general terms as "this percent *or more* of clay and that percent *or less* of carbonates or of quartz."

The most nearly complete single exposure of the Joachim dolomite in these quadrangles was found about 1/4 mile south of the northern end of the Cap au Grès bluff. The upper 45 feet of the formation is particularly well exposed in the old quarry face just north of the mouth of West Point Creek.

Stratigraphic relations.—In Calhoun County, Ill., as in Missouri,[48] the Joachim dolomite seems to be conformable with the underlying St. Peter sandstone. At the one place where the contact was found well exposed, in the center E½NE¼ sec. 30, T. 12 S., R. 2 W., there is at least 1 foot of beds that show a complete gradation between the two formations.

The stratigraphic relations with the overlying Plattin limestone are uncertain. The contact probably is an unconformable one, but no definite evidence of this relationship was found.

Name and identification.—No fossils were found in the Joachim dolomite by the writer. Weller,[48a] however, found a few ostracods and trilobites in this area, but here, as in Missouri,[49] fossils are very scarce in the formation.

Keyes[50] in 1897 proposed the local name "Folley"—correctly spelled "Foley"— limestone for these beds that crop out nearby in Lincoln County, Mo. Weller[51] and Shepard[52] in 1907 adopted for these rocks in Calhoun County, Ill., and Lincoln County, Mo., the name "Joachim,"[53] first proposed for beds in eastern Missouri, and later writers have followed their usage.

PLATTIN AND DECORAH LIMESTONES

The Joachim dolomite is overlain by about 140 or 150 feet of dominantly thin-bedded, dense, gray, more or less dolomitic Plattin limestone which in turn is overlain by 5 or 10 feet of thin-bedded brown Decorah limestone. These formations crop out in the bluffs and stream valleys along the west side of Calhoun County from Dogtown Hollow northward for 5 miles to the mouth of Dixon Hollow. The dip of these rocks to the east-northeast carries them below the stream valleys within less than 1 mile from the bluffs, and they do not reappear on the eastern side of Calhoun County or in southwestern Jersey County.

Lithologic character.—The Plattin limestone is characteristically thin-bedded in layers only a few inches thick, but here and there throughout the formation are some relatively massive beds more than 1 foot thick. Locally the beds of dolomitic limestone are separated by thin argillaceous layers, and a few of the bedding planes are distinctly ripple-marked.

The texture is commonly fine-grained to dense or almost lithographic, and the rock breaks with a splintery conchoidal fracture. However, some of the highly fossiliferous beds are coarsely granular and the more argillaceous layers are soft and earthy. The limestone is generally hard and compact. Most of the rock is light buffy gray upon fresh structure and weathers gray or nearly white. The thin argillaceous layers are distinctly brownish.

In composition the rock ranges from limestone to dolomite, although most of it seems to be only slightly dolomitic limestone. Chemical analysis of a sample (see p. 156), taken from the basal half of the Plattin limestone near the abandoned quarry in the NE¼SE¼ sec. 19, T. 12 S., R. 2 W., Calhoun County, indicates that about 96.4 percent of the rock consists of magnesian calcite with an average molecular ratio, calcium to magnesium, of 13 to 2, or approximately 3/4 calcite and 1/4 dolomite. The remaining impurities, chiefly silica and alumina, are probably combined as some one of the clay minerals. (See p. 16.) Physical tests[54] of this sample (p. 156) indicate, by the rather high "specific gravity" of the rock, the moderate amount of water that it absorbs, and the "wear" that it undergoes, that the rock is fairly dense and compact. Briefly, in explanation, "specific gravity" is the bulk density of the rock, absorption measures roughly the porosity, and wear might be called loss by abrasion. In a rock composed solely of one mineral species, say calcite, increasing porosity lowers the density and, in general, increases the loss by abrasion. But in rocks of varying composition, the relationships are much more complex.

A distinctive feature of the formation is the occurrence, in beds of the dense limestone, of irregular ramifying rods, about 3/8 or 1/2 inch in diameter, of crystalline dolomitic limestone. On weathered surfaces, these rods suggest organic, perhaps fucoidal,[55] structures but on fresh fractures and especially on polished faces, they seem to be, at least in part, of secondary development. (See pl. 4*B*.) These "fucoidal" beds

[48] Dake, C. L., The sand and gravel resources of Missouri: Missouri Bur. Geology and Mines, vol. 15, 2d ser., p. 109, 1918; The problem of the St. Peter sandstone: Missouri School of Mines and Metallurgy, Bull. vol. 6, no. 1, p. 26, 1921. Weller and St. Clair, op. cit., pp. 103–104.

[48a] Weller, Stuart, op. cit., p. 222.

[49] Dake, C. L., The problem of the St. Peter sandstone: Missouri School of Mines and Metallurgy, Bull., vol. 6, no. 1, pp. 27–28, 1921. Weller, Stuart and St. Clair, Stuart, op. cit., p. 104.

[50] Keyes, C. R., op. cit., p. 61.

[51] Weller, Stuart, op. cit., p. 222.

[52] Shepard, E. M., op. cit., p. 17.

[53] Winslow, Arthur, Lead and zinc in Missouri: Missouri Geol. Survey, 1st ser., vol. 6, pp. 331, 352, 1894.

[54] For an explanation of the significance of these physical tests see Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, p. 31, 1925.

[55] Worthen, op. cit., p. 5. Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 22, p. 106, 1928.

occur at two or more horizons—one near the base and the other just above the middle of the formation.

Associated with both these horizons of "fucoidal" beds are local layers of limestone conglomerate a few inches thick. The clastic grains in these conglomerates are rounded fragments of limestone and of shells. These grains, from 0.1 to 15 millimeters in diameter, are set in a matrix of clear buffy calcite. (See pl. 4*A*.)

Another distinctive feature of the Plattin limestone is a peculiarly honey-combed or pitted weathering surface that develops on many of the beds. These pits range from less than 1 inch to several inches in diameter.

A few small chert nodules were noted in the lower and middle parts of the formation.

At the base of the formation is a fairly persistent argillaceous bed rarely more than 1 foot thick. This bed commonly consists of thinly laminated and ripple-marked brown limestone, very similar to that in the overlying limestone, interbedded with chocolate-brown shale and bluish-gray sandy clay. This thin argillaceous layer occupies approximately the same strategraphic position as the Glenwood shale [56] of Iowa State reports, but no further evidence to support this correlation was found.

The most complete exposure of the Plattin limestone was found in the bluff, in the SE¼NE¼ sec. 19, T. 12 S., R. 2 W., about 1,000 feet north of the old quarry near the mouth of West Point Creek.

The thin Decorah limestone was found overlying the Plattin at all outcrops in Calhoun County. It is from 5 to 10 feet thick and consists chiefly of very thin, ripple-marked nodular beds of dense chocolate-brown limestone, which alternate with thin layers of rich brown calcareous shale. (See pl. 5*A*, *B*.) The thin limestone beds weather to a very pale gray or nearly to white. A few layers are highly fossiliferous. Both the thin limestone and the shale may be called a fairly rich "oil shale." When heated with a match they give off a strong odor of petroleum and it is reported that thin slivers of the shale will burn when ignited.[57] Qualitative distillation tests by E. T. Erickson, of the United States Geological Survey indicate that a sample collected by the writer in the SE¼NE¼ sec. 6, T. 12 S., R. 2 W., carries from 15 to 25 gallons of crude oil to the ton.

Locally the brown limestone of the Decorah is much thicker bedded and at a few places thin sandy beds, green sandy clay, and coarsely granular limestone were noted. Small nodules of dark gray chert, similar to those in the Plattin limestone, occur sparingly.

Stratigraphic relations.—No positive evidence of unconformable relations between the basal beds of the Plattin and the underlying Joachim were observed in the Calhoun County exposures. Weller, in his report on the geology of southern Calhoun County, did not record an unconformity at this contact. In fact, he wrote that "the lower beds of the formation indicate a gradual change in character of the sediments from that now forming the subjacent formation. The complete transition occupies a thickness of about five feet." [58] However, Weller is quoted by Bevan [59] as saying in an oral communication that "the Glenwood and the overlying Plattin (or Platteville) limestone rest on the eroded surface of the Joachim limestone in Calhoun County."

A widespread unconformity between the Joachim and Plattin is reported in Missouri [60] but the only suggestion of such a relationship in Calhoun County is the rather sharp lithologic change and the fairly persistent argillaceous beds at the contact of the two formations.

These thin argillaceous beds at the base of the Plattin limestone, which may possibly be equivalent to the Glenwood shale of Iowa State reports, seem to grade upward into the typical Plattin limestone with no suggestion whatever of an unconformity. The Glenwood shale is said to be conformable with the overlying Platteville limestone, and it carries Platteville fossils.[61]

The Decorah limestone is apparently conformable with the underlying Plattin limestone, for, although the contact between the two formations is generally recognizable, it is not marked by an abrupt lithologic change. In Ste. Genevieve County, Mo.,[62] the Decorah seems to be completely conformable with the Plattin limestone. Similarly at its type locality in Iowa, the Decorah is reported [63] to be conformable with the underlying Platteville.

The Decorah limestone seems to lie conformably, but with a very sharp lithologic change, below the Kimmswick limestone.

Names.—Organic remains, useful for correlating and establishing the appropriate names, are relatively abundant in these formations, especially in the lower 10 feet of the Plattin and throughout the Decorah limestone. Collections made during the field work on which this report is based are listed on pp. 167–168.

In northwestern Illinois rocks of approximately the same age as the Plattin limestone have been called the Platteville [64] limestone. Keyes [65] proposed the local name "Bryant limestone" for beds in Lincoln County,

[56] Calvin, Samuel, Geology of Winneshiek County: Iowa Geol. Survey, vol. 16, pp. 74–75, 1906.

[57] Krey, Frank, op. cit., p. 20.

[58] Weller, Stuart, op. cit., p. 222.

[59] Weller, Stuart, in Bevan, Arthur, The Glenwood beds as a horizon marker at the base of the Platteville formation. Illinois Geol. Survey Rept. Inv. no. 9, p. 12, 1926.

[60] Dake, C. L., The problem of the St. Peter sandstone: Missouri School of Mines and Metallurgy Bull. vol. 6, no. 1, p. 44, 1921. Weller and St. Clair, op. cit., pp. 107–108.

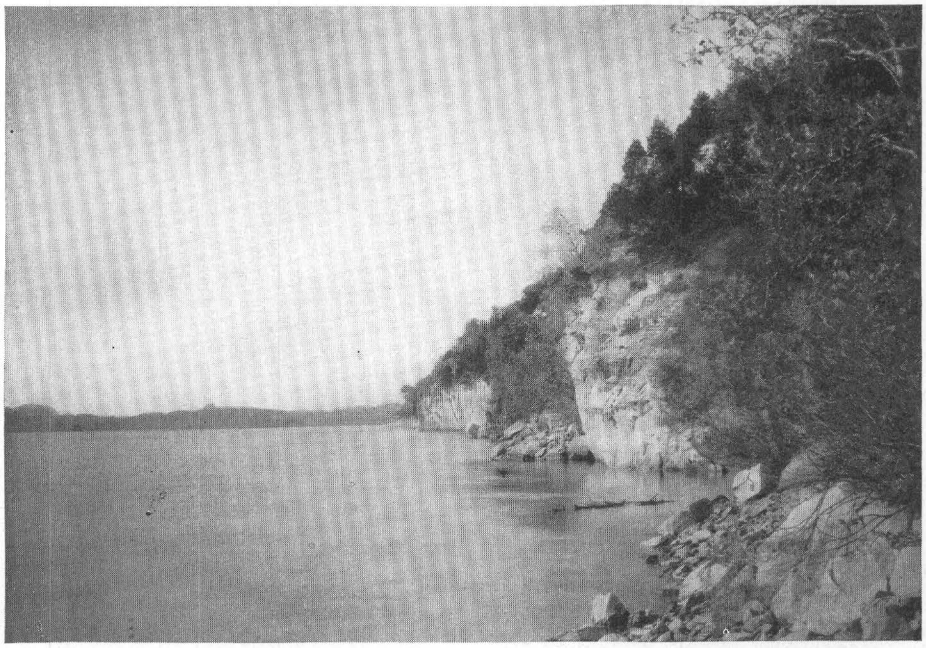
[61] Weller, Stuart, in Bevan, Arthur, op. cit., pp. 6, 12.

[62] Weller and St. Clair, op. cit., pp. 110–111.

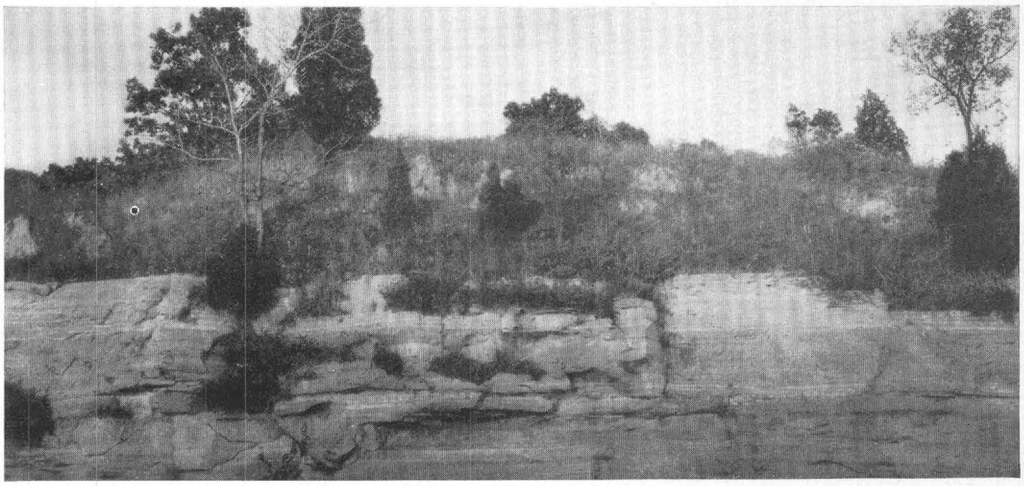
[63] Kay, G. M., Stratigraphy of the Decorah formation. Jour. Geology, vol. 37, pp. 644–645, 1929.

[64] Bain, H. F., Zinc and lead deposits of northwestern Illinois: U. S. Geol. Survey Bull. 246, pp. 18–20, 1905.

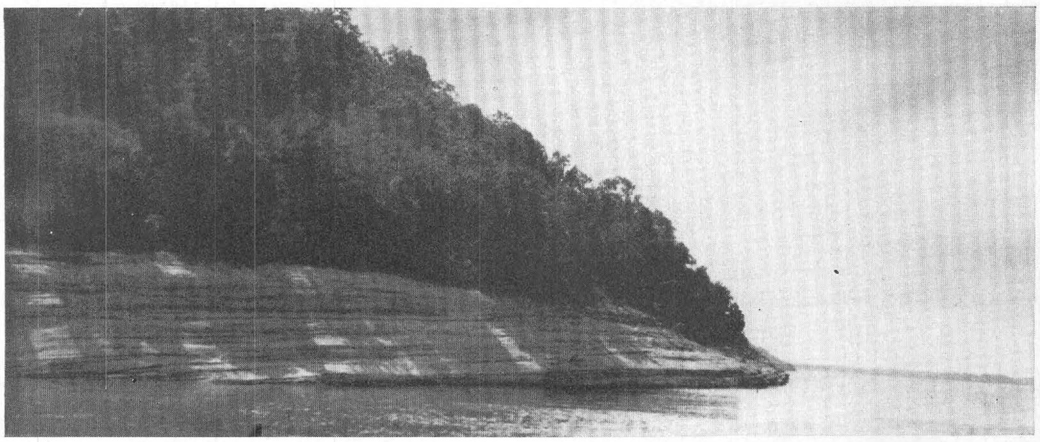
[65] Keyes, C. R., op. cit., p. 61.



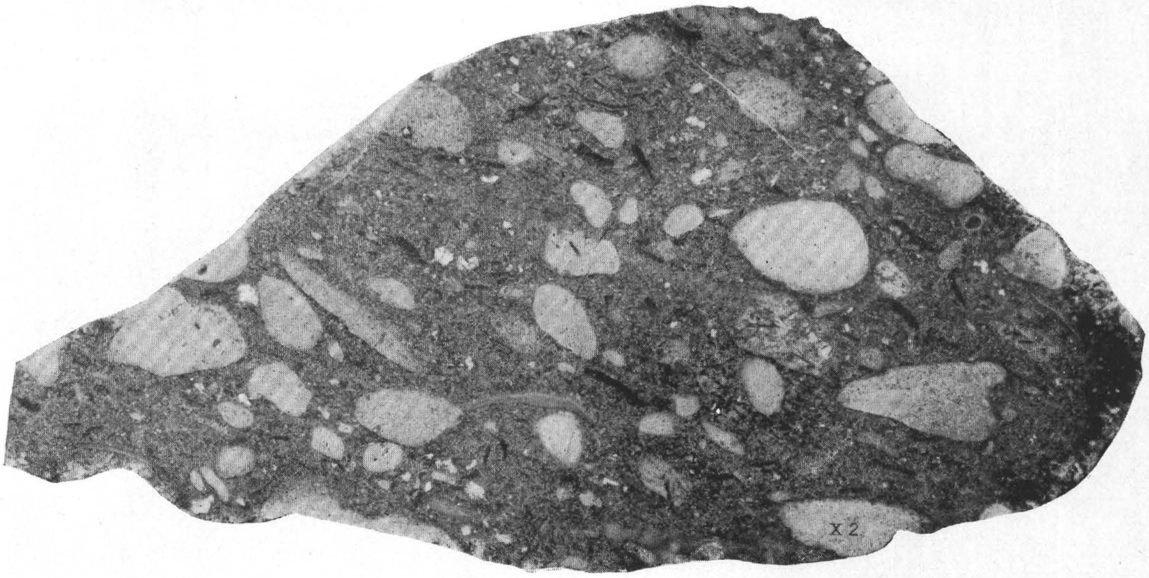
A. EXPOSURE OF ST. PETER SANDSTONE ALONG MISSISSIPPI RIVER IN CAP AU GRÈS.
View northward from near Dogtown Landing in SW¼ sec. 29, T. 12 S., R. 2 W.



B. REGULARLY BEDDED LAYERS OF ST. PETER SANDSTONE AT SOUTHERN END OF CAP AU GRÈS.
SW¼ sec. 29, T. 12 S., R. 2 W.



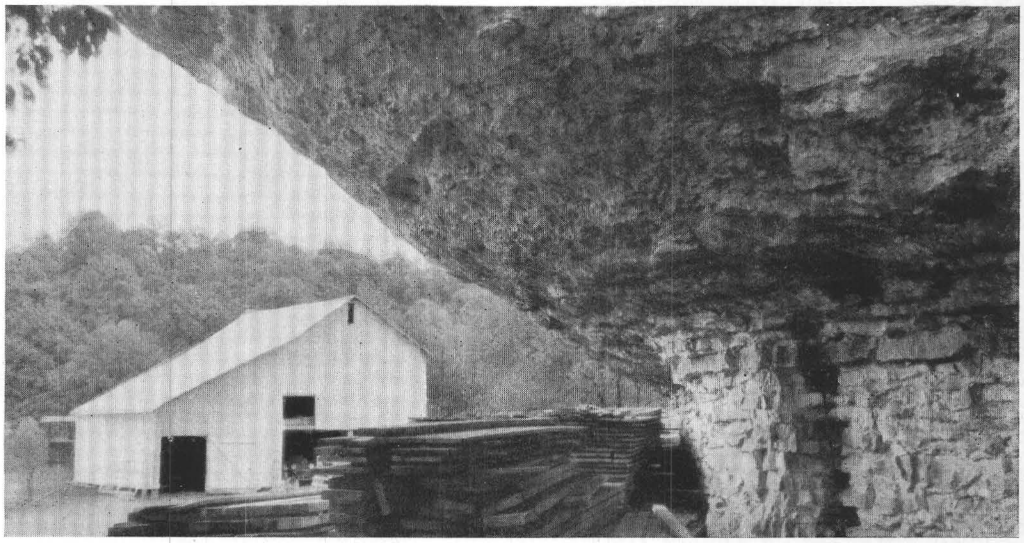
C. REGULARLY BEDDED LAYERS OF ST. PETER SANDSTONE AT NORTHERN END OF CAP AU GRÈS.
NE¼ sec. 30, T. 12 S., R. 2 W.



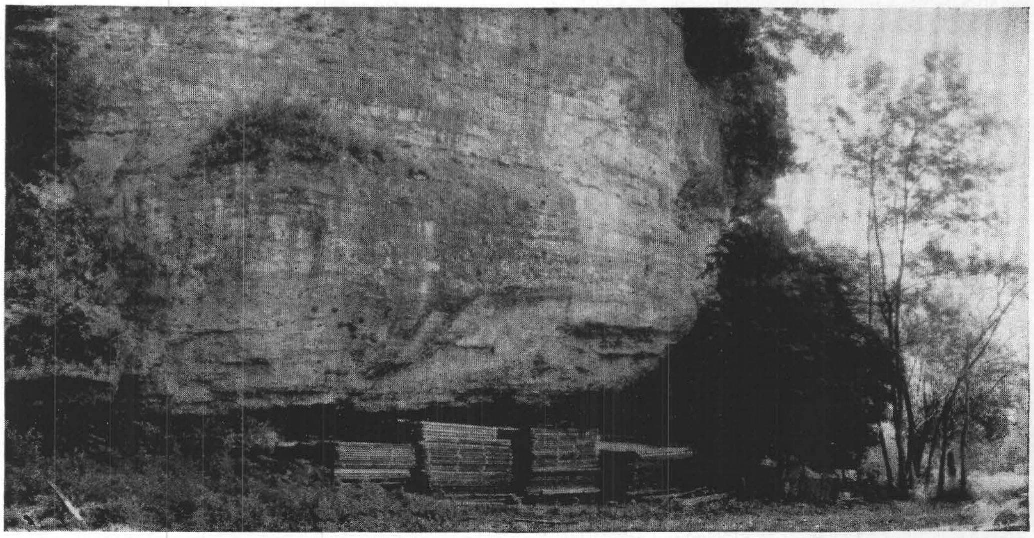
A. LIMESTONE CONGLOMERATE IN UPPER PART OF PLATTIN LIMESTONE.
NE¼SW¼ sec. 20, T. 12 S., R. 2 W. Enlarged 2 times.

B. FROM "FUCOIDAL" BED FROM LOWER PART OF PLATTIN LIMESTONE.
Irregular tubes of crystalline dolomite in dense limestone that contains many tests of *Tetradium syringoporoides*. N. center NW¼ sec. 29, T. 12 S., R. 2 W. Enlarged 2 times.

A. DECORAH LIMESTONE, THIN RIPPLE-MARKED BEDS OF LIMESTONE ALTERNATING WITH THIN LAYERS OF CALCAREOUS SHALE.
NE¼ sec. 6, T. 12 S., R. 2 W.



B. DECORAH LIMESTONE, OVERLAIN BY MASSIVE (OVERHANGING) KIMMSWICK LIMESTONE.
NE¼ sec. 6, T. 12 S., R. 2 W.



C. BLUFF OF MASSIVE KIMMSWICK LIMESTONE OVERLYING DECORAH LIMESTONE.
NE¼ sec. 6, T. 12 S., R. 2 W.

Mo., that are approximately, if not exactly, the same age as those in Calhoun County, Ill. In 1907, however, Weller [66] adopted the name Plattin, previously applied by Ulrich [67] to the rocks lying between the Joachim and Kimmswick formations in Jefferson County, Mo., and this usage was followed by Krey. In 1911, however, Ulrich [68] redefined the Plattin so as to include only the beds between the Joachim and the Decorah, and this restriction of the Plattin limestone has been adopted by most other writers.

The thin argillaceous layer at the base of the Plattin may possibly be the equivalent of the Glenwood shale [69] of Iowa State reports, but no definite faunal or lithologic evidence to support this correlation was found.

Rowley [70] suggested the name Auburn chert for weathered chert beds in the upper part of the Plattin limestone in Lincoln and Pike Counties, Mo. The fauna of these beds has been studied by Branson [71] and their equivalence with the thin-bedded chocolate-brown limestones at the top of the Plattin was established by Krey.[72] The application of the name Decorah,[73] first used for rocks exposed near the city of Decorah, Iowa, to the rocks that crop out in Calhoun County was suggested by E. O. Ulrich, who studied the fossils collected by the writer. In accordance with the original definition of the Plattin limestone, these rocks have sometimes been classified as the Decorah member of that formation, and in the Hardin and Brussels quadrangles they might very appropriately be so treated, because of their thinness, their apparently conformable relations, and the presence of lithologically similar beds within the Plattin limestone. Nevertheless, in the interest of uniformity of usage in different areas, these beds are here described as a separate formation overlying the Plattin limestone. Still, it would be misleading to apply the name Decorah shale in the Hardin and Brussels quadrangles, and the more appropriate lithologic term "Decorah limestone" is therefore used.

KIMMSWICK LIMESTONE

Above the Decorah limestone lies the Kimmswick limestone, a formation about 70 feet thick that is made up dominantly of rather coarse grained, massive, and exceptionally pure limestone. It crops out in the bluffs and stream valleys for nearly 7 miles along the western side of Calhoun County, and it was found at a depth of only 14 feet below the surface in a well 4½ miles farther north in the NE¼SE¼ sec. 6, T. 11 S., R. 2 W. It comes to the surface also in three small areas in southwestern Jersey County.

Topographic expression.—The Kimmswick is the uppermost unit in the thick series of hard limestones and dolomites that lie below the soft Maquoketa shale. As these hard beds are much more resistant to erosion than the soft shale, they tend to stand in bluffs and hills whereas the shale forms broad valleys. Because it is the uppermost unit of these hard rocks, the Kimmswick limestone, even though it is a relatively thin formation, crops out as the bedrock over a fairly large area under the long gentle dip slopes on one side of the shale valleys. Although the area where the Kimmswick limestone forms the underlying bedrock is fairly large, the area of actual exposure at the surface is much smaller, for on the uplands and gentle hill slopes the limestone has been heavily mantled with much later deposits of loess. (See pp. 5–6.)

The exceptional purity of the limestone makes it especially susceptible to solution by percolating ground waters and, consequently, to the development of underground drainage. Where the Kimmswick limestone forms the bedrock under gently sloping loess-covered uplands, as in the S½ sec. 8 and NW¼ sec. 20, T. 12 S., R. 2 W., the topography is marked by an exceptional development of sinkholes. (See airplane photograph, pl. 15*B*.)

Lithologic character.—In its lower half the Kimmswick limestone consists almost entirely of very massive, coarsely crystalline beds (see pl. 5*C*) but higher in the formation thin-bedded fine-grained layers become progressively more abundant until in the upper 20 feet there are only a few massive, coarse-grained beds.

The lower, massive, coarsely crystalline limestone is commonly light yellowish or brownish gray on fresh fractures, but it weathers to various shades of dull brownish gray or very pale gray. The coarse granular texture of this rock seems to be due at least in part to the abundance of crystalline fragments of crinoid stems. Upon weathering, this coarse massive phase of the Kimmswick develops a characteristically rough surface marked by large rounded pits or small caverns from several inches to a few feet in diameter similar to but much larger than those in the Plattin limestone. These lower beds of the Kimmswick are excellently exposed in the bluff just south of Dixon Hollow, in the NE¼ sec. 6, T. 12 S., R. 2 W. (See pl. 5*C*.)

The upper thin-bedded phase is variable in its characteristics. Though normally fine-grained, it ranges from dense to medium-grained, and some of the more highly fossiliferous layers are even coarsely crystalline. Its color also is variable though it may be said broadly to include two main types—a distinctly brown and a

[66] Weller, Stuart, op. cit., p. 222.

[67] Ulrich, E. O., in Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 2, p. 111, 1904.

[68] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull., vol. 22, pl. 27, 1911.

[69] Calvin, Samuel, Geology of Winneshiek County: Iowa Geol. Survey, vol. 16, pp. 74–75, 1906.

[70] Rowley, R. R., Geology of Pike County: Missouri Bur. Geology and Mines, 2d ser., vol. 8, p. 14, 1908.

[71] Branson, E. B., The fauna of the residuary Auburn chart of Lincoln County, Missouri: Acad. Sci. St. Louis Trans., vol. 18, pp. 39–52, 1909.

[72] Krey, Frank, op. cit., pp. 20–21.

[73] Calvin, Samuel, Geology of Winneshiek County: Iowa Geol. Survey, vol. 16, p. 61, 1907.

very light purplish gray limestone—and many intermediate shades. This fine-grained limestone lacks the pitted weathering surface of the coarse phase, but it is characterized by a faint petroliferous odor when freshly broken. These upper layers of the Kimmswick are well exposed in many stream beds from the SW¼ sec. 29, T. 11 S., R. 2 W., south to the NW¼ sec. 28, T. 12 S., R. 2 W. The best individual exposure is probably that in the creek bed in Dixon Hollow in the SE¼ sec. 5, T. 12 S., R. 2 W.

The Kimmswick limestone is exceptionally pure calcium carbonate. Chemical analysis of a sample (p. 156) taken from 37 feet in the middle part of the formation in the NW¼SE¼ sec. 17, T. 12 S., R. 2 W., Calhoun County, indicates that the rock consists of about 98.3 percent calcite. (See pp. 16–17.) The physical tests on this sample (p. 156) show, by the low bulk density and the high absorption and loss by abrasion, that the rock is softer, more porous, and less resistant than most limestones.[74] Small nodules of chert occur sparingly here and there throughout the formation but not in sufficient quantities to mar the exceptional purity of the rock.

Stratigraphic relations.—The exact stratigraphic relations between the Kimmswick and the underlying limestones in Calhoun County are uncertain. Weller[75] reported that "the line of contact is often sharp, though at times the transition from the lower formation to the upper occupies a foot or two in thickness." Krey[76] concluded that, although "the break between the Kimmswick and Plattin [used by him to include Decorah] is in most cases distinct, and the change from the dense lithographic limestones of the Plattin to the granular limestone of the Kimmswick is accomplished within 2 feet or less, * * * the presence throughout the region of outcrop of the thin, lithographic phase at the top of the Plattin precludes any erosional surface separating the two in this area and the two formations appear conformable." Dake[77] had seen no physical evidence of a break at this horizon in Missouri, but Weller and St. Clair[78] record an unconformity in Ste. Genevieve County, Mo. The writer recognized no evidence of an unconformity between the Decorah and the Kimmswick formations in Calhoun County, Ill., but he also failed to see the transitional beds referred to by Weller and by Krey. In fact, wherever the contact was found well exposed, as in the NW¼SW¼ sec. 8, T. 12 S., R. 2 W., the lithologic change between the Decorah and Kimmswick limestones was very sharp.

Within the formation the beds appear to be conformable. There is a complete gradation, through 25 feet or more, between the lower, massive, coarse-grained phase and the upper thin-bedded fine-grained phase of the limestone.

The Kimmswick limestone lies unconformably beneath the Maquoketa shale throughout the area, except at one locality where some evidence was found that there may be a very thin remnant of the Fernvale limestone between the two formations.

Fossils (Kimmswick and possible Fernvale faunas).—The Kimmswick limestone is highly fossiliferous throughout. Strophomenoid brachiopods occur abundantly in nearly every bed. The index fossil, *Receptaculites*, the sunflower coral, is abundant only in the brown, thin-bedded, fine-grained limestone in the upper third of the formation. This fossil may be found up to within a few feet or even a few inches of the top of the formation.

Collections were made from all fossiliferous beds that were found above the highest occurrence of *Receptaculites* to determine whether or not the Fernvale or other later formations are present in the area. With one possible exception these collections do not contain any Fernvale faunas and Dr. Ulrich reported on them as follows:

> As now determined all these lots [from the upper part of the formation] should provisionally be referred to as upper Kimmswick. The fauna is in some respects markedly different from that of the main mass of the formation. In Missouri south of St. Louis it is usually absent—probably eroded away before Fernvale time. Evidently these beds correspond to those observed by me in the Mississippi Valley exposures south of Goetz's quarry and between that place and Riverside, Mo., which I described in the "Revision" as lapping out beneath the Fernvale in following the bluff outcrops northward from Riverside. * * * The 30 or more species comprised in the collections under consideration are strongly indicative of the Trenton age of the beds in which you found them.
>
> As I see it now the typical Kimmswick is very old Trenton, and these locally deposited or unremoved beds may represent younger beds of the same group. The fauna of both is of northern origin and must have invaded from the general direction by paths that varied from time to time.

However, at one locality in the creek bed in the SE¼NE¼SE¼ sec. 17, T. 12 S., R. 2 W., fossils were collected (Colls. 170 k and f, table on pp. 167–168) from the upper 8 inches of the Kimmswick limestone and from the upper surface of this 8-inch bed, which include not only forms characteristic of the Kimmswick but others which, according to Dr. Kirk, "suggest an Upper Ordovician age earlier than Maquoketa and may be of Fernvale age." Furthermore, at this very locality the Kimmswick limestone is overlain unconformably by a thin layer of weathered chert fragments at the base of

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[74] Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, p. 31, 1925. For comparison with tests on other samples of Kimmswick and other limestones from Illinois, see Krey and Lamar, op. cit., pp. 47, 311.

[75] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 223, 1907.

[76] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Missouri, to Nauvoo, Illinois: Illinois Geol. Survey Bull. 45, p. 22, 1924.

[77] Dake, C. L., The problem of the St. Peter sandstone. Missouri School of Mines and Metallurgy Bull., vol. 6, no. 1, p. 33, 1921.

[78] Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 22, p. 113, 1928.

the Maquoketa shale that contain fossils (Colls 171 f and m, table on pp. 167–168) characteristic of the Maquoketa and also other forms that "are probably post-Kimmswick in age and may be Fernvale residuals." (See p. 23.)

Name.—The name Kimmswick limestone, first used for rocks in eastern Missouri,[79] was applied to these beds in Calhoun County by Weller.[80] Bradley [81] later confirmed this correlation by a comparison of the fauna at the type locality of the Kimmswick with that collected from the formation near Batchtown in Calhoun County.

Keyes [82] in 1897 proposed the name McCune limestone for the "25 or 30 feet" of fossiliferous, "massive, buff, dolomitic limestone" that succeeds the 125 or 150 feet of light-blue or gray, rather thinly bedded, compact, somewhat fossiliferous "Bryant" [= (?) Plattin] limestone in Pike and Lincoln Counties, Mo. In a later paper [83] he assigned a thickness of 50 feet to his McCune limestone in this area. Whether or not Keyes' name, McCune limestone, as thus proposed, was originally intended to include all the beds now referred to the Kimmswick is not certainly known,[84] but the term has since been used by some writers in a restricted sense, to include only beds younger than or in the upper part of the Kimmswick.[85]

In northern Illinois, rocks that overlie the Platteville limestone are known as the Galena dolomite. Some geologists have correlated the Galena dolomite with the Kimmswick limestone. Ulrich,[86] however, reported beds of lower to middle Galena age resting on upper Kimmswick limestone in Pike and Lincoln Countries, Mo.

No representatives of either the McCune limestone of Keyes (in its restricted sense) or the Galena dolomite were recognized in Calhoun County.

MAQUOKETA SHALE

The Maquoketa shale is of Richmond age. The Illinois Geological Survey and the Federal Geological Survey classify the Richmond as Ordovician; E. O. Ulrich [87] considered the Richmond Silurian.

The Maquoketa, which succeeds the Kimmswick limestone, crops out over a much larger area than any of the older formations. Along the west side of Calhoun County its outcrop is continuous and extends northward in the bluffs and small tributaries of Mississippi River to within 1½ miles of Hamburg. On the east side of Calhoun County and the west side of Jersey County it crops out almost continuously along the bluffs and tributary valleys for 5 or 6 miles north of the Cap au Grès faulted monocline. It comes to the surface again in three inliers or isolated exposures in Lincoln Valley and Lead Hollow, 1 and 3 miles, respectively, south of Hardin in Calhoun County, and at the base of the bluffs ½ mile northward of Nutwood in Jersey County. The Maquoketa crops out in almost every valley along the Cap au Grès faulted flexure eastward from Twin Springs in the southwest corner of Jersey County to near Grafton, more than 3 miles east of the Brussels quadrangle.

Thickness.—The exposures of the Maquoketa shale are not such that very precise measurements of its thickness can be made, but it seems to thicken northeastward from slightly less than 100 feet in its southwesternmost exposures to more than 150 feet in southwestern Jersey County and to 200 or more near Star City in sec. 6, T. 11 S., R. 2 W., Calhoun County. A few widely scattered well records suggest that from Star City the formation thickens gradually northwestward. Records of wells drilled south and east of southern Calhoun County indicate rather definitely that, where buried under younger rocks, the Maquoketa shale continues to thin southwestward toward the Ozarks. In the Little Silver well, only a few miles south of Calhoun County, the formation seems to be less than 40 feet thick.

Topographic expression.—The Maquoketa shale is a thick unit of soft relatively unresistant rocks lying between two units of much harder and more resistant limestones and dolomites. The streams have been able to cut down and carry away the shale much more rapidly than the limestone and dolomite, and they have thereby developed broad valleys along the outcrop of the Maquoketa and left the harder rocks standing as highlands.

The most striking development of these shale valleys within the area is the continuous topographic depression or valley from near Mount Victory School southward through Batchtown for 7 miles to the head of Dogtown Hollow. This valley is formed by the coalescence of the upper or middle courses of five separate westward-flowing streams. It probably was carved out by these

[79] Ulrich, E. O., in Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 2, p. 111, 1904.

[80] Weller, Stuart, op. cit., pp. 222–223.

[81] Bradley, J. H., Jr., Stratigraphy of the Kimmswick limestone of Missouri and Illinois: Jour. Geol., vol. 33, pp. 60–61, 1925; Fauna of the Kimmswick limestone of Missouri and Illinois: Contr. from Walker Museum, vol. 2, no. 6, 1930.

[82] Keyes, C. R., Some geological formations of the Cap-au-Grès uplift: Iowa Acad. Sci. Proc., vol. 5, p. 61, 1898.

[83] Keyes, C. R., Scheme of the stratigraphic succession in Missouri, p. 3, Des Moines, 1914.

[84] Dake, C. L., The problem of the St. Peter sandstone: Missouri School of Mines and Metallurgy, Bull. vol. 6, no. 1, p. 38, 1921.

[85] Ulrich, E. O., Revision of the Paleozoic systems: Geol. Soc. America Bull. vol. 22, pl. 27, 1911. Foerste, A. F., The Kimmswick and Plattin limestones of northeastern Missouri: Denison Univ., Sci. Lab. Bull. vol. 19, pp. 182–183, 1920. Bradley, J. H., op. cit., p. 62.

[86] Ulrich, E. O., op. cit., pp. 524–525.

[87] Ulrich, E. O., Relative values of criteria used in drawing the Ordovician-Silurian boundary: Geol. Soc. America Bull., vol. 37, pp. 279–348, 1926; Ordovician trilobites of the family Telephidae and concerned stratigraphic correlations: U. S. Nat. Mus. Proc., vol. 76, pp. 61–69, 1929.

separate streams, but it seems to have been used for a short time and perhaps modified somewhat by a single southward-flowing stream or river, which in Pleistocene time was crowded eastward by the Kansan ice sheet. (See pp. 75–76, 117.)

The Maquoketa shale is relatively impervious to percolating ground water and in its upper part it contains beds that are a very plastic, sticky clay once they become soaked with water. Water seeping downward through the overlying limestones and dolomites encounters these impervious clays and flows along their upper surface until it reaches the outcrop, where it escapes in seeps and springs. There it runs over and softens the clayey beds beneath. Inasmuch as hills capped by the more resistant limestones and dolomites are commonly steep-sided, this softening of the supporting clay at seeps and springs permits heavy ledges of limestone and dolomite to break loose from the bed, sometimes in large masses, and creep or slide downhill. This creeping and sliding is a common feature of the upper contact of the Maquoketa shale in the Hardin and Brussels quadrangles. Wet boggy ground, strewn with large blocks of the overlying beds, and in places marked by leaning trees, is a characteristic feature of this contact.

Lithologic character.—The rocks that make up the Maquoketa shale change progressively and fairly uniformly in their lithologic character from bottom to top.

In the lower part, especially in the lower 25 feet or so, the rocks consist dominantly of thin-bedded or flaggy, argillaceous dolomite and calcareous mudstone in beds from 1 to 6 inches thick. These beds are commonly buff, tan, or dark bluish gray, though some layers weather to a dark reddish brown. A few thin layers are gritty or granular and seem sandy, but upon inspection they are seen to contain small phosphatic grains and microscopic fossils and very few grains of sand. Thin layers less than 1 inch thick of very pale gray clay separate some of the layers of argillaceous dolomite.

The lower beds grade imperceptibly upward into the softer and less calcareous rocks that make up the remainder of the formation. These softer rocks consist chiefly of massive mudstone and platy to fissile clay shale. On fresh surfaces these rocks are commonly buffy gray in the lower part and greenish gray in the upper part; where weathered they become pale buffy or yellowish gray. In the upper part of the formation, especially in the upper 25 feet or so, the shales become more variegated, and thin beds may be seen that are reddish, maroon, bright tan, green, blue, purple, lavender, or white.

In this report the terms "fissile shale," "platy shale," and "massive siltstone," "claystone," and "mudstone" are applied to rocks that are sometimes grouped together loosely under the single name shale.[88] In lithologic descriptions the term "shale" is here used in a purely descriptive sense and applied only to those rocks that have the so-called "shaly structure," and the question of whether this structure is caused by bedding laminations or by incipient load metamorphism is not discussed. Rocks that in weathering tend to break up into very thin flakes are called "fissile shales," and those that make thicker fragments—1/8 to 1/2 inch thick—are called "platy shales." Rocks of similar composition, which, however, are more massive in their structure, are called "massive siltstones," or "massive claystones," depending upon the size of the constituent grains, or "massive mudstones" if both silt- and clay-sized grains are about equally abundant.

The proportion of carbonate in the shale decreases upward, although some beds even in the lower part of the formation seem to be totally free from it. Fresh samples, presumably from the middle part of the Maquoketa shale, that had been core-drilled in the NE1/4 NE1/4 sec. 13, T. 6 N., R. 13 W., Jersey County, 1 mile east of the Brussels quadrangle, at the proposed bridge site on Illinois River, were found to contain from 30 to 50 percent of material that is soluble in hydrochloric acid. These core samples, although they greatly resemble limestone, contain a large amount of clay, for they disintegrate in water more rapidly than in the acid.

Chemical analysis of a sample taken to represent the upper third of the formation in the NE1/4SW1/4 sec. 17, T. 11 S., R. 2 W., Calhoun County (p. 158), indicates that the rock consists dominantly, probably more than 80 percent, of clay minerals. The remainder of this sample seems to consist of 15 percent or less, probably about 8 percent, of quartz and 9.1 percent or less of dolomite and magnesite. (See pp. 16–17.) Other samples that have been collected nearby[89] contain more magnesia. Preliminary burning tests by the Department of Ceramic Engineering of the University of Illinois indicate that, except for the manufacture of brick and tile, the shale represented by this sample has no economic value.

Interlaminated with the calcareous shales in the lower and middle parts of the formation are occasional persistent but nodular sideritic beds a few inches thick. These beds commonly weather reddish brown and contain numerous rounded and irregularly shaped phosphatic grains from 1 to 10 millimeters in diameter. They also contain a small amount of iron sulfide, present as irregular masses and as spherules and small

[88] Lewis, J. V., Fissility of shale and its relations to petroleum: Geol. Soc. America Bull., vol. 35, pp. 570–589, 1924. Rubey, W. W., Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U. S. Geol. Survey Prof. Paper 165–A, pp. 38–40, 1930.

[89] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. Inv. no. 8, p. 14, 1926.

cubes. Associated with these sideritic beds are very finely sandy layers a few inches thick.

Except for these thin sandy layers, the shale in the middle and upper parts of the formation is exceptionally free from grit. However, minute crystals of pyrite and small phosphatic grains are not uncommon in fresh samples of the shale and mudstone, and small nubbins or concretionary nodules of dense buff and gray limestone were found in a few exposures of the upper part of the formation. At many outcrops the shale is cut by veinlets of crystalline gypsum and here and there selenite crystals are strewn over the weathered slopes. At one locality, in the SW¼SE¼ sec. 4, T. 6 N., R. 13 W., veins of calcite cut through the shale.

On Cave Spring or Madison Creek, in the SE¼NE¼ SE¼ sec. 17, T. 12 S., R. 2 W., the basal few inches of the Maquoketa shale consists of deeply weathered, rich reddish-brown fossiliferous chert and a few phosphatic grains. This thin layer of chert fragments contains some fossils (Coll. 171 f, pp. 167–169) that may possibly be residual from the Fernvale limestone; it overlies the Kimmswick limestone with apparent unconformity and it is in turn separated from the overlying shale by a sharp contact. At other outcrops nearby this cherty bed is absent.

At no place in the area was the entire thickness of the Maquoketa shale found well exposed. Two of the most nearly complete exposures were seen (1) in the bluff in the SW¼ sec. 20, T. 11 S., R. 2 W., where 80 feet of the lower and middle beds are well exposed but the lowermost layers and the upper 42 feet of the formation are covered, and (2) in the north slope of the hill in the NW¼ sec. 4, T. 12 S., R. 2 W., where the upper 85 feet of the formation is fairly well exposed. The basal beds of the Maquoketa are well exposed in many stream beds from the SW¼ sec. 29, T. 11 S., R. 2 W., south to the NW¼ sec. 28, T. 12 S., R. 2 W.—the same localities where uppermost Kimmswick can best be seen.

Fossils.—The Maquoketa shale contains relatively few fossils in this area. Some layers in the basal flaggy beds and several of the higher phosphatic and sideritic zones are very fossiliferous and contain the typical depauperate fauna—all individuals exceedingly small—of the lower Maquoketa. The writer found no organic remains in the upper third of the formation but Weller [90] recorded graptolites in the higher green shales.

One of the most interesting occurrences of fossils in the formation is an abundance of well-preserved trilobites of the genus *Ampyxina* in thin beds of argillaceous dolomite about 3 feet above the base of the formation in the ditch along the roadside and in a small valley 300 feet east of the road in the SW¼SW¼ sec. 29, T. 11 S., R. 2 W., Calhoun County (Coll. 38, p. 168).

[90] Weller, Stuart, Notes on the geology of southern Calhoun County: Ill. Geol. Survey Bull. 4, p. 224, 1907.

The weathered fossiliferous chert at the base of the formation on Madison Creek in the SE¼NE¼SE¼ sec. 17, T. 12 S., R. 2 W., contains a mixed fauna (Colls. 171f and m, pp. 167–169), which includes species characteristic not only of the Maquoketa but also of some older yet probably post-Kimmswick formation (see pp. 20–21). The upper few inches of the immediately underlying limestone here contains both Kimmswick and post-Kimmswick fossils (Colls. 170k and f, pp. 167–169), and Dr. Ulrich inferred that the chert

> may therefore represent a thin, perhaps local early Richmond and probably pre-Fernvale siliceous deposit that was eroded before the advent of the normal Maquoketa shale deposition and its chert residual mixed with the phosphatic conglomerate that usually alone marks the base of the typical Maquoketa shale. Still, it is quite possible that that chert was derived from some post-Kimmswick Trenton formation.[91]

Stratigraphic relations.—The contact between the Maquoketa shale and the Kimmswick limestone in this area is almost certainly unconformable. The discontinuous layer of weathered chert at the base of the Maquoketa on Madison Creek indicates rather definitely that the underlying limestone was exposed to weathering before the overlying shale was deposited. The probable significance of this thin but interesting chert bed has been discussed by Weller [92] and by Ladd.[93] The presence of the fauna (Colls. 171f and m, pp. 167–169) and the absence of rounding in the soft chert fragments seem to show that the material was not derived by erosion and transportation from pre-Kimmswick rocks exposed some distance away at the time of deposition but is instead a residuum of post-Kimmswick limestone, weathered in place, and redeposited with the very earliest Maquoketa sediments.

Other physical evidence also points to an unconformity at this contact. In places the upper surface of the Kimmswick limestone is somewhat irregular, and in a few exposures, as in the NW¼NW¼ sec. 32, T. 11 S., R. 2 W., small sinkholes, about 10 feet in diameter, seem to have been formed before the deposition of the Maquoketa shale. Somewhat indirect evidence of unconformity has been found [94] in other areas in the Mississippi Valley, but the Calhoun County example of physical unconformity between rocks of Trenton and Richmond age apparently is one of the clearest cases known in the region.

[91] Personal communication, July 1, 1929.

[92] Weller, Stuart, op. cit., pp. 223–224; The pre-Richmond unconformity in the Mississippi Valley: Jour. Geology, vol. 15, pp. 521–523, 1907.

[93] Ladd, H. S., The stratigraphy and paleontology of the Maquoketa shale of Iowa, Part I: Iowa Geol. Survey, vol. 34, pp. 349, 382 [1929?].

[94] Weller, Stuart, The pre-Richmond unconformity in the Mississippi Valley: Jour. Geology, vol. 15, pp. 523–524, 1907. Shaw, E. W., and Trowbridge, A. C., U. S. Geol. Survey Geol. Atlas, Galena-Elizabeth folio (no. 200), p. 6, 1916. Dake, C. L., The problem of the St. Peter sandstone. Missouri School of Mines and Metallurgy, vol. 6, no. 1, pp. 83, 94, 1921. Weller, Stuart, and St. Clair, Stuart, op. cit., p. 123. Ladd, H. S., op. cit., pp. 346–349.

Krey [95] noted an unconformity within the Maquoketa in Pike County, Mo., at a sandy phosphatic layer above the basal flaggy beds and below the overlying shale. It has been pointed out [96] that phosphates and iron sulfides commonly are present at basal contacts. The writer saw no evidence of an unconformity at any of the phosphatic, pyritic, or sideritic layers within the Maquoketa shale, but, if concentrations of these minerals do record breaks in sedimentation, the formation may contain many such obscure unconformities.

The contact with the overlying Silurian rocks also seems to be an unconformable one.

Name.—Keyes [97] proposed the local name Buffalo shales for the beds in Pike and Lincoln Counties, Mo., which, he said, had "been generally considered as representatives of the Maquoketa shales of northeastern Iowa." The name Maquoketa shale, first used in Iowa,[98] was adopted for the Calhoun County beds by Weller.[99] Savage, in an early report,[1] thought that the upper part of the Maquoketa shale in this region was equivalent to his Orchard Creek shale of southern Illinois, but he later [2] abandoned this interpretation.

Savage [3] reported the presence of thin layers of Thebes [4] sandstone lying unconformably upon the Kimmswick limestone along Madison (= Cave Spring) Creek in the SE¼ sec. 8, T. 11 [12?] S., R. 2 W., Calhoun County. These beds are probably the ones described in this report as the granular, phosphatic, slightly sandy layers in the lower part of the Maquoketa. As the Maquoketa shale and Thebes sandstone are generally considered to be time equivalents [5] or as "two distinct facies of contemporaneous sedimentation," [6] and as the formation contains very little sand in the Hardin and Brussels quadrangles, the name Maquoketa is used in this report.

In certain other areas the Maquoketa has been subdivided into subordinate members of limestone and of shale, each of which has been given a separate name.[7] Where these subordinate units are distinct, continuous, and thick enough to be mapped separately, it has been considered appropriate to classify them as formations instead of as members; and when thus subdivided into several formations, the Maquoketa there becomes a group instead of a formation. However, there seems to be no reason to change the classification of Maquoketa previously followed in the Hardin and Brussels quadrangles. The shale unit has not yet been subdivided here and it is thus appropriate to consider it as a single formation, the Maquoketa shale.

[95] Krey, Frank, op. cit., p. 23.

[96] Goldman, M. I., Lithologic subsurface correlation in the "Bend series" of north-central Texas. U. S. Geol. Survey Prof. Paper 129, pp. 4–5, 1921; Basal glauconite and phosphate beds. Science, new ser., pp. 171–173, 1922; Mississippian formations of San Saba County, Texas; U. S. Geol. Survey Prof. Paper 146, p. 56, 1926.

[97] Keyes, C. R., op. cit., pp. 61–62.

[98] White, C. A., Geology of Iowa, vol. 1, p. 181, 1870.

[99] Weller, Stuart, op. cit., pp. 223–224.

[1] Savage, T. E., Alexandrian series in Missouri and Illinois. Geol. Soc. Amer. Bull., vol. 24, pp. 356–357, 1913.

[2] Savage, T. E., Silurian rocks of Illinois: Geol. Soc. America Bull. vol. 37, pp. 514, 516, 1926; also by personal communication.

[3] Savage, T. E., The Thebes sandstone and Orchard Creek shale and their faunas in Illinois: Illinois Acad. Sci. Trans., vol. 10, p. 261, 1917.

[4] Worthen, A. H., Geology of Illinois: Devonian and Silurian systems, Illinois Geol. Survey vol. 1, p. 139, 1866.

[5] Ulrich, E. O., in Bassler, R. S., Bibliographic index of American Ordovician and Silurian fossils: U. S. Nat. Museum Bull. 92, pls. 3 and 4, 1915.

[6] Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: p. 120. Missouri Bur. Geology and Mines, 2d ser., vol. 22, p. 113, 1928.

[7] Ladd, H. S., op. cit., p. 329.

SILURIAN

The Silurian rocks that come to the surface in the Hardin and Brussels quadrangles include the Alexandrian of Savage (Edgewood and Brassfield limestones) and the Niagaran Joliet limestone. The stratigraphic relations of these formations are more difficult to decipher than those of any other rocks exposed within the area. This difficulty comes partly from the greater complexity of the stratigraphic relations of the Silurian rocks, because the different formations and members include several unconformities and the beds thicken and thin abruptly within short distances. This natural complexity is aggravated, however, by lateral variation and vertical similarity in the lithologic character of the rocks and by the scarcity of fossils where they are most needed. In the northern part of the area the dolomitic Edgewood limestone is readily differentiated from the Brassfield limestone but the Brassfield and the Joliet limestones can be separated from one another only by the fossils they contain. In the southern part of the area all three formations consist of dolomites and they are nearly if not quite indistinguishable from one another. The fossils, which are essential to a proper understanding of the Silurian stratigraphy of this region, are not only scarce but even where found are poorly preserved and fragile. Because of these difficulties, the stratigraphic interpretations of these rocks in this report, while consistent with all observations, are necessarily somewhat less certain than those of other formations in the two quadrangles.

The gross thickness of all Silurian rocks within the region ranges from less than 10 feet in the southwestern part of T. 11 S., R 2 W., to approximately 100 feet in the exposures at Grafton, 3 miles east of the Brussels quadrangle, and in a well drilled near Kampsville, 2 miles north of the Hardin quadrangle. However, in most of the outcrops the Silurian rocks are between 20 and 60 feet thick.

This series of limestones and dolomites, augmented in places by the overlying Devonian rocks, expresses itself topographically as a more or less definite unit. Lying between the soft Maquoketa and Hannibal shales below and above it, the unit commonly forms steep bluffs or distinct stratum benches (p. 113) on the sides of hills, the summits of which are made by still higher formations. In the southern part of the area the Silurian rocks are dolomitic and very resistant to weathering and in the southwestern corner of Jersey County, where very thick, they not uncommonly form vertical cliffs. In the northern part of the area the Brassfield and Joliet are relatively pure limestones in which caves, like the "Cave Spring" in McNabb Hollow in sec. 19, T. 10 S., R. 2 W., and sinkholes are locally developed.

Although fossils are relatively uncommon within the Silurian formations, they can usually be found by careful search. Those collected during the field work on which this report is based were studied by Prof. T. E. Savage, whose identifications are given in tabular form. (See pp. 170–171.)

EDGEWOOD LIMESTONE

At all exposures within the area the Maquoketa shale seems to be overlain by the Edgewood limestone. This formation consists of a variable series of brown dolomitic limestones with local oolitic beds at its base. Within the Hardin and Brussels quadrangles its area of outcrop extends northward from the Cap au Grès flexure nearly to Hamburg on the western and to Hardin on the eastern side of Calhoun County and more than a mile north of Nutwood in Jersey County.

Thickness.—The Edgewood limestone ranges from less than 10 to about 50 feet thick. In a broad area that includes the southern part of T. 10 S., R. 2 W. and all but the southeastern corner of T. 11 S., R. 2 W., it is less than 10 feet thick, and it may be absent locally. To the north, east, and south it becomes thicker.

Northward from this broad area the formation thickens gradually until in the NW¼SW¼ sec. 18, T. 10 S., R. 2 W., about 35 feet of beds are present. Still farther north, the thickness averages only 15 or 20 feet, but it is variable because of a marked erosional unconformity at the upper limit of the formation (fig. 2*A*). Locally, as in sec. 12, T. 10 S., R. 3 W., this unconformity seems to reduce the thickness of the Edgewood to less than 10 feet.

Eastward from the broad area in T. 11 S., R. 2 W. the formation seems to thicken very gradually to about 20 feet at the northernmost exposures in Jersey County. Here, as to the north, the upper limit of the formation is distinctly unconformable.

Southward from this broad area the Edgewood limestone thickens abruptly to 30 or 40 feet within less than 1 mile along a line that extends east-west through the northern part of T. 12 S., R. 2 W., and the middle of T. 7 N., R. 13 W. This southward thickening continues more gradually until a thickness of about 50 feet is reached along an east-west line or zone that extends through the middle of T. 12 S., R. 2 W., and the southern part of T. 7 N., R. 13 W. From this zone of maximum thickness, the formation again thins gradually southward to about 25 or 30 feet at the southernmost exposure.

The outcrops of Edgewood limestone within these quadrangles thus fall naturally into three fairly distinct zones or areas: (1) a central area where the formation is very thin, (2) a northern and northeastern area where the thickness is normally greater but, because of an unconformity, variable, and (3) a southern area where the formation is rather uniformly thicker and where it attains its maximum thickness. It so happens that these three areas or zones of differing thicknesses of the formation likewise constitute convenient divisions for discussing the differing lithologic characteristics and stratigraphic relations of the formation.

Lithologic character.—The Edgewood limestone includes several distinct lithologic types. In the northern area all but the lower few feet of the formation consists of a rather soft fine-grained powdery or earthy dolomitic limestone. This rock (presumably the Bowling Green limestone member of the Edgewood) is everywhere brown, although the color ranges from a bright tan to a dull brownish gray. The layers are massive to thin-bedded—some of them a few feet thick, others only a few inches. In the more massive layers, the rock not uncommonly spalls off in thin slabs parallel to the face of the exposure. Weathered surfaces of this brown dolomitic limestone commonly show many very small black or purplish spots, which may be manganese dioxide. A few small masses of pyrite and nodules of chert were noted, but very few fossils were found in this member. Savage[8] reports that in this region the Bowling Green member of the Edgewood limestone contains from 15 to 25 percent of very fine sand. A readily accessible exposure of these beds may be seen near the north ¼ corner sec. 13, T. 10 S., R. 3 W., in the south bank of Indian Creek.

Northward from sec. 9, T. 11 S., R. 2 W. to sec. 12, T. 10 S., R. 3 W., the lower few feet of the formation is a hard, massive, gray oolite or oolitic limestone. This rock, the Noix oolite member of the Edgewood, is light buffy gray where fresh and a darker grayish brown on weathered surfaces. The member commonly ranges from 1½ to 3½ feet thick but in the SW¼ sec. 34, T. 10 S., R. 2 W., it appears to be more than 10 feet thick.

The oolite grains or spherules in the Noix oolite are uniformly between ½ and 1 millimeter in diameter. Apparently most of the spherules have nuclei of crystalline calcite though a few contain pale green fragments of fossil shells (probably glauconitized echinoderm spines) and some have no recognizable centers (pl. 6*A*). These spherules are very light gray and set in a dense darker-gray limestone matrix. The rock is commonly very oolitic, but the spherules are not everywhere uniformly distributed. Although in some places they make up nearly all the rock, elsewhere they are scattered sparingly through the dense gray limestone.

[8] Savage, T. E., Alexandrian series in Missouri and Illinois: Geol. Soc. America Bull., vol. 24, p. 364, 1913.

Associated with the most highly oolitic layers of the limestone are many angular to well-rounded phosphatic pebbles or grains from 1 to 6 millimeter in diameter. In some places rounded quartz pebbles from 2 to 8 millimeters in diameter and large crystals of calcite occur sparingly at the bottom and at the top of the member. At the mouth of Indian Creek, near the north 1/4 corner sec. 13, T. 10 S., R. 3 W., the basal layers of the oolite carry many large masses of pyrite and, according to local reports, sphalerite and galena. Some layers of the Noix oolite are highly fossiliferous.

In the southern area the Edgewood limestone is a much harder and more dolomitic rock. (See fig. 2A.) In most exposures in that area it is a hard, massive, porous, brown dolomite or very dolomitic limestone, the outcrop of which forms a prominent ledge. It ranges from light gray to pale tan on fresh fractures and from dull grayish brown to rich tan where weathered. Locally it is mottled with pinkish stains. The rock is dominantly massive in beds from 1 to 4 feet thick although a few thin-bedded layers occur, chiefly in the lower part of the formation. It is fine-grained to dense and characteristically pitted with minute pores that suggest its dolomitic composition. Small chert nodules, though not abundant, may be found in nearly every exposure and small pyritic masses and dark (manganese dioxide?) spots like those in the northern exposures may be seen in some layers. In a few places, pyritohedrons of iron oxide, presumably secondary after pyrite, line joint surfaces in the upper part of the formation. In the SW1/4NE1/4 sec. 16, T. 12 S., R. 2 W., where the formation is well exposed, thin-bedded bluish-gray dolomite at the base contains pyritic nodules and phosphatic pebbles and may be a southern representative of the Noix oolite. Fossils, poorly preserved as casts, are either somewhat commoner or else are more readily seen in this hard dolomite than in the soft dolomitic limestone farther north.

In the central area, where the formation is thin, the lithologic character is varied. In the main it is intermediate between that of the soft dolomitic limestone of the northern area and the hard dolomite of the southern area, but this gradation is also marked by interlamination of soft limestone and hard dolomite. At one locality, near the south 1/4 corner of sec. 10, T. 11 S., R. 2 W., thin masses of pale buff limestone grade into deep brown dolomite. The central area also includes a lithologic phase of the formation not found in the other areas. This is a hard bluish to brownish-gray, moderately crystalline, dolomitic limestone a few feet thick. At a few localities, as in the N. center sec. 16, T. 11 S., R. 2 W., this grayer, more definitely crystalline phase of the formation is distinctly granular in its lower part.

The change in character of the Edgewood between the northern and the southern areas is not an abrupt one. Some evidences of the gradation may be recognized through a distance of 5 miles or more. However, the sharpest modification comes near the middle of the area, where the formation is thinnest, and extends approximately east-west across the northern part of T. 11 S., R. 2 W. It is not certain whether this change in lithologic character is a subsequent one caused by dolomitization of the rocks in the southern area long after they were deposited or whether the difference is an essentially original one caused by differences in the type of sediments deposited. The restriction of the Noix oolite member to the northern area and the occurrence of the grayer, more crystalline phase in the central area suggests that the differences may have been largely depositional. On the other hand, the apparently residual masses of limestone in the dolomite indicate that at least some of the change is of secondary origin. Analogous differences in the lithologic character of the Brassfield limestone (see pp. 28–29) also seem to favor subsequent dolomitization.

Chemical analysis of a sample (p. 156), collected by T. B. Root and assistant, from the abandoned quarry just north of Meppen, SE1/4 sec. 23, T. 12 S., R. 2 W., Calhoun Co., represents 12 feet of the Edgewood and 7 feet of the overlying Brassfield formation, which at this locality is lithologically indistinguishable from the Edgewood. The analysis shows that the rock consists of about 92 percent of dolomite in which the average molecular ratio of calcium to magnesium is as 12 to 11. The remainder of the rock consists chiefly of silica, of which probably more than half is combined with alumina as clay and the rest is free silica in small sand grains or as disseminated chert. (See pp. 16–17.) The sample also contains more iron and somewhat less sulfur than most other samples of dolomite and limestone from this region. As might be expected from its porous texture, physical tests (p. 156) show that the rock has a lower bulk density and absorbs more water than most other limestones and dolomites of this region. However, from the wear or attrition test one might conclude that the dolomite of the Edgewood is softer than the rocks of most of the other formations of the area,[9] a conclusion that seems inconsistent with the obvious hardness and superior resistance to weathering of natural outcrops of the rock.[10]

Stratigraphic relations.—Everywhere within the Hardin and Brussels quadrangles the Edgewood limestone seems to overlie the Maquoketa shale unconformably, for the lithologic change between the two formations is very abrupt and the actual contact is usually

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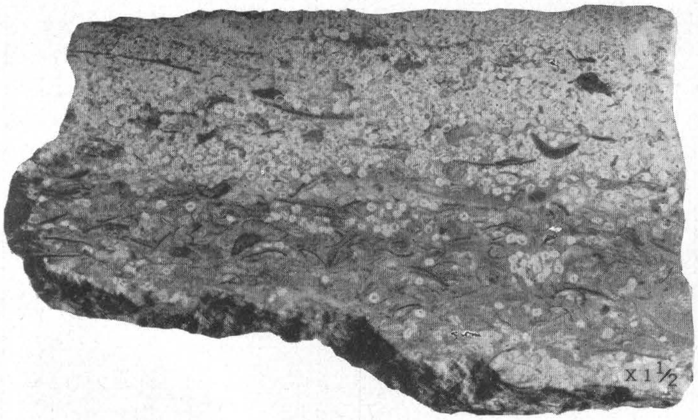
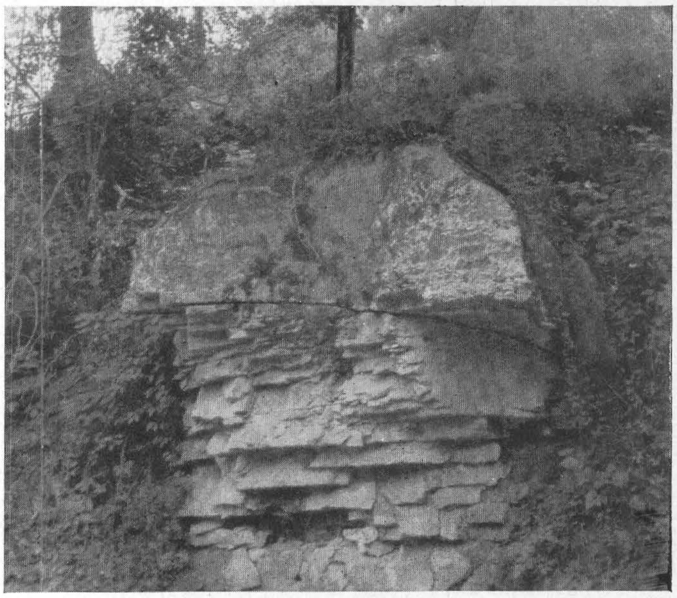
[9] Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, p. 31, 1925.

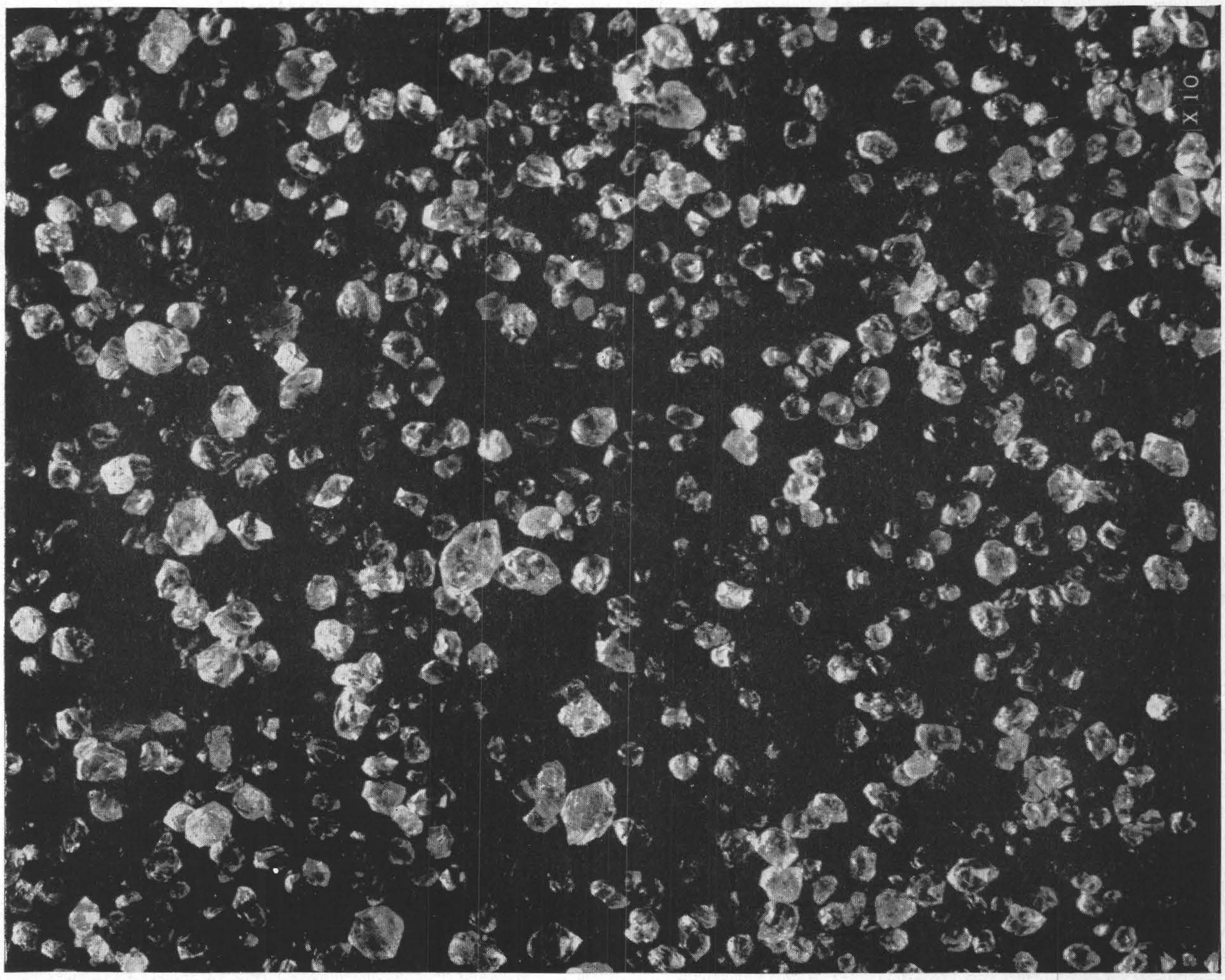
[10] For a comparison with chemical analyses and physical tests of other limestones and dolomites of Illinois, see Krey, Frank, and Lamar, J. E., op. cit., pp. 51, 311, 318–319, and for an analysis of Niagaran dolomite from Pike County, Mo., see Buehler, H. A., The lime and cement resources of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 6, p. 237, 1907.



A. NOIX OOLITE.
NW¼NE¼ sec. 13, T. 10 S., R. 3 W. Enlarged 1½ times.



B. BRASSFIELD LIMESTONE, LYING UNCONFORMABLY UPON EDGEWOOD LIMESTONE.
SW¼SW¼ sec. 18, T. 10 S., R. 2 W.



C. SECONDARILY ENLARGED QUARTZ GRAINS IN THIN SANDSTONE IN BRASSFIELD LIMESTONE.
NE¼SE¼ sec. 17, T. 7 N., R. 13 W. Enlarged 10 times.

somewhat wavy. Savage [11] reports that throughout Illinois and Missouri the Alexandrian rocks lie unconformably upon beds of Richmond age.

Within the Edgewood limestone the stratigraphic relations are complex. (See fig. 2*A*.) In the northern part of the Hardin quadrangle the Noix oolite member is everywhere sharply separated from the overlying Bowling Green limestone member and near the north ¼ corner of sec. 13, T. 10 S., R. 3 W., the contact is undulatory and suggests an unconformity. In the southern area there are at least two slight erosional unconformities within the series of beds here called the Edgewood formation. Two small but unmistakable unconformities, 18 and 25 feet below the top of the formation, and two other higher somewhat irregular bedding planes are well exposed in the south central part of sec. 28, T. 7 N., R. 13 W. Near Monterey schoolhouse, in the center of sec. 11, T. 12 S., R. 2 W., an unconformity and an irregular bedding plane may be seen, 47 and 22 feet, respectively, below the top of the formation. Savage [12] has stated that in this general region there are no stratigraphic breaks within the Edgewood and these small unconformities may be very local in their occurrence and have no stratigraphic significance.

The upper limit of the Edgewood limestone everywhere within the area is marked by an unconformity.

Fossils.—The formation contains relatively few fossils. Those found by the writer were almost all in the Noix oolite member of the formation in the northern area or in the hard brown dolomite in the southern area. (See table pp. 170–171.)

Formation and member names.—The Silurian rocks along the Lincoln anticline were all referred to the Niagaran by earlier geologists.[13] Later, Savage [14] recognized his Alexandrian series as an older subdivision of the Silurian and referred most of the Silurian rocks of Pike and Lincoln Counties, Missouri, and Calhoun, Pike, and Jersey Counties, Illinois [15] to the Edgewood [16] and Sexton Creek [17] formations of this series.

He proposed [18] that three members be recognized within the Edgewood limestone—a lower member, which he called Cyrene, a local Noix [19] oolite member, said to be equivalent to the upper part of his Cyrene, and an upper member called Bowling Green.[20] Savage [21] believed that these members are conformable throughout. He stated [22] that from its type locality in Missouri the Noix oolite thins eastward and that its lower part is absent in Calhoun County.

The Noix oolite member is readily recognizable at the base of the Edgewood in the northern part of the Hardin quadrangle and the overlying soft brown dolomitic limestone is presumably the Bowling Green limestone member. No representative of Savage's Cyrene member was recognized within the area, unless the grayer, more crystalline facies in the central area should be referred to it. The hard brown dolomite in the southern area probably corresponds to the Bowling Green limestone member,[23] although some of the basal beds in southern Calhoun County may represent equivalents of the Noix or of Savage's Cyrene.

BRASSFIELD LIMESTONE

The Edgewood limestone is overlain at most places in the Hardin and Brussels quadrangles by the Brassfield limestone and the outcrops of the two formations are essentially coextensive. The Brassfield limestone consists dominantly of finely crystalline gray limestone in the northern part of the area and porous brown dolomite in the southern part.

Thickness.—At only one exposure within the two quadrangles, in the NE¼SW¼ sec. 35, T. 11 S., R. 2 W., was the Brassfield found to be absent, but it is less than 10 feet thick at almost all exposures in Calhoun County south of the middle of T. 11 S., R. 2 W., and in the exposures near Nutwood in Jersey County. Within this area the formation may be absent at other places, but over much of the region it persists with thicknesses of only 6 or 8 feet. Northward from this area the formation thickens gradually and, because of an unconformity at its base, very irregularly until in secs. 1 and 2, T. 10 S., R. 3 W., it is nearly 30 feet thick. From there northward it again becomes thinner. (See fig. 2*A*.) Southeastward from the area where the formation is thin, it thickens gradually and apparently much more uniformly to about 20 feet in sec. 9, T. 6 N., R. 13 W., and to nearly 30 feet near Grafton, about 3 miles east of the Brussels quadrangle.

Lithologic character.—In the northern part of the Hardin quadrangle, the Brassfield limestone is a very hard, massive to thin-bedded, finely crystalline to dense limestone. On fresh surfaces the rock is commonly a light, faintly buffy gray, mottled with irregular green-

[11] Savage, T. E., Alexandrian series in Missouri and Illinois: Geol. Soc. America Bull., vol. 24, p. 356, 1913; Silurian rocks of Illinois: Geol. Soc. America Bull., vol. 37, p. 513, 1926.

[12] Savage, T. E., Alexandrian series in Missouri and Illinois: Geol. Soc. America Bull., vol. 24, p. 360, 1913.

[13] Worthen, A. H., Geology of Illinois; Jersey County: Illinois Geol. Survey, vol. 3, pp. 116–117, 1868; Geology of Illinois: Calhoun County: Illinois Geol. Survey, vol. 4, pp. 6–8, 1870. Keyes, C. R., Some geological formations of the Cap-au-Grès uplift: Iowa Acad. Sci. Proc., vol. 5, p. 62, 1898. Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey, Bull. 4, p. 225, 1907.

[14] Savage, T. E., On the Lower Paleozoic stratigraphy of southwestern Illinois: Amer. Jour. Sci., vol. 25, pp. 433–434, 1908; Alexandrian series in Missouri and Illinois: Geol. Soc. America Bull., vol. 24, pp. 351–353, 1913.

[15] Savage, T. E., Alexandrian series in Missouri and Illinois: Geol. Soc. America Bull., vol. 24, pp. 360–361, 367, 371, 375–376, 1913.

[16] Savage, T. E., The Ordovician and Silurian formations in Alexander County, Illinois: Amer. Jour. Sci., vol. 28, p. 517, 1909.

[17] Savage, T. E., op. cit., pp. 518–519.

[18] Savage, T. E., Alexandrian series in Missouri and Illinois: Geol. Soc. America Bull., vol. 24, p. 361, 1913.

[19] Keyes, C. R., op. cit., p. 62.

[20] Keyes, C. R., op. cit., p. 62.

[21] Savage, T. E., op. cit., p. 360.

[22] Savage, T. E., op. cit., p. 367.

[23] Savage, T. E., Silurian rocks of Illinois: Geol. Soc. America Bull., vol. 37, p. 516, 1926.

ish stains. Locally, however, these stains are pinkish rather than greenish, and in a few places the rock is very dark gray. Weathered surfaces of the limestone are very light gray to dull buffy gray and are in many places overgrown with moss. Irregular or current-marked bedding surfaces are common, and a peculiar weathering surface marked by pits a few inches in diameter is characteristic of the formation. Small chert nodules are fairly abundant in some of the limestone beds. This northern development of the formation is typically exposed in the SW¼SW¼ sec. 1, T. 10 S., R. 3 W., where the Brassfield is 26 feet thick and the underlying and overlying formations also are well exposed.

In the southern part of the two quadrangles the Brassfield is almost, if not entirely, indistinguishable in lithologic character from the underlying Edgewood formation. (See fig. 24.) That is to say, it is a hard, massive, porous, grayish-brown dolomite or dolomitic limestone. This rock seems to be a slightly paler grayish brown and somewhat more cherty than the similar dolomite of the Edgewood and, locally, the greenish stains, the irregular bedding planes, and the pitted weathering surface characteristic of the northern Brassfield limestone can be recognized in the dolomite. However, in this southern area, the two formations are so nearly identical in lithologic character that faunal evidence is required to distinguish them with certainty. Fossils are uncommon in these beds of dolomite and when found they are difficult to extract. Fortunately, however, a thin faunal zone, marked by casts of shells of the brachiopod *Platymerella*, immediately below a cherty horizon near the base of the formation, seems to be persistent throughout the area. This dolomitic facies of the Brassfield is well exposed in the bluff immediately north of Monterey School in the center sec. 11, T. 12, S., R. 2 W. Here *Platymerella* casts were found 10 feet below the top of the Silurian dolomite and 3 feet above a wavy bedding surface that may mark the base of the Brassfield.

In the intervening region there is but little actual gradation between the northern gray limestone and the southern brown dolomite. From north to south, the gray limestone passes rather abruptly and largely by interlamination into brown dolomite, first at the base of the formation and then at successively higher horizons farther southward. In Calhoun County this entire change takes place within a short distance in the northern part of T. 11 S., R. 2 W., along very nearly the same line that marks the analogous change in lithologic character of the underlying Edgewood limestone. But in Jersey County, where the Brassfield is somewhat thicker, the transition extends through a distance of 6 miles or more, and the two types of rock may be seen in most exposures of the Brassfield from Nutwood south to Twin Springs.

In the southernmost exposure at which any gray limestone was recognized, in the SW¼NE¼ sec. 9, T. 6 N., R 13 W., a mass of gray limestone 2 feet thick in the lower part of the Brassfield may be seen to grade upward, downward, and laterally into the brown dolomite.

In the NE¼SE¼ sec. 17, T. 7 N., R 13 W., the Brassfield consists of 18 feet of brown dolomite below and 5 feet of gray limestone above, and the contact of the two rock types is marked by a bed or elongate lens of sandstone about 8 inches thick. As sandstone was seen nowhere else within the Brassfield formation, fossils were carefully collected from the adjacent rocks to determine its stratigraphic significance at this locality. Collections 147*a* and *b*, 148, and 149, from the underlying dolomite, and Collection 151 from the overlying limestone were determined as Brassfield by Professor Savage. (See pp. 170–171.) A few shells of pelecypods within the sandstone itself were very fragile and too poorly preserved for identification.

This thin sandstone is rather friable and ranges from white to pale brown. It seems to be made up entirely of exceedingly angular sparkling quartz grains, nearly all of which are between ⅙ and ⅔ millimeter in diameter, with ⅓ millimeter the commonest diameter. Under the binocular microscope each sand grain is seen to be bounded by many perfect crystal faces, none of which show the least evidence of any abrasion, though a very few are marred by broad rough pits that look like the impressions of rounded sand grains. (See pl. 6*C*.)

Under the petrographic microscope and immersed in an oil with the same index of refraction as quartz, the sandstone is seen to be a remarkable example of secondary enlargement. The original sand grains are composed of somewhat murky quartz that contains small inclusions and rutile needles. These original grains are all well rounded, and their surfaces are frosted and somewhat discolored by impurities. The quartz that has been added later to make the sharp crystal faces is clear and colorless and almost invariably in optical continuity with the original grain. The original grains seem never to be in contact with one another but to be separated by the thin layers of added quartz.

This sandstone resembles the sandstone in the overlying Cedar Valley limestone in its purity, grain size, and the extent of secondary enlargement. (See p. 31.) The Cedar Valley limestone overlaps the Silurian rocks and in the southern part of the area Devonian sandstone is found filling joints in the Silurian rocks. These facts, together with the absence of sandstone elsewhere within the Brassfield, suggest the possibility that this thin sandstone may not be a truly interlaminated bed in the Brassfield limestone but a later filling. The correct interpretation of this sandstone is not known, but its thinness and apparent lateral persistence in the single exposure where it was seen and the presence in it of pelecypod shells suggest strongly that it was laid down on the sea floor before the deposition of the overlying gray limestone.

In a few places, notably in the SE¼NE¼ sec. 29, T. 8 N., R. 13 W., the change from the northern gray limestone to the southern brown dolomite is marked by a very different type of rock. This is a hard, dense or lithographic, massive limestone, dove-colored where fresh and pale gray where weathered, which is spotted with abundant crystals or tubes of calcite from ½ to 3 millimeters in diameter. These calcite crystals seem to fill continuous branching pores or tubes that may represent fucoidal structures.

Chemical analysis of a sample of this spotted dove-colored limestone at this locality (p. 156) shows that the rock contains about 97 percent of relatively pure calcite. The chief impurity of this sample is silica, more than half of which very probably occurs free as scattered sand grains or as disseminated chert, and the rest is combined with alumina as clay (see pp. 16–17). Partial chemical analysis of a sample of Brassfield limestone from three-quarters mile south of Hamburg indicates an even greater purity of the calcite. See Lamar, J. E. Preliminary report on the economic mineral resources of Calhoun County: Ill. State Geol. Survey Rept. Investigations No. 8, p. 14, 1926.

The nature and the place of the lithologic change in the Brassfield limestone coincides so closely with that in the underlying Edgewood limestone that it seems almost certain that the difference in lithologic character must be caused by subsequent dolomitization in the southern area. It is true that the occurrence of the spotted dove-colored limestone and the apparently interlaminated sandstone in the transition zone suggest some initial differences within the formation there. However, the apparently residual masses of gray Brassfield limestone in the brown dolomite, the fairly uniform northward descending limit of the hard dolomite in both the Edgewood and Brassfield formations, and the fact that there are similar differences in the lithologic character of the overlying Joliet limestone are all much more simply explained by secondary dolomitization.

Stratigraphic relations.—In the northern part of the Hardin quadrangle the Brassfield limestone lies with pronounced erosional unconformity upon the Edgewood limestone. (See pl. 6*B*; fig. 24.) At many exposures the hard gray Brassfield limestone cuts down sharply 5 feet or more into the underlying soft brown dolomitic Edgewood limestone, and the total relief at the contact in this area must be at least 25 feet. In the central and southern areas the unconformity at the base of the Brassfield is much less conspicuous, and at most exposures it is represented by an irregular bedding plane a foot or two below the cherty *Platymerella*-bearing horizon.

Within the Brassfield limestone no evidence of stratigraphic breaks was noted anywhere except the indirect evidence afforded by the thin sandstone in sec. 17, T. 7 N., R. 13 W. (See p. 28.)

The upper contact of the formation is unconformable. In the northwestern and the southeastern parts of the area, the Brassfield limestone is overlain by the Joliet limestone and, although no evidence of a break in sedimentation between the two formations could be detected, the faunas indicate that many feet of strata present between rocks of these ages in other regions are missing here. Throughout most of its area of outcrop in the Hardin and Brussels quadrangles, the Brassfield is overlain by the Devonian Cedar Valley limestone. The contact, though fairly smooth, is unquestionably unconformable because, both southward and westward from the outcrops of Joliet limestone, successively lower faunal zones within the Brassfield limestone are overlapped by the Devonian.

Fossils.—Organic remains are not common in the Brassfield and even where they are present the fossils are difficult to break out of the hard brittle rock. However, a persistent faunal zone was pointed out to the writer by Professor Savage. It is marked by cross sections of brachiopod shells and can be located with careful search near the base of the formation in most exposures. In the northwestern and southeastern parts of the area, where the Brassfield is thicker, a few fossils representative of higher faunal zones may be found. (See table, pp. 170–171.)

Name.—Savage [24] was the first to recognize Silurian rocks older than the Niagaran in Calhoun and Jersey Counties, and at that time he applied the name Sexton Creek [25] limestone to the beds here called Brassfield. A few years later, however, he proposed to restrict the name Sexton Creek limestone to the rocks "equivalent in age to the Brassfield strata of Ohio and Kentucky" [26] that were laid down in a basin of deposition in southern Illinois; whereas "the strata of corresponding age that accumulated in the northern basin, including western Illinois and eastern Missouri north of Saint Louis and northeastern Illinois * * * will hereafter be referred to by the name 'Kankakee' limestone." [27] The northern basin thus included the Hardin and Brussels quadrangles, and in later papers Savage specifically applied the name "Kankakee (Brassfield) limestone" [28] in this area. Krey [29] and Lamar,[30] however, used the term Sexton Creek limestone in the area. To avoid the con-

[24] Savage, T. E., Alexandrian series in Missouri and Illinois: Geol. Soc. America Bull., vol. 24, pp. 360–376, 1913.

[25] Savage, T. E., The Ordovician and Silurian formations in Alexander County, Illinois: Amer. Jour. Sci., 4th ser., vol. 28, pp. 518–519, 1909.

[26] Savage, T. E., Alexandrian rocks of northeastern Illinois and eastern Wisconsin; Geol. Soc. America Bull., vol. 27, p. 315, 1916.

[27] Savage, T. E., op. cit., pp. 315–316.

[28] Savage, T. E., Silurian rocks of Illinois: Geol. Soc. America Bull., vol. 37, pp. 515, 516, 517, 530, 1926.

[29] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Missouri, to Nauvoo, Illinois: Illinois Geol. Survey Bull. 45, pp. 27–28, 1924.

[30] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. Inv., no. 8, p. 9, 1926.

fusion that may arise from several different names for beds faunally and lithologically very similar and believed to represent the same time interval, Professor Savage later recommended [31] that Brassfield [32] limestone, a name widely used in many of the Middle Western States, be applied to these beds in the Hardin and Brussels quadrangles.

JOLIET LIMESTONE

In two small areas, one near Hamburg in Calhoun County and the other along the Cap au Grès flexure in Jersey County, the Brassfield limestone is overlain by the Joliet limestone. Possibly a few feet of beds that belong to the Joliet limestone may be present above the Brassfield in the exposures north of Hardin and north of Nutwood, but no definite evidence of their presence there could be found.

The formation is about 16 feet thick at Hamburg, at the northernmost exposure of Silurian rocks within the Hardin quadrangle. From Hamburg it thins southward and southeastward, and it is absent in sec. 13, T. 10 S., R. 3 W. (See fig. 2*A*.) In the southeastern area the Joliet limestone is reported [33] to reach a thickness of 45 feet at Grafton, 4 miles east of the Brussels quadrangle. From Grafton it thins westward and northwestward; near Twin Springs it seems to be about 15 feet thick, and it is absent in sec. 28, T. 7 N., R. 13 W.

Lithologic character.—Both in the northwestern and the southeastern areas of its outcrops, the Joliet limestone is essentially indistinguishable in lithologic character from the underlying Brassfield, and it can only be recognized with certainty by the fossils that it contains. At Hamburg it is a hard, massive to thin-bedded, finely crystalline limestone. Its color is somewhat darker and more pinkish or brownish gray than that of the underlying Brassfield limestone. It also tends to have more irregular bedding surfaces and a slightly coarser texture than the underlying formation. Along Cap au Grès flexure, the Joliet is a hard, massive to thin-bedded, brown to buffy-gray dolomite or dolomitic limestone. It seems to be somewhat more massive and less cherty than the underlying dolomite beds of the Brassfield formation.

Chemical analysis of a sample collected from the 16 feet of Joliet limestone and 6 feet of the immediately underlying Brassfield limestone in the creek bed in the southern part of Hamburg, in the NW¼SE¼ sec. 35, T. 9 S., R. 3 W., Calhoun Co. (see p. 156), indicates that about 96 percent of the rock is relatively pure calcite. The impurities are largely silica, nearly all of which must occur as scattered sand grains or as disseminated chert, for there is very little alumina or clay. (See pp. 16–17.) Physical tests (p. 156) show that the limestone is relatively dense and compact as compared with most other rocks from this region.[34]

Stratigraphic relations.—In good exposures the contact of the Joliet limestone and the underlying Brassfield limestone appears to be perfectly conformable yet the faunas of the two formations indicate that all beds of lower Niagaran or Clinton age are missing.[35] In the exposure at Hamburg, a prominent but very smooth bedding plane that comes between the beds yielding the lowest Joliet and the highest Brassfield fossils may be chosen as the contact.

At its upper limit the Joliet limestone is overlain unconformably by the Devonian Cedar Valley limestone.

Name.—The name Joliet marble, first used in 1865 by Shufeldt,[36] was revived in 1925 by Savage [37] as the Joliet limestone, and apparently restricted to the lower part of the original unit. At that time Savage also applied the name Joliet limestone to rocks cropping out at Grafton.[38] The extension of the name westward and northward from Grafton into the Hardin and Brussels quadrangles was made on the advice of Professor Savage who, several years before visiting the writer in the field, had determined the presence of Joliet limestone at Hamburg.

DEVONIAN

The Silurian rocks of the Hardin and Brussels quadrangles are overlain by a series of brown and gray fossiliferous limestones and sandstones that are treated here as one formational unit, the Cedar Valley limestone.

CEDAR VALLEY LIMESTONE

This formation crops out more or less continuously on both sides of the Calhoun County upland from Hamburg and from north of Hardin southward to near Batchtown and to the head of Greenbay Hollow south of Meppen. In the southernmost few miles of these Calhoun County outcrops the Cedar Valley is a thin discontinuous sandstone; farther south the formation is entirely absent. In Jersey County the area of outcrop extends from near Lone Star School north of Nutwood southward to Twin Springs and, except where cut out by faulting, from there eastward to and beyond Grafton.

Thickness.—The Cedar Valley limestone varies greatly but rather uniformly in thickness. In its northernmost exposures at Hamburg the formation is only

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[31] Personal communication, Feb. 1932, to the Chairman of the Committee on Geologic Names, U. S. Geological Survey.

[32] Foerste, A. F., Silurian clays: Ky. Geol. Survey Bull. 6, p. 145, 1905.

[33] Savage, T. E., Silurian rocks of Illinois: Geol. Soc. America Bull., vol. 37, p. 515, 1926.

[34] Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, p. 31, 1925.

[35] Savage, T. E., Silurian rocks of Illinois: Geol. Soc. America Bull., vol. 37, p. 533, 1926.

[36] Shufeldt, G. A., Jr., On an oil-well boring at Chicago: Amer. Jour. Sci., 2d ser., vol. 40, p. 389, 1865.

[37] Savage, T. E., Silurian rocks of Illinois: Geol. Soc. America Bull., vol. 37, p. 522, 1926.

[38] Idem, pp. 515, 530.

$3\frac{1}{2}$ feet thick, but from there southward and southeastward it thickens gradually to about 15 feet in the southern part of T. 10 S., R. 2 W. and then rather abruptly to 40 feet in the western part of a narrow zone that trends east-northeastward through the middle of T. 11 S., R. 2 W. Southward and southeastward from this narrow zone the formation thins rather abruptly to about 15 feet in the southern part of T. 11 S., R. 2 W., and the middle of T. 7 N., R. 13 W., and then thins more gradually southwestward until it is absent in the southwestern half of T. 12 S., R. 2 W. In the southernmost exposures in Jersey County the Cedar Valley is everywhere less than 10 feet thick.

It is noteworthy that the narrow zone of maximum thickness of this formation coincides almost exactly in position with the center of the broad area where the underlying Silurian, especially the Edgewood limestone, is thinnest. (See fig. 2*B*.) Although this tendency for the Devonian rocks to be thickest where the Silurian rocks are thinnest does not result in even an approximately uniform gross thickness for the two systems, yet the tendency towards compensating thicknesses suggests that the Devonian may be thicker where the Silurian is thinner because it was laid down in a valley previously cut in the underlying rocks. This interpretation that the unconformity is an erosional one may be partially correct, and it could neither be proved or disproved without a much more detailed tracing of the individual beds within the Devonian than was attempted by the writer. Nevertheless, the thinning of the Edgewood limestone below the Brassfield limestone shows that most of the Silurian thinning was due to some earlier cause. Furthermore, such field evidence as was gathered indicates that the Cedar Valley thickens very largely by interlamination and by thickening of individual beds rather than by the local presence of older strata where the formation reaches its maximum thickness. (See fig. 2*B*.) This thickening by interlamination suggests that the zone where the Cedar Valley is thickest was downwarped while the beds were being deposited. With present data it seems more probable that the thickness relations within both the Silurian and the Devonian formations were due largely to gentle crustal warping and truncation by erosion rather than to erosion alone.

Lithologic character.—In most exposures in the Hardin and Brussels quadrangles the Cedar Valley limestone is made up of a gradational series, the lower part of which is a deep-brown, thin-bedded, fine-grained limestone, which is rather soft, somewhat fossiliferous, cherty, argillaceous, and sandy. These lower beds grade almost imperceptibly upward into a grayer brown, more massive, purer, harder, highly fossiliferous and more crystalline limestone. This gradational series commonly makes up nearly all of the formation, but in the middle and northern part of the area the formation includes a few feet of buff to gray, denser limestone at its base, and in the southern and middle part the uppermost layers pass into a thin and somewhat discontinuous sandstone. The formation is 20 feet thick and is typically exposed in the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 3, T. 11 S., R. 2 W.

The soft thin-bedded sandy layers in the lower part of the formation become very sandy locally, and elsewhere they are interlaminated with thin layers of sandy calcareous clay. Some of the bedding surfaces separating these thin layers are very irregular, and it is possible that some of the more irregular ones may represent small unconformities. The chert occurs as abundant small light-brown nodules.

The hard crystalline limestone in the upper part of the formation commonly forms a prominent ledge at its outcrop. Locally these upper beds contain large nodules of chert, and in some places the limestone is cross-bedded, and the bedding surfaces are very irregular. Here and there both the upper and the lower beds contain large scattered crystals of calcite, and in the SW$\frac{1}{4}$ sec. 35, T. 7 N., R. 13 W., they contain small crystals of sphalerite. Some of the limestone layers weather to a pitted surface that resembles the weathered surface commonly developed on the Kimmswick limestone.

In most exposures south and east from sec. 9, T. 11 S., R. 2 W., the uppermost beds of the formation are either very sandy limestone or pure sparkling noncalcareous sandstone. These sandy beds, though nowhere more than $2\frac{1}{2}$ feet thick and locally absent, continue southward, overlapping the lower beds of the formation until they come to lie upon the underlying Silurian dolomite. The sandstone is pale buff to white and very friable where fresh but it case-hardens and discolors to a grayish or reddish brown quartzite on weathered surfaces. In its more northern outcrops, as in the N. center sec. 16, T. 11 S., R. 2 W., and the NW$\frac{1}{4}$SW$\frac{1}{4}$ sec. 28, T. 8 N., R. 13 W. (Colls. 28 and 137, p. 171), this sandstone is highly fossiliferous but farther south it contains few organic remains. Locally, as in the abandoned quarry north of Meppen, it contains a few angular pebbles of chert, some of which are as much as $1\frac{1}{2}$ inches in diameter. At a number of localities, as in the NW$\frac{1}{4}$NE$\frac{1}{4}$ sec. 26, T. 12 S., R. 2 W., and in the NW$\frac{1}{4}$ sec. 11, T. 6 N., R. 13 W., the sandstone fills joint cracks $1\frac{1}{2}$ feet wide to a depth of 20 feet below the top of the underlying Silurian dolomite.

The sand grains are composed of clear angular quartz crystals from one-quarter to three-quarters of a millimeter in diameter. Like the sandstone in the Brassfield limestone (see pp. 28–29) nearly every particle is bounded by fresh crystal faces, showing that since the grains were deposited they have been enlarged by the growth of silica on their surfaces.

Chemical analysis of a sample of the upper 13 feet of the Cedar Valley limestone that is exposed along the highway in the NE¼NE¼ sec. 29, T. 8 N., R. 13 W., Jersey County (see p. 157), indicates that about 89 percent of the rock is relatively pure calcite. The chief impurity is silica, nearly all of which almost certainly occurs as scattered grains of quartz in the sandy layers at the top of the formation. (See pp. 16–17.)

Partial analysis of a sample collected[39] from exposures near Hardin indicates a higher percentage of even purer calcite. However, the formation is variable in its composition and a sample collected[40] near Grafton was found to be distinctly dolomitic limestone and to contain only 75 percent of carbonates. It is possible that the Devonian limestone near Grafton has been somewhat dolomitized since deposition, as the Silurian limestones in that region seem to have been (see p. 29), but the large percentage of insoluble impurities in the Grafton sample indicates that the rock was originally more sandy or more argillaceous than the limestone farther north.

Stratigraphic relations.—The Devonian limestone rests unconformably on the Silurian rocks but at most exposures the contact is relatively smooth. In the southern part of the area the Devonian sandstone fills joint cracks deep in the underlying Silurian dolomite, thus showing that a period of exposure to weathering preceded the Devonian deposition. Yet it is only by a comparison of the beds immediately underlying the Cedar Valley at different places that the importance of the unconformity becomes evident. In the northwestern and southeastern areas the Devonian overlies the Joliet limestone, and southward and westward it overlaps successively lower horizons within the Brassfield limestone. The total stratigraphic interval thus cut out at the basal contact of the Devonian in this region is at least 40 and probably 70 feet. (See fig. 2*B*, p. 42.)

Within the beds here referred to the Cedar Valley limestone there seem to be no important stratigraphic breaks. Some of the irregular bedding surfaces in the thin-bedded lower part of the formation may represent unconformities, but the similarity in lithologic character and faunal content of the rocks above and below these possible unconformities makes it seem unlikely that they represent important breaks. As has been stated in another place (p. 31), the variations in thickness of the Devonian limestone appear to be caused largely by interlamination and by thickening of the individual beds. (See fig. 2*B*.) The thin sandstone at the top, which in the southern part of the area overlaps the lower beds of the formation, is conformable with and in many exposures clearly gradational into the typical Cedar Valley.

[39] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. Inv. no. 8, p. 14, 1926.

[40] Worthen, A. H., Geology and paleontology: Illinois Geol. Survey, vol. 3, p. 574, 1868.

The upper, like the lower, contact of the Cedar Valley limestone is distinctly unconformable but remarkably smooth. In the northeastern part of the area the Devonian is overlain by the Louisiana limestone, but to the south this is overlapped by the Hannibal shale.

Fossils.—The Cedar Valley limestone is perhaps the most highly fossiliferous formation in the Hardin and Brussels quadrangles. The upper hard crystalline layers, in particular, are thickly crowded with the shells of brachiopods, crinoids, bryozoans, and corals. Some layers may appropriately be called crinoidal limestones, and others are made up largely of corals. The collections made by the writer and Doctor Ball can be considered as barely more than indicative of the fauna of such a highly fossiliferous formation. These collections were studied by Prof. T. E. Savage whose identifications are given on page 171.

Name.—The early writers[41] applied the New York name "Hamilton" to the Devonian limestones of Calhoun and Jersey Counties and correlated them with the Devonian of Iowa.[42] Keyes[43] tentatively correlated the Devonian limestones of Lincoln and Pike Counties, Mo., with the Callaway limestone[44] of central Missouri. In 1920, Savage[45] referred the Devonian rocks of Iowa and northern Illinois to the Upper Devonian, using the Iowa names Wapsipinicon[46] and Cedar Valley[47] for both States.

In 1922, Branson[48] applied the names "Mineola" and "Callaway" to the Devonian limestones in Lincoln County, Mo.

Branson[49] and Savage[50] have correlated the Callaway limestone with at least part of the Cedar Valley limestone, but there is a difference of opinion about the age of the underlying limestone that has been called Mineola.

In this report all the Devonian rocks in the Hardin and Brussels quadrangles are referred to the Cedar

[41] Worthen, A. H., Geology of Illinois: Jersey County: Illinois Geol. Survey, vol. 3, p. 116, 1869; Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, pp. 8–9, 1870. Savage, T. E., On the Lower Paleozoic stratigraphy of southwestern Illinois: Amer. Jour. Sci., vol. 25, p. 438, 1908; Alexandrian series in Missouri and Illinois: Geol. Soc. America Bull., vol, 24, 357, 1913.

[42] Savage, T. E., On the Lower Paleozoic stratigraphy of southwestern Illinois: Am. Jour. Sci., vol. 25, p. 438, 1908; Alexandrian series in Missouri and Illinois: Geol. Soc. American Bull., vol. 24, p. 357, 1913. Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 225, 1907.

[43] Keyes, C. R., Some geological formations of the Cap-au-Grès uplift: Iowa Acad. Sci. Proc., vol. 5, pp. 62–63, 1898.

[44] Keyes, C. R., Paleontology of Missouri, Part 1: Missouri Geol. Survey, vol. 4, p. 43, 1894.

[45] Savage, T. E., The Devonian formations of Illinois: Am. Jour. Sci., vol. 49, pp. 179–180, 1920.

[46] Norton, W. H., Notes on the lower strata of the Devonian series in Iowa: Iowa Acad. Sci. Proc., vol. 1, pt. 4, pp. 22–24, 1894.

[47] Owen, D. D., Report of a geological survey of Wisconsin, Iowa, and Minnesota and incidentally of a portion of Nebraska Territory, p. 81, Philadelphia, 1852.

[48] Branson, E. B., The Devonian of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 17, pp. 17, 20, 31–33, pl. C, 1922.

[49] Branson, E. B., op. cit., pp. 2, 36.

[50] Savage, T. E., Comparison of the Devonian rocks of Illinois and Missouri: Jour. Geology, vol. 33, pp. 551, 555, 558, 1925.

Valley limestone. This name was adopted because of Professor Savage's report that all fossils collected in the area were those typical of the Cedar Valley limestone and because of the writer's inability to recognize any lithologic or stratigraphic basis for subdividing the unit.

CARBONIFEROUS (MISSISSIPPIAN SERIES)

The Mississippian rocks in the Hardin and Brussels quadrangles comprise many formations, which can conveniently be lumped together into the Kinderhook, Osage, and Meramec groups. No representatives of the Chester group, present about 35 miles southeast of the Brussels quadrangle,[51] were recognized in the area. The Mississippian rocks in the two quadrangles are dominantly limestone, but they also contain thick beds of shale and thin layers of sandy and of dolomitic limestone.

The present aggregate thickness of the Mississippian strata ranges from slightly less than 500 to somewhat more than 700 feet. It is not known that the Ste. Genevieve limestone or any of the overlying Chester formations were ever deposited in this area; [52] if so, they may possibly have had a combined thickness of an additional 500 or 600 feet. The distribution of the formations is such that in general the lower units can be seen to thicken northeastward down the flanks of the Lincoln anticline and the upper units to thicken eastward down the trough of the Troy-Brussels syncline. These Mississippian rocks appear to record successive stages in the preliminary warping which culminated in sharp folding of the Lincoln anticline near the end of the epoch.

The fossils collected from Mississippian strata were studied by Dr. J. M. Weller whose identifications are given on pp. 172–173.

KINDERHOOK GROUP

The lower Mississippian rocks, those which make up the Kinderhook group,[53] in the Hardin and Brussels quadrangles consist of nearly equal parts of limestone and shale. The lower formations of the group—the Louisiana limestone and the Glen Park formation—are thin units that are restricted by overlap of the higher beds to the northeastern half of the area. The higher formations—Hannibal shale and Chouteau limestone—are thicker and much more widespread.

Except for the Chouteau limestone, which thins northeastward, each of the Kinderhook formations thickens northeastward down the flanks of the Lincoln anticline. The gross thickness of the group ranges from less than 90 feet at the southwesternmost exposures to more than 150 feet near Hardin, where the beds begin to disappear below higher formations.

The Kinderhook rocks record a history of gentle but repeated movements, which were either a northeastward tilting of the entire area or an uplift of the Lincoln anticline. Inasmuch as the Kinderhook formations are not exposed for many miles south of the anticline, it is not certain that the local fold was in existence during Kinderhook time. In fact, the absence of the Louisiana limestone and the continued thinning of the Hannibal shale southward from the Cap au Grès flexure suggest that at least part of the Kinderhook movement may have been a regional tilting unrelated to any local anticline. On the other hand, the presence of Glen Park beds north and south of the Lincoln anticline, the thickness relations of the Chouteau limestone, and the distribution of the early Kinderhook faunal provinces indicate that this anticline or a closely related fold was in existence at that time. (See fig. 2*C*.)

LOUISIANA LIMESTONE

In the northeastern half of the Hardin and Brussels quadrangles, the Devonian rocks are overlain by a few feet of Louisiana limestone. These limestone beds, and some included shale beds, reach their maximum thickness of 5½ or 6 feet in this area at the northeasternmost exposures of the underlying rocks in sec. 35, T. 9 S., R. 3 W., sec. 23, T. 10 S., R. 2 W., and sec 28, T. 8 N., R. 13 W., and from these exposures they thin gradually and uniformly until they are absent southwest of sec. 32, T. 10 S., R. 2 W., sec. 23, T. 11 S., R 2 W., and sec. 21, T. 7 N., R. 13. W.

Lithologic character.—The lower part of the unit here treated as the Louisiana limestone is a soft platy shale or a thin but massive mudstone. The lower bed is nowhere more than 12 inches thick and, like the entire unit, it thins very gradually and uniformly southwestward. In its basal part the bed is clayey and dark bluish gray to black; in its upper few inches it is sandy and is somewhat calcareous and greenish gray on fresh surfaces but brownish gray where weathered. The sandy layers contain a few well-rounded coarse grains of quartz.

The upper part of the Louisiana limestone unit is perhaps the most easily recognized formation in the region. It is a hard, exceedingly dense, thin-bedded limestone, the layers of which are commonly 2 to 6 inches thick. On fresh surfaces the rock is a light somewhat buffy gray; where weathered it ranges from brownish gray to nearly white. It is very brittle and breaks with a conchoidal fracture. The bedding surfaces are very irregular and they are crossed by vertical fractures or joints. As a result, the natural exposures of the rock have a characteristic hackly surface and a

[51] Weller, Stuart, The Chester series in Illinois: Jour. Geology, vol. 28, pp. 407, 413–414, 1920.

[52] Weller, Stuart, The Mississippian brachiopoda of the Mississippi Valley Basin: Illinois Geol. Survey Mon. 1, pp. 22–23, 1914; The Chester series in Illinois: Jour. Geology, vol. 28, pp. 283, 407, 408, 412–413, 1920.

[53] Meek, F. B., and Worthen, A. H., Remarks on the age of the Goniatite limestone at Rockford, Ind.: Amer. Jour. Sci., 2d ser., vol. 12, p. 288, 1861. Worthen, A. H., Geology of Illinois: Illinois Geol. Survey, vol. 1, pp. 108–109, 1866.

blocky appearance that has been likened very appropriately to that presented by a wall of masonry. Scattered vugs in the limestone and a few of the irregular fractures are filled with crystalline calcite.

The Louisiana limestone unit is 5½ feet thick (lower part, shale, 1 foot, upper part, limestone, 4½ feet), and its relations to underlying and overlying formations are well shown in the creek bank, in the NW¼SE¼ sec. 35, T. 9 S., R. 3 W., upstream from the main road which enters Hamburg from the south.

Stratigraphic relations.—The lower part of the unit, the shale bed, appears to rest unconformably upon the Devonian Cedar Valley limestone. Viewed regionally, the contact is very smooth, and it does not seem to cut across any Devonian beds (fig. 2*C*); but in any one exposure it is an irregular surface, and there was at least a sharp break in sedimentation after the deposition of the Devonian limestone. In the SE¼NW¼ sec. 12, T. 10 S., R. 3 W., the shale contains reworked Devonian fossils showing that the underlying rocks were eroded slightly before the deposition of the shale.

The uniform thinness of the lower shale and the upper limestone suggests that the two parts of the unit are conformable. However, the contact between them is everywhere sharp and in the SW¼NW¼ sec. 20, T. 10 S., R. 2 W., it is wavy and suggests large ripple marks.

The Louisiana limestone is overlain unconformably by the Glen Park formation. (See p. 36.)

Fossils.—Both the limestone and the shale at its base contain fossils. Those in the shale are well preserved and easily collected but those in the limestone, although more numerous, are much more difficult to extract from the rock. The collections made by the writer and Doctor Ball were studied by Dr. J. Marvin Weller, whose identifications are given on page 172. Collections have been made from the Louisiana limestone at Hamburg and 3 miles south of Hardin by R. C. Moore.[54]

Name.—The limestone of this unit was called the "Lithographic" limestone in early reports.[55] Keyes [56] in 1892 defined the Louisiana limestone from exposures of the formation at Louisiana, Mo., and Weller [57] adopted this name for the rocks in Calhoun County.

It is difficult to decide what name should be applied to the thin bed of shale beneath or in the lower part of the Louisiana limestone. In northern Illinois, beds that unconformably overlie the Cedar Valley limestone have been referred [58] to the Sweetland Creek shale.[59] Krey [60] adopted this name for beds in northern Calhoun and south central Jersey counties, but he stated that the formation does not extend into the area covered by this report. D. M. Collingwood, in an unpublished report of the State Geological Survey of Illinois, identified the Sweetland Creek in Mason Hollow, in the SE¼ SE¼ sec. 4, T. 6 N., R. 12 W., about 3 miles east of the Brussels quadrangle, by the presence of *Sporangites*. However, stratigraphic relations near Mason Hollow indicate that the beds from which he collected these fossils may be the much younger Hannibal shale, a possibility that seems to be strengthened by the presence of *Sporangites* in shale above the Glen Park limestone in southeastern Missouri.[61]

In and near Pike County, Mo., beds between the Louisiana limestone and the Devonian limestone, and presumably equivalent [62] to the Sweetland Creek of Iowa, have been called Grassy Creek shale [63] and Saverton shale.[64] Branson [65] recognized the Grassy Creek shale of Keyes in northern Lincoln Co., Mo. Moore,[66] however, reports that in Illinois this shale does not extend south of northern Calhoun County, but he recognizes the Saverton shale farther south.

The terminology is complicated still further by the fact that the Louisiana limestone itself has been interpreted [67] to include some shaly beds in its lower part. The fossils in the shale give little assistance in the solution of this problem of nomenclature, because the fauna of the Saverton shale is very similar to that of the Louisiana limestone.[68] They merely show that the thin shale in the Hardin and Brussels quadrangles is of Kinderhook and not Devonian age. In this report the beds are questionably referred to as Louisiana limestone, but it seems probable that they may represent part of the Saverton shale. On the geologic map (pl. 1), the Louisiana limestone (with this included shale) and the overlying Glen Park formation are mapped as one unit.

GLEN PARK FORMATION

The series of thin beds of argillaceous and sandy limestone, oolite, and shale here referred to the Glen Park

[54] Moore, R. C., Early Mississippian formations in Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 21, pp. 46–47, 1928.

[55] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, p. 10, 1870.

[56] Keyes, C. R., The principal Mississippian section: Geol. Soc. America Bull., vol. 3, p. 289, 1892.

[57] Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, pp. 466, 468, 1906; Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 226, 1907.

[58] Savage, T. E., The Devonian formations of Illinois: Amer. Jour. Sci., vol. 49, p. 182, 1920.

[59] Udden, J. A., The Sweetland Creek beds: Jour. Geology, vol. 7, pp. 65–78, 1899.

[60] Krey, Frank, op. cit., pp. 33–34.

[61] Weller, Stuart, and St. Clair, Stuart, op. cit., pp. 158, 160. Moore, R. C., op. cit., pp. 50, 138–140.

[62] Moore, Idem, p. 36.

[63] Keyes, C. R., Some geological formations of the Cap-au-Grès uplift, Iowa Acad. Sci., Proc., vol. 5, pp. 59, 63, 1898.

[64] Keyes, C. R., Marked unconformity between the Carboniferous and Devonian strata in the upper Mississippi Valley: Am. Jour. Sci., 4th ser., vol. 36, p. 160, 1913.

[65] Branson, E. B., The Devonian of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 17, pp. 5, 7, 31–33, 1922.

[66] Moore, R. C., op. cit., pp. 34, 37, 38, and fig. 2.

[67] Rowley, R. R., Geology of Pike County: Missouri Bur. Geology and Mines, 2d ser., vol. 8, pp. 25, 29–30, 1908. Krey, Frank, op. cit., p. 35. Moore, R. C., op. cit., pp. 38, 40.

[68] Moore, R. C., op. cit., pp. 39–40, 48.

formation coincides very closely in its distribution with the underlying Louisiana limestone. Like this underlying formation, it is thickest at its northeasternmost exposures and thins uniformly southwestward. The maximum thickness found exposed in the area is about 25 feet in Poor Farm Hollow, in the NW¼ sec. 10, T. 10 S., R. 2 W. From there the formation thins southwestward and disappears along a line almost identical with that which marks the southwestern margin of the Louisiana limestone. It may extend a short distance farther south on the western side of Calhoun County, and it seems not to extend quite so far south in western Jersey County as the Louisiana limestone. However, exposures are such that the exact limits of the two formations could not be determined with sufficient accuracy to detect any differences in their distribution.

Lithologic character.—The rocks that make up the Glen Park formation may conveniently be divided into three units or lithologic types: (1) a basal unit of slabby argillaceous limestone which, where the formation is thickest, grades into (2) an upper unit of calcareous shale, and (3) discontinuous lenses of sandy fossiliferous oolitic limestone at the top of the formation.

The basal unit is composed of hard, silty, more or less sandy limestone in layers from 1 to 4 inches thick, interlaminated with thinner beds of soft argillaceous fine-grained sandstone. The thin beds of impure limestone are light to dark bluish gray on fresh surfaces, but where weathered they become brownish gray. The limestone is dense to fine-grained and contains a few scattered vugs filled with crystalline calcite and occasional sphalerite. It also contains some small pyritic and phosphatic nodules. The layers of fine-grained sandstone are commonly yellowish brown and consist of very poorly sorted quartz grains and clay particles. The quartz grains are mostly subangular, although some are well-rounded; they range from about ½ millimeter in diameter down to the limit of visibility with the unaided eye.

The bedding surfaces between and within the thin layers of limestone and sandstone are strikingly irregular and wavy in large ripples that are commonly from 6 to 12 inches from crest to crest and from ½ to 1½ inches deep. These rippled surfaces trend in nearly every direction, but most of them seem to be elongated in a west-northwesterly direction. Some of the bedding planes are minutely cross-bedded and dip northeastward.

This basal unit is between 5 and 10 feet thick and it grades almost imperceptibly upward and laterally into the upper shale unit. (See fig. 2*C*.)

The upper unit consists of soft calcareous platy shale or massive mudstone and thin discontinuous layers of ripple-bedded silty or sandy limestone. The shale is somewhat sandy but plastic when wet. On fresh surfaces it is light blue gray, but where weathered it becomes a pale tan or yellowish gray. A few very thin layers of soft bright-yellow calcareous clay are interbedded with the shale. A thin section of a sample of this clay from the SE¼SE¼ sec. 12, T. 10 S., R. 3 W., shows a yellow clay mineral of low birefringence, calcite, and a few small quartz grains. As the shale is soft and underlies other soft shale beds, it is rarely well exposed, and its relations to overlying and underlying beds can be seen in only a few places. The greatest thickness found well exposed was 15 feet in the NW¼NW¼ sec. 14, T. 10 S., R. 2 W., but at this locality the base is not exposed.

At three places in the Hardin quadrangle the uppermost part of the Glen Park formation is marked by a hard, sandy fossiliferous oolitic limestone. This bed, which is obviously discontinuous in each of the three localities, varies widely in lithologic character and thickness.

Along the river front just north of Hamburg the bed consists partly of calcareous oolite and partly of highly fossiliferous, slightly oolitic limestone. Both the oolite and the fossiliferous limestone contain many rounded pebbles and small particles of a fine-grained limestone. The oolite grains or spherules are set in a matrix of clear calcite, and they are uniformly about ½ or ⅔ millimeter in diameter. Each spherule seems to be built up of concentric layers of calcite about a small center that seems to be a fragment of fine-grained limestone. (See pl. 7*A*.) This bed, called the "Hamburg" oolite by Weller,[69] is interlaminated with thin layers of hard silty limestone and soft argillaceous sandstone. At the time of the writer's field work in the area, the exposures did not permit exact measurements of thickness or detailed tracing of the bed, but Bassler[70] reports that it thins from 15 feet at the river front to only a few inches along the creek, several thousand feet to the southeast, where most of it is replaced by soft shale.

The other two occurrences of the bed are in Poor Farm Hollow in the NE¼ sec. 21 and the NW¼ sec. 22 and at the mouth of French Hollow in the NW¼ sec. 14, T. 10 S., R. 2 W. At these places the limestone is less oolitic, less fossiliferous, and more sandy than the rock at Hamburg, but it can be recognized as a representative of the same bed by its general lithologic character, its fossils, and its stratigraphic position. Here the bed is a hard, sandy, crystalline limestone, massive and dark brownish gray to black where fresh, and thin-bedded and brownish gray where weathered. It is commonly from 2 to 3½ feet thick and rests with sharp contact on the underlying calcareous shale and thin-bedded silty limestone. The lower part of the bed

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[69] Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, pp. 465, 470, 1906; The Mississippian Brachiopoda of the Mississippi Valley Basin: Illinois Geol. Survey Mono. 1, p. 14, 1914.

[70] Bassler, R. S., quoted in Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, pp. 464–465, 1906.

is fine-grained, thin-bedded, very dark gray, and in places highly fossiliferous; the upper part is more granular, massive, brownish gray, and oolitic. The bedding within the limestone is wavy and in places minutely cross-bedded like that in the lower part of the Glen Park formation. The oolite grains or spherules are about ⅓ to ½ millimeter in diameter and the sand grains are well-rounded to subangular and commonly ¼ millimeter or less in diameter. The limestone contains many small pellets or pebbles that seem to be phosphatic, some pyrite nodules, a few large calcite crystals, and some sphalerite in a small veinlet of calcite.

Stratigraphic relations.—The contact between the Glen Park formation and the underlying Louisiana limestone is everywhere sharp and somewhat irregular and in at least one exposure, along the northwest bank of the creek in the NW¼SE¼ sec. 35, T. 9 S., R. 3 W., it is a slight but definite erosional unconformity that cuts down somewhat more than one foot into the Louisiana.

It is difficult to tell whether or not there were breaks in sedimentation within the Glen Park formation, for the irregular bedding of the lower slabby limestones might conceal many minor unconformities. However, the gradual change of these hard limestone beds both upward and laterally into calcareous shale indicates that the formation may properly be considered as a depositional unit. At Hamburg the lenticular oolitic bed at the top is clearly interlaminated with the lower part of the formation, but in French and Poor Farm Hollow it is sharply separated from the underlying beds. In fact, in the SE¼NE¼ sec. 21, T. 10 S., R. 2 W., it seems to rest unconformably on these lower beds.

The precise stratigraphic relations of the upper limit of the Glen Park formation are not known. The contact with the soft overlying Hannibal shale is rarely exposed, and it was observed only in French and Poor Farm Hollows. There the hard oolitic limestone which marks the top of the formation is discontinuous (fig. 2*C*), but it is not certain that this discontinuity is caused by an unconformity at the top of the formation. It is possible that, where the oolitic limestone is absent, the calcareous shale of the Glen Park formation grades upward into the noncalcareous Hannibal shale.

Fossils.—The oolitic limestone at the top of the Glen Park is fossiliferous (see table on p. 172), but no organic remains were observed by the writer in the lower beds of the formation. The fauna of the oolite at Hamburg has been described by the Weller.[71]

Name.—The beds here referred to the Glen Park formation have been included with the overlying shale by most writers. Worthen [72] noted the occurrence of the oolitic limestone in the Kinderhook group at Hamburg and in northeastern Calhoun County and in Pike County. Potter [73] recorded oolitic limestone in the "Vermicular shales and sandstones" in Lincoln County, Mo. Weller [74] included the oolitic limestone in his Kinderhook shale, but in other reports [75] separated it from the overlying Hannibal shale as the "Hamburg" oolite. Krey [76] recognized the oolitic beds in Illinois at Hamburg, in northeastern Calhoun County, in Pike County, and at Grafton, and in Missouri in St. Charles County and included them in the Hannibal shale. However, his descriptions and one of his illustrations [77] seem to show that he included the lower slabby argillaceous limestone beds with the Louisiana limestone. His plate 9*A* clearly shows the lower part of the slabby argillaceous limestone beds of the Glen Park formation, the Louisiana limestone, including the shale beds at its base, and the upper part of the Cedar Valley limestone.

The Glen Park limestone was defined by Ulrich [78] as the middle or Glen Park (oolitic) limestone member of the Sulphur Springs formation of east-central Missouri. Weller [79] concluded that the fauna of the "Hamburg oolite" and the Glen Park limestone at its type locality were "synchronous within comparatively narrow limits." After later studies he correlated the beds in the two areas, stating that they must be considered as "essentially contemporaneous in origin." [80] Moore [81] believes that the "fauna at Hamburg * * * must be regarded as contemporaneous with that of the Glen Park limestone" and he applied the name Glen Park limestone to the beds overlying the Louisiana limestone and underlying the Hannibal shale in Calhoun County.[82]

It is possible that only the uppermost of the three units here treated together as parts of one formation is equivalent to the original Glen Park limestone. However, it is significant that at Hamburg the lenticular fossiliferous oolite is interlaminated not only with the upper but also with the middle and lower parts of the formation.

In this report Moore's usage of the name Glen Park for the entire unit is followed, partly because of the

[71] Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, pp. 465–466, 1906.

[72] Worthen, A. H., Geology of Illinois, Calhoun County: Illinois Geol. Survey, vol. 3, pp. 10–11, 1870.

[73] Potter, W. B., Geology of Lincoln County in Preliminary report on the iron ores and coal fields: Missouri Geol. Survey, pp. 245–246, 1873.

[74] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey, Bull. 4, p. 226, 1907.

[75] Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, pp. 465, 466, 470, 1906. The Mississippian Brachiopoda of the Mississippi Valley Basin: Illinois Geol. Survey, Mon. 1, p. 14, 1914.

[76] Krey, Frank, op. cit., p. 36.

[77] Idem, p. 35 and pl. 9A.

[78] Ulrich, E. O., in Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 2, p. 110, 1904.

[79] Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, p. 466, 1906.

[80] Weller, Stuart, and St. Clair, Stuart, op. cit., p. 160.

[81] Moore, R. C., op. cit., p. 138.

[82] Moore, R. C., op. cit., pp. 45, 50, 52, 60, 76, 140; fig. 2.

correlation on faunal grounds and partly because of the apparent similarity in lithologic character of the rocks in the Hardin quadrangle to the Glen Park limestone in Ste. Genevieve Co., Mo.[83] However, the term "Glen Park formation" instead of "Glen Park limestone" is used here because of the impurity of the limestone beds and the thickness of the included shale. On account of their thinness and nearly identical distribution, the Glen Park formation and the Louisiana limestone are mapped together on the geologic map (pl. 1).

HANNIBAL SHALE

In the Hardin and Brussels quadrangles the Hannibal shale overlaps successively older beds southwestward. In the northeastern part of the area it overlies the Glen Park formation; farther southwest, where this formation and the underlying Louisiana limestone are absent, it overlies the Devonian Cedar Valley limestone; and in the southwestern part of the area, where the Cedar Valley and the Silurian Joliet limestone are absent, it lies upon the lower part of the Brassfield limestone. In Calhoun County the area of outcrop of the Hannibal shale extends northward from the Cap au Grès flexure to and beyond the northern limits of the Hardin quadrangle. In Jersey County the formation crops out along the flexure and for about 12 miles northward before the dip of the rocks carries it below the base of the bluffs.

Thickness.—The Hannibal shale thins southwestward from 90 or 100 feet to 30 or 40 feet. (See fig. 2*C*.) The maximum thickness exposed within the area is in French Hollow at the northeasternmost exposure of the underlying Glen Park formation, and presumably the formation continues to thicken to the northeast. The minimum undisturbed thicknesses of the Hannibal are at its southwesternmost exposures in Calhoun County, but for a short distance in Jersey County the formation is cut out by faulting or is squeezed abnormally thin by overturning.

As stated more fully elsewhere (p. 39), the thickness of the Hannibal shale and that of the overlying Chouteau limestone are approximately complementary, the Chouteau thickening as the Hannibal thins so that their gross thickness remains about constant.

Topographic expression.—The Hannibal shale, like the Maquoketa, is a unit of relatively soft unresistant rock that lies between two units of much harder and more resistant limestone or limestone and dolomite. Consequently, its topographic expression is similar to that of the Maquoketa. But the Hannibal shale is much thinner than the Maquoketa, and it lies below a thick series of limestones instead of a relatively thin series. Hence it is commonly expressed as a gentle slope or bench on hillsides and bluffs between the steeper slopes made by the adjacent formations.

Like the Maquoketa, the Hannibal shale is relatively impervious to ground water, and in many places the upper contact of the formation is marked by springs and seeps. However, the Hannibal does not soften to clay quite so readily when wet, the overlying limestone creeps and slides less, and the exposures are somewhat better than in the Maquoketa shale.

Lithologic character.—The formation is made up of very slightly sandy, essentially noncalcareous, gray massive siltstone and fissile shale. (See p. 22.) Although exposures are poor, the rocks in the northern part of the area, where the formation is thickest, are soft and lighter colored below and hard and darker gray above. Approximately the lower and upper thirds of the formation consist of slightly sandy, massive to platy, jointed siltstone and the middle third of fissile clay shale. In the lower part the rock is pale greenish gray on fresh surfaces but dirty buffy gray to pale tan where weathered; in the middle and upper parts the color is dark bluish gray to black where fresh and bluish gray where weathered. Because of the overlap at the base of the formation and the thickening of the Chouteau at the top, the lower and upper beds of the formation are absent in the southern part of the area. (See fig. 2*C*.) No slabs of sandstone such as reported by Bassler[84] near Hamburg were found by the writer. One of the best exposures of the Hannibal shale in the area is in the bluff in the NW¼SW¼ sec. 23, T. 11 S., R. 2 W.

In many places the dark-gray to black platy shale in the middle and upper parts of the Hannibal shale has been mistaken by the local residents for the "black slate" frequently found associated with coal beds, and much fruitless work has been done in efforts to locate coal in this formation.

Locally, the very base of the Hannibal shale is marked by yellow-brown ferruginous concretions. The upper and especially the middle parts of the formation in many places contain abundant small elongate nodules of pyrite, shaped like coprolites, in which there are a few small veinlets of sphalerite. The upper few inches of the formation is commonly somewhat calcareous and lighter in color than the dark shale below it.

At least some of the massive, very dark gray siltstone in the Hannibal is minutely laminated. Microscopic examination by the writer of thin sections of samples from the middle of the formation in the NE¼NE¼ sec. 1, T. 10 S., R. 3 W., (pl. 7*B*) show that these laminations are marked by alternations of much and little organic matter and by alternations of clay and quartz. These samples and thin sections were studied also by W. H. Bradley, of the Federal Geological Survey, in a comparison[85] of minutely laminated rocks of different

[83] Weller, Stuart, and St. Clair, Stuart, op. cit., p. 157.

[84] In Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, p. 465, 1906.

[85] Bradley, W. H., Nonglacial marine varves: Amer. Jour. Sci., 5th ser., vol. 22, pp. 318–330, 1931.

ages from many areas. Bradley found that the laminations in the Hannibal siltstones range from 0.049 to 0.74 and average about 0.14 millimeter in thickness, and his comparison of different samples led him to suggest that these laminations perhaps may be, like those of other rocks [86] studied by him and by the writer, the record of successive annual deposits.

A definitely crystalline micaceous clay mineral, probably beidellite, is the dominant constituent of the rock. Most of the crystals of clay lie approximately parallel to one another and to the bedding and, as the individual crystals show parallel extinction under crossed nicols and as the slow ray vibrates in the plane of elongation, thin sections of the shale cut perpendicular to the bedding exhibit an aggregate positive elongation very much as they would if they were cut from single crystals. This rather striking optical property of the rock has been noted in shales from other regions.[87] The clay crystals are pale brownish gray and predominantly platy or micaceous in habit. They occur chiefly in uniformly oriented aggregates that are commonly about 0.08 millimeter or 80 microns long and about half that thick. The individual crystals that are recognizable as such are flat or slightly curved plates or discs, commonly 1½ to 2 microns thick and 10 to 13 microns wide. Many of the layers of clay contain much organic matter, which is present as dark brown to black opaque structureless fragments and flat lenses that lie parallel to the bedding and are from less than 1 micron to more than 100 microns long.

Quartz grains are the second most abundant constituent of the rock. They occur as thin continuous layers about 0.1 millimeter or 100 microns thick that are made up of well-sorted subangular silt grains from 12 to 25 microns in diameter. A few grains of zircon, apatite, and hornblende were noted. These thin layers of quartz silt contain no organic matter, but a few scattered masses of carbonate fill the minute pores in some of the layers.

Chemical analysis (p. 158) of a sample collected from the upper 40 feet of the Hannibal shale in the SW¼NW¼ sec. 31, T. 9 S., R. 2 W., and the SW¼NE¼ sec. 36, T. 9 S., R. 3 W., indicates that from one-half to three-quarters (probably about 55 percent) of the rock is clay and from one-fourth to one-half (probably about 38 percent) is quartz. The analysis also indicates, rather surprisingly, that the rock may contain about 7.6 percent dolomite or dolomite and magnesite (see pp. 16–17), an amount much greater than might be estimated from crude tests with concentrated hydrochloric acid and nearly as great as that in the sample of calcareous Maquoketa shale (pp. 22, 158).

Samples of the Hannibal shale collected by Lamar [88] contain more magnesia than this sample.

Because of the large proportion of very finely divided quartz grains in the Hannibal shale, this sample contains a much larger percentage of silica than the samples of Maquoketa (p. 22) and Carbondale (p. 58) shale from this area or than average shales from other regions.[89]

Ceramic tests by the Department of Ceramic Engineering of the University of Illinois indicate that the Hannibal shale represented by this sample might be used for the manufacture of brick and tile (p. 160).

Stratigraphic relations.—The contact of the Hannibal shale with the underlying Glen Park formation was found exposed in so few places that the precise stratigraphic relations are unknown. Where the bed of hard oolitic limestone forms the top of the Glen Park, the contact is sharp. The lateral discontinuity of this oolitic bed perhaps suggests the presence of an unconformity above it, but where it is absent the exposures, though incomplete, suggest that the calcareous shale unit of the Glen Park may grade upward into the noncalcareous shale of the Hannibal.

The contact between the Hannibal shale and the overlying Chouteau limestone seems to be truly gradational, both vertically and laterally, in all except the southernmost exposures. (See p. 40 and fig. 2 *C*.)

Fossils.—Very few recognizable fossils were found in the Hannibal shale. In a few places the black shale and the pyritic concretions in the upper part of the formation contain small carbonaceous bladelike fragments that may be plant remains, and some of the pyritic concretions may be coprolites. Weller [90] reported specimens of a small *Lingula* from near the base of the Kinderhook shale and Worthen [91] some fucoidal markings from this unit of the Kinderhook group. The only identifiable fossils found by the writer were in the uppermost beds of the formation (Coll. 181).

Name.—In his Jersey County reports [92] Worthen excluded the outcrops of this formation in the southwestern part of the county from the Kinderhook group and referred to them as the "Black Slate," but in his Calhoun

[86] Rubey, W. W., Possible varves in marine Cretaceous shale in Wyoming (abstract): Washington Acad. Sci. Jour., vol. 18, pp. 260–262, 1928. Bradley, W. H., Varves and duration of the Eocene epoch (abstract): Geol. Soc. America Bull., vol. 40, p. 133, 1929; The varves and climate of the Green River epoch: U. S. Geol. Survey Prof. Paper 158, pp. 95–107, 1929. Rubey, W. W., Lithologic studies of fire-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U. S. Geol. Survey Prof. Paper 165, pp. 40–53, 1930.

[87] Rubey, W. W., Origin of the siliceous Mowry shale of the Black Hills region: U. S. Geol. Survey Prof. Paper 154, p. 161, 1929; Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U. S. Geol. Survey Prof. Paper 165, pp. 5–6, 1930.

[88] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. Inv. no. 8, p. 14, 1926.

[89] Clarke, F. W., The data of geochemistry, 5th ed.: U. S. Geol. Survey Bull. 770, p. 631, 1924.

[90] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 226, 1907.

[91] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, p. 11, 1870.

[92] Worthen, A. H., Geology of Illinois; Jersey County: Illinois Geol. Survey, vol. 3, pp. 115–116, 1868.

County report[93] the beds here called the Hannibal shale were treated as part of the Kinderhook group. Weller in 1906[94] and 1914[95] applied the name Hannibal[96] shale to the beds overlying the "Hamburg" oolite, but in his 1907 report[97] he included the oolite and the overlying beds in what he called the Kinderhook shale. Krey[98] used the name Hannibal shale not only for these overlying beds but also for most of the beds here referred to the Glen Park formation. He noted that, to the north and west, where the name "Vermicular Sandstone" was at one time applied to it, the upper part of the Hannibal shale is predominantly sandy. He also traced the Hannibal southward and found that in southern St. Charles Co., Mo., about 15 miles south of the Brussels quadrangle, "6 feet of pure, medium-grained, massive sandstone" lies between an oolite and the Chouteau limestone. This oolite and the overlying sandstone probably correspond to the Glen Park limestone and Bushberg sandstone, for R. B. Cozzens of Washington University has identified both of these formations below the Chouteau limestone in adjacent portions of western St. Louis County, Mo. Moore[1] also used the name Hannibal for the rocks in Calhoun and Jersey counties, but he restricted it to the beds above the Glen Park.

CHOUTEAU LIMESTONE

Throughout the Hardin and Brussels quadrangles, the Hannibal shale is overlain by beds of gray limestone known as the Chouteau limestone. This formation crops out along the bluffs, hillsides, and small valleys from the Cap au Grès flexure northward to and beyond the limits of the Hardin quadrangle in Calhoun County and along the west side of Jersey County north into the southwest corner of Greene County.

Thickness.—Over a fairly wide area—north to the southern part of T. 11 S., R. 2 W., and to the center of T. 7 N., R. 13 W., and east to the eastern edge of T. 6 N., R. 13 W.—the Chouteau limestone is between 55 and 60 feet thick. Northward and eastward from this area the formation thins gradually to 40 feet in the northern part of T. 10 S., R. 2 W., and the center of T. 8 N., R. 13 W., and then more abruptly to 22 feet at the northern limit of the quadrangle in SW¼NE¼ sec. 29, T. 9 S., R. 2 W. and to 3¼ feet in the NW¼SW¼SW¼ sec. 3, T. 9 N., R. 2 W., 3 miles north of the Hardin quadrangle.

[93] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, pp. 9–11, 1870.

[94] Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, p. 466, 1906.

[95] Weller, Stuart, The Mississippian Brachiopoda of the Mississippi Valley Basin: Illinois Geol. Survey Mono. 1, p. 14, 1914.

[96] Keyes, C. R., The principal Mississippian section: Geol. Soc. America Bull., vol. 3, p. 289, 1892.

[97] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 226, 1907.

[98] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Missouri, to Nauvoo, Illinois: Illinois Geol. Survey Bull. 45, 35–36, 1924.

[1] Moore, R. C., op. cit., p. 52, fig. 2.

Well records south of the southernmost exposures in this area and outcrops[2] in western St. Louis County, Mo., indicate that from the area of maximum thickness along the Lincoln fold the Chouteau limestone thins also rather abruptly southward.

The northeastward thinning of the formation is almost exactly complementary to the thickening of the underlying Hannibal shale and, northeast of the southern limit of the Glen Park formation, the combined thickness of the Chouteau limestone and the Hannibal shale seems to be approximately 115 feet at all exposures, although it may actually thicken slightly northeastward. Southwest of the area in which the Glen Park formation is present, the Hannibal thins more rapidly than the Chouteau thickens, and the combined thickness of the two formations decreases to less than 90 feet at the southwesternmost exposures. (See fig. 2 *C.*)

This approximately constant interval from the base of the Hannibal shale to the top of the Chouteau limestone was noted by Krey.[3] The relative constancy of this interval, together with the gradational character of the contact between the two formations (see p. 40), probably indicates that the upper beds of the Hannibal shale in the northern part of the area were deposited at the same time as the lower beds of the Chouteau limestone in the southern part of the area.

Topographic expression.—The Chouteau limestone is much more resistant to weathering and erosion than the underlying Hannibal shale but somewhat less resistant than the Burlington limestone, which lies above it. Consequently, except where the Chouteau is exposed in a vertical cliff below the higher limestones, it tends to form a steep slope covered with talus and float below outcrops of the overlying limestone and above a gentle grassy slope made by the Hannibal.

Lithologic character.—The formation is made up of rather hard, dense to fine-grained, cherty, somewhat argillaceous and sandy limestone in beds from a few inches to a few feet thick. On fresh surfaces the limestone is buffy gray but where weathered it is light gray. The bedding surfaces are somewhat irregular, and on weathered outcrops the rock develops a characteristic nodular surface. (See pl. 7 *C.*)

Typical exposures of the Chouteau limestone may be seen along the creek in the SW¼NE¼ sec. 29, T. 9 S., R. 2 W., near the north edge of the Hardin quadrangle, where the formation is 22 feet thick; in the bluff in the NE¼SW¼ sec. 35, T. 11 S., R. 2 W., where 58 feet of Chouteau is exposed; and along the road up Graham Hollow in the north center NW¼ sec. 1, T. 6 N., R. 13 W., a quarter of a mile east of the northeast corner of the Brussels quadrangle, where 57 feet of the formation is exposed.

[2] Cozzens, R. B., Personal communication.

[3] Krey, Frank, op. cit., p. 37.

The most distinctive feature of the Chouteau limestone is an abundance of calcite crystals, which on freshly fractured surfaces may be seen scattered through the dense limestone. These calcite crystals are usually from ½ to 2 millimeters in diameter, and many of them are obviously fragments of crinoid stems.

Calcite geodes about 1 inch in diameter are common in many beds of the formation. The outer margins of a few of these geodes are somewhat silicified so that they resemble the much larger, partially silicified calcite geodes of the Keokuk and Warsaw formations (pp. 46, 47). Flat lenses and continuous concretionary beds of chert a few inches thick are relatively abundant in the formation. The centers of these chert nodules are dark gray, but where partially weathered the rim of surrounding chert is light gray. Locally the lower beds contain a few concretionary masses of iron sulfide.

Thin brown argillaceous layers occur here and there in the lower and upper parts of the Chouteau. In the northern part of the area where the formation is thin, the limestone seems to be more argillaceous; there it weathers readily to a soft tan chalky limestone.

In the NW¼ sec 1, T. 6 N., R. 13 W., a bed of yellowish-brown clay 1 inch thick lies between beds of limestone about 10 feet above the base of the formation. A sample of this clay, collected in the belief that it might be bentonite or altered volcanic ash,[4] was examined under the microscope and found to consist dominantly of well-crystallized yellow clay and calcite and subordinately of small fragments of chert and plant remains, a few rounded quartz grains, some dendrites of manganese oxide, and the mineral titanite. Although no evidence of volcanic origin was recognized, the occurrence of titanite is interesting, because the mineral is present as flat unabraded crystals several millimeters in diameter.

Chemical analysis of a sample (p. 157) collected from the upper 15 feet of the Chouteau limestone in an abandoned quarry in the town of Hardin, center E½ sec. 27, T. 10 S., R. 2 W., Calhoun County, indicates that about 82 percent of the rock consists of slightly magnesian calcite, 10 or 11 percent of silica—probably present both as chert and as quartz sand—and 6 to 9 percent of clay. (See pp. 16–17.) Partial analysis of a sample collected nearby by Lamar[5] shows a much larger percentage of magnesia.

Physical tests (p. 157) indicate that this impure limestone is somewhat more porous but about as resistant to abrasion as most of the other limestones from this area.[6]

[4] Hewett, D. F., The origin of bentonite: Washington Acad. Sci. Jour., vol. 7, pp. 197–198, 1917. Ross, C. S., and Shannon, E. V., The minerals of bentonite and related clays and their physical properties: Amer. Ceramic Soc. Jour., vol. 9, pp. 77–96, 1926. Ross, C. S., Altered Paleozoic volcanic materials and their recognition: Amer. Assoc. Petroleum Geologists Bull., vol. 12, pp. 143–164, 1928.

[5] Lamar, J. E., op. cit., p. 14.

[6] Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, p. 31, 1925.

Stratigraphic relations.—Throughout most of the area the lower contact of the Chouteau appears to be gradational, the limestone grading imperceptibly through several inches into the underlying noncalcareous Hannibal shale. (See pl. 7*D*.) But in the southern part of the area where the Chouteau is thickest this contact, though apparently conformable, is a much sharper lithologic change (fig. 2*C*). The gradational contact of the Chouteau and Hannibal, together with the approximately constant interval occupied by the two formations (p. 39), is believed to indicate that the upper part of the shale in the north was laid down at the same time as the lower part of the limestone in the south, a conclusion that seems to be consistent with the evidence afforded by the faunas of the two formations.[7]

The upper contact of the Chouteau limestone is sharp, and locally it is an angular unconformity. (See pp. 44–45.)

The stratigraphic relations and the geographic variations in thickness of the Chouteau limestone are of especial interest in any effort to interpret the geologic and structural history of the area embraced in the Hardin and Brussels quadrangles. The stratigraphic relations of the underlying Kinderhook formations — the southwestward thinning of the Louisiana and the Glen Park and the southwestward overlap of the Hannibal—all seem to indicate gentle but repeated uplift of the Lincoln anticline during early Mississippian time. Also a study of the faunas is said to show "that in early Kinderhook time there were two distinct faunal provinces within the present Mississippi valley region, a northern province and a southern province, separated by an east and west line at a point near the mouth of the present Illinois River."[8] Other evidence also indicates repeated uplift of this area again in middle Mississippian time. (See pp. 45, 144–145; fig. 3*A*.)

The question naturally arises whether the thickening of the Chouteau toward the crest of the Lincoln anticline probably indicates another upwarp of the area at that time or a complete reversal of the movement and temporary downwarp there. Limestone, even impure limestone like the Chouteau, presumably was formed in clearer water than that in which argillaceous beds like the Hannibal were laid down. Furthermore, outside the limits of the Hardin and Brussels quadrangles some beds of the Hannibal shale pass northwestward and very probably southward into sandier rocks that must have been laid down in shallower water or nearer shore. These relations seem to indicate that, while the Chouteau was accumulating, the site of the Lincoln anticline was relatively far from the land areas that were the source of the sand and shale.

However, it does not necessarily follow, because the Chouteau limestone was deposited farther from land,

[7] Moore, R. C., op. cit., pp. 56, 57, 59, 60, 76.

[8] Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, p. 468, 1906.

that it was laid down in deeper water than the Hannibal shale. In fact, warm shallow banks [9] separated from the land areas by deeper troughs in which the land-derived muds may all settle out are probably one of the most favorable environments for the deposition of limestone. In a case of lateral gradation of Greenhorn limestone into Belle Fourche shale in southeastern Montana, very similar to that of the Chouteau and the Hannibal, the writer [10] found evidence indicating that the limestone probably accumulated in shallower water than the shale. The thin laminations (pp. 37–38; pl. 7*B*) in at least some of the layers of Hannibal shale seem to show that this shale was deposited in water deep enough to be beyond the effects of disturbance by waves, and the irregular bedding surfaces in the Chouteau limestone suggest that the limestone was deposited in much shallower water.

It therefore seems that the distribution or areal relations, the lithologic character, and the bedding of the Chouteau limestone in Calhoun and Jersey Counties can be most simply explained if the site of the Lincoln anticline had been covered by water shallower than that in which the Hannibal shale accumulated. This conclusion accords with the evidence afforded by the other Kinderhook and by later Mississippian formations that the Lincoln anticline was gently but repeatedly uplifted throughout Mississippian time.

Fossils.—Fragments of crinoid stems are scattered through the dense Chouteau limestone, but other organic remains are abundant in only a few places. The upper beds of the formation seem to be more fossiliferous than the lower beds and, at the southernmost exposures, where the formation is thickest, fossils are locally abundant. (See table, p. 172, and Moore,[10a] pp. 67–68.)

Name.—The Chouteau limestone was named from outcrops in central Missouri.[11] Potter [12] applied the name to beds in Lincoln County, Mo., and Worthen [13] correlated the upper unit of the Kinderhook group in Calhoun County with the Chouteau limestone of Missouri. Weller [14] and later writers [15] have used the name Chouteau limestone for the beds exposed in the Hardin and Brussels quadrangles. These early usages of the name Chouteau limestone in the Hardin and Brussels quadrangles appear to correspond exactly with Moore's [16] restricted usage of the name in Missouri.

[9] Twenhofel, W. H., Treatise on sedimentation, pp. 245–246, 1926.

[10] Rubey, W. W., Lithologic studies of fine-grained Upper Cretaceous sedimentary rocks of the Black Hills region: U. S. Geol. Survey Prof. Paper 165, pp. 7, 12–13, 51–52, 53, 1930.

[10a] Moore, R. C., op cit., pp. 67–68.

[11] Swallow, G. C., Missouri Geol. Survey, 1st and 2d Ann. Repts., pp. 101–103, 1855.

[12] Potter, W. B., Geology of Lincoln County, in Preliminary report on the iron ores and coal fields: Missouri Geol. Survey, pp. 245–246, 1873.

[13] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, p. 10, 1870.

[14] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, pp. 226–227, 1907.

[15] Krey, Frank, op. cit., p. 37. Lamar, J. E., op. cit., p. 8.

[16] Moore, R. C., op. cit., pp. 61–63, 84.

The lower part of the Chouteau limestone in the southern part of the two quadrangles appears to be contemporaneous with the upper part of the Hannibal shale to the north (p. 40). Thus, the idealized "time lines" of strict contemporaneity seem to cut obliquely across the Hannibal-Chouteau contact (fig. 2*C*). Yet it seems perfectly clear that the name Chouteau must be applied to the limestone unit and Hannibal to the shale unit. Both formations are distinct lithologic and faunal units. Apparently there are no lithologic marker beds or faunal zones that might be mapped as reliable time lines of strict contemporaneity. Even if beds that marked true time lines could be found, it would still be of very questionable value to map them instead of the lithologic contacts as formation boundaries. The lithologic units are of fundamental importance in the development of mineral resources or in the interpretation of geologic history, and their boundaries cannot be ignored. It is of course essential to learn the time relationships of the lithologic facies but, even when this information is finally complete, it is immaterial which is taken as the basis of reference—whether time lines cross lithologic contacts or vice versa. Of the two, one is so eminently well suited and the other so poorly suited to the conditions of actual mapping that American geologists have come generally to accept lithologic units as the fundamental basis for mapping and, where these are known to transgress time lines, to show their time relationships diagrammatically.

OSAGE GROUP

The limestone beds in the Hardin and Brussels quadrangles that make up the Sedalia, Burlington, and Keokuk limestones—the Osage group [17]—range from 200 to 275 feet in total thickness. Lithologically these formations are all very similar, and they seem to be conformable and locally even gradational throughout. The faunas also are said not to be strikingly different from one another.[18] The Fern Glen formation, a member of this group that crops out just east of the Brussels quadrangle, appears to grade laterally within a relatively short distance into the Sedalia and the lower part of the Burlington limestones.

Inasmuch as the formations of this group are lithologically, stratigraphically, and faunally so closely related to one another over wide areas, it has been proposed that they might appropriately be grouped together into one comprehensive Osage formation and the subordinate divisions reduced in rank to faunal zones or members.[19]

[17] Williams, H. S., Correlation papers—Devonian and Carboniferous: U. S. Geol. Survey Bull. 80, p. 169, 1891.

[18] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, p. 17, 1911. Weller and St. Clair, op. cit., pp. 173, 183.

[19] Wachsmuth, Charles, and Springer, Frank, Transition forms in crinoids, and descriptions of five new species: Nat. Acad. Sci. Proc., Philadelphia, p. 224, 1878. Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 22, p. 173, 1928.

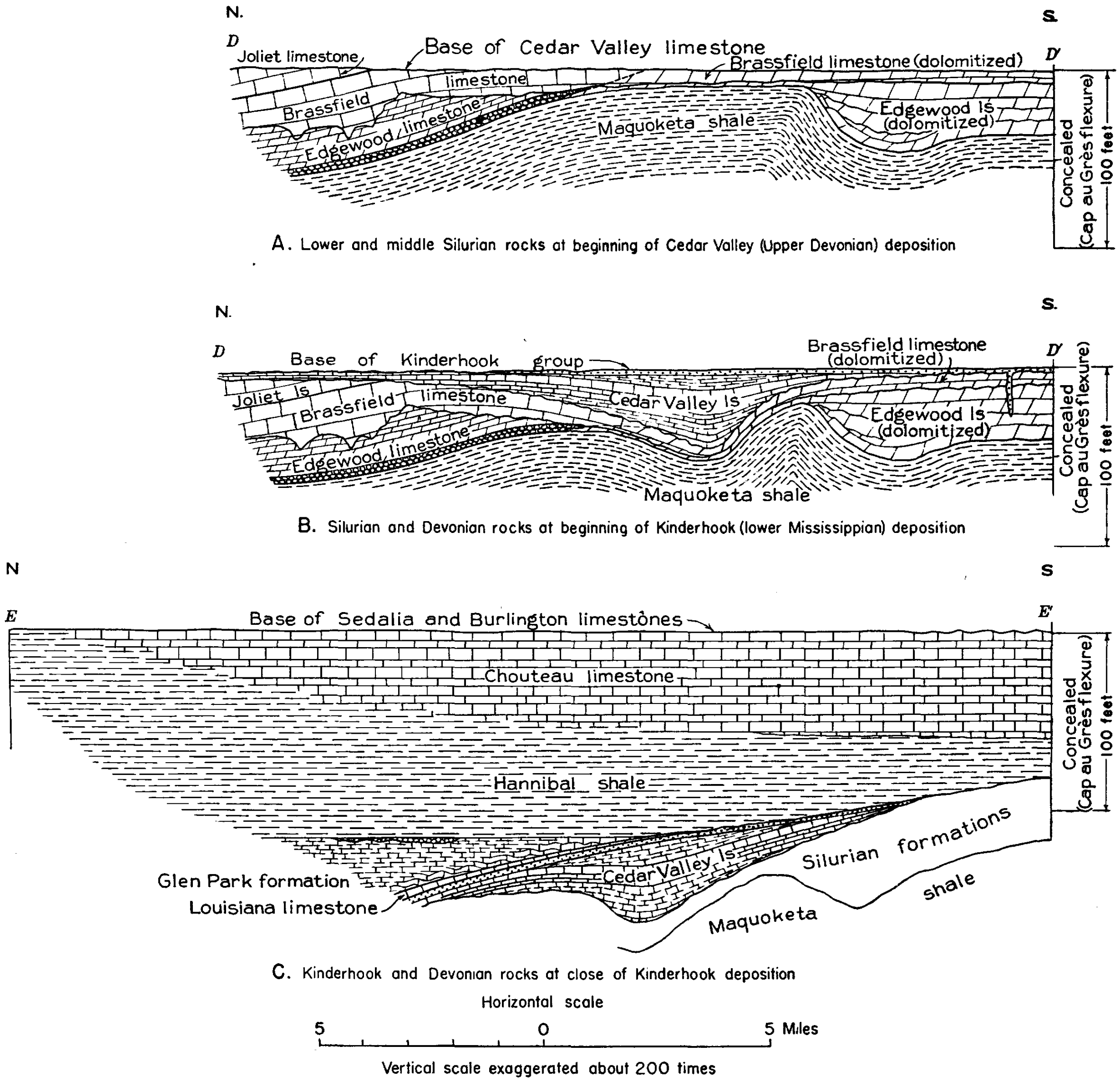


FIGURE 2.—Generalized cross sections along lines shown in figure 14, showing approximate structural relations.

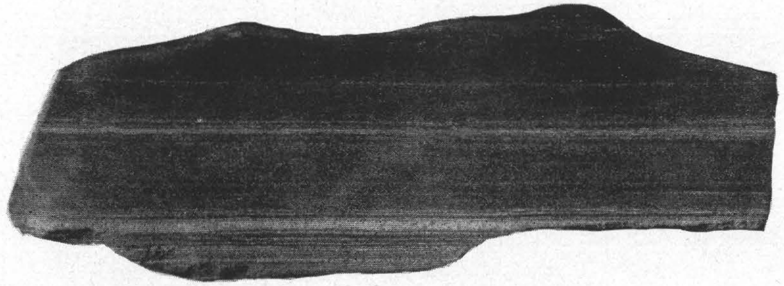
However, in this report the usual classification is followed.

SEDALIA AND BURLINGTON LIMESTONES

The Chouteau limestone is overlain by the thick series of cherty limestone beds that make up the Sedalia and Burlington formations. These formations crop out over a wide area, forming parts of the bluffs and nearly all of the uplands throughout the Hardin quadrangle and that portion of the Brussels quadrangle north of the Cap au Grès flexure. Like the Kimmswick and the St. Louis limestones, and unlike nearly all the other formations of the region, the Burlington limestone caps the uplands; hence, it is not restricted to narrow lines of outcrop along the steep bluffs but is the bedrock underlying wide areas. (See pl. 1.) However, the Burlington limestone is actually exposed in only a small part of its wide zone of outcrop for in most places it is covered by surficial deposits of Pleistocene and Recent age. (See pp. 5–6.)

Thickness.—Paleozoic formations younger than the Burlington limestone are present in the Hardin and Brussels quadrangles only in the area south of the Cap au Grès flexure and in the northeast corner of the area. Consequently, variations in thickness, as observed in the lower formations, cannot be traced throughout the region. Along the Cap au Grès flexure in both Calhoun and Jersey counties the combined thickness of the Sedalia and Burlington limestones seems to be uniformly about 140 feet. In the northeast part of the Hardin quadrangle the beds are flat lying, and their thickness is difficult to determine. The best locality for a measurement is in the NW¼NW¼ sec. 12, T. 8 N., R. 13 W. There 190 feet of Burlington limestone comes to the surface and neither underlying nor overlying formations are exposed. From a series of rather poor measurements it seems probable that the combined thick-

A. "HAMBURG" OOLITE IN GLEN PARK FORMATION.
SW¼ sec. 26, T. 9 S., R. 3 W. Enlarged 1½ times.



B. THINLY LAMINATED SILTSTONE IN HANNIBAL SHALE.
NE¼NE¼ sec. 1, T. 10 S., R. 3 W. Enlarged 2 times.

C. OVERTURNED BEDS ALONG CAP AU GRÈS FLEXURE.
Cedar Valley limestone and Hannibal shale at right, Chouteau limestone in center and at left.
SW¼SE¼ sec. 11, T. 6 N., R. 13 W.

D. GRADATIONAL CONTACT BETWEEN HANNIBAL SHALE AND CHOUTEAU LIMESTONE.
SW¼NW¼ sec. 31, T. 9 S., R. 2 W.

ness of the Sedalia and Burlington limestones in the northeast part of the area is approximately 200 or 210 feet.

The Sedalia limestone lies below the Burlington and above the Chouteau limestone. In some places it is a well-defined lithologic unit ranging from 5 to 30 feet thick. Elsewhere its upper limit is unrecognizable for it seems to grade imperceptibly into the overlying Burlington. The measurements taken where its limits are recognizable indicate that it thins, very irregularly, northward.

Topographic expression.—The Burlington and Sedalia limestones make up a thick unit of hard cherty limestone. Because of the hardness of the cherty limestone or the protecting effect of residual chert that accumulates on weathered outcrops, the unit is exceedingly resistant to erosion; thus, it caps the uplands and forms the steep bordering cliffs.

Although resistant to erosion, the limestone is very pure and readily dissolved by percolating ground water. Hence, where they are not covered by glacial till, the uplands on the Burlington limestone are marked here and there by sinkholes. These Burlington sinkholes are most abundant along the narrow remnant of upland surface in Tps. 11 and 12 S., R. 2 W., Calhoun County. Even within the till-covered areas, as near the common corner of secs. 15, 16, 21, and 22, T. 8 N., R. 13 W., Jersey County, some sinkholes are developed.

The lower and middle parts of the Burlington limestone seem to be more resistant to erosion than the upper part, and they not uncommonly form nearly vertical or even overhanging cliffs above the Sedalia and Chouteau limestones. The Sedalia limestone, on the other hand, is somewhat less resistant than the lower part of the Burlington and the Chouteau and in many places it forms a reentrant ledge or niche in the steep bluff face.

Lithologic character.—The Sedalia limestone is commonly a buff, massive, fine-grained, somewhat crinoidal, and perhaps slightly dolomitic limestone. The limestone contains calcite geodes and flat lenticular beds of dark-gray chert with light-gray rims. In this respect it resembles the Chouteau limestone, but the geodes are larger and the chert less abundant than in the Chouteau. This common phase of the Sedalia is not everywhere present, and locally the formation is interlaminated with other very diverse rock types. In places it contains layers that are lighter gray or darker brown, or thinner-bedded and more argillaceous, or more coarsely crystalline and crinoidal. This diversity may possibly be explained as part of the gradation of the Sedalia upward into the coarsely crystalline crinoidal Burlington limestone and laterally into the thin-bedded argillaceous Fern Glen formation, which crops out only a few miles to the east near Grafton and Chautauqua. The Sedalia limestone, here about 20 feet thick, and 100 feet of the overlying Burlington limestone are excellently exposed in the bluff in the center W½ sec. 23, T. 11 S., R 2 W.

The Burlington limestone consists dominantly of hard, light gray and brown, cherty, crinoidal, coarsely crystalline limestone, almost like marble, which is massive where fresh and moderately thin and somewhat irregularly bedded where weathered. Many of the harder and purer layers contain abundant stylolites. Here and there throughout the formation are a few layers of fine-grained, brown limestone similar to those in the Sedalia limestone. In general, the formation becomes more coarsely crystalline, more highly crinoidal, softer, and somewhat thinner bedded above. Good exposures of the upper part of the formation are relatively uncommon, but where found they show thin argillaceous layers between some of the beds of limestone, and bedding surfaces that are marked by thin layers of green clay. Although commonly light gray, or nearly white where fresh, the Burlington limestone weathers to a brownish gray, especially in the upper and more granular part of the formation. The upper 125 feet of the Burlington limestone is well exposed on the north side of the hill in the NE¼ sec. 35, T. 12 S., R. 2 W.

The degree of crystallinity or the coarseness of texture of the Burlington limestone seems to run closely parallel with the proportion of crinoid fragments in the rock. Some layers appear on casual inspection to consist entirely of crystalline fragments of crinoid stems, but upon close examination this rock can be seen to contain much coarse and fine crystalline calcite which is not obviously at least of crinoidal origin. It therefore is not certain how much of the crystalline texture of the limestone may be due to some process of recrystallization,[20] which the calcite has undergone, and how much to the presence of crystalline fragments of crinoids.

The chert of the Burlington limestone is probably its most widely known characteristic. Yet the chert is exceedingly lenticular and discontinuous in its occurrence; in places the formation contains much chert and elsewhere the same layers contain almost none.

The chert in the Burlington limestone is of at least two distinct types. The commoner type consists of sharply defined nodular masses several feet in diameter and several inches thick. These nodules lie parallel to bedding planes and locally they coalesce to form concretionary beds. The chert is dense to somewhat granular, light gray to bluish gray and locally even black and banded where fresh, and nearly white to brownish gray where weathered. In general this nodular chert is more abundant in the upper part of the formation, but the writer was unable to trace any especially cherty layers from one exposure to another. In some exposures it makes up 10 or 15 percent of the volume of the rock, but

[20] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, p. 21, 1911.

elsewhere apparently the same beds contain very little chert.

The second type of chert in the Burlington limestone is distinctly different in its mode of occurrence and localized in its distribution. It is rather soft, pale brown to white, porous, granular, bedded chert which seems to be restricted to the till-covered upland surfaces and to grade imperceptibly into the underlying limestone. Where best developed, as in the SE¼SW¼ sec. 14, T. 8 N., R. 13 W., it is at least 40 feet thick. A thin section of this bedded chert from the NW¼ sec. 24, T. 8 N., R. 13 W., consists almost entirely of microcrystalline quartz. Neither chalcedony nor opal was observed, but the rock is streaked or mottled by a few stringers of clay and tiny crystals of calcite. This bedded chert contains angular fragments of harder dense chert, and its bedding is somewhat irregular and slightly disturbed. These characteristics seem to show that the bedded chert is in part the slumped-down residue left by the solution of cherty limestone.

However, this explanation taken alone does not appear to explain satisfactorily the gradational lower limit, the local distribution, and the thickness of this type of chert. A thickness of 267 feet of limestone that contained 15 percent of chert would have to be dissolved away to yield a chert residue 40 feet thick. The beds of limestone immediately below the thick chert are in the upper part of the Burlington, and the upper part of this chert contains none of the easily recognizable upper Keokuk and Warsaw concretions. Hence, from the known thickness of the intervening beds, it seems clear that less than 125 feet and probably even less than 60 feet of cherty limestone has been leached to form the 40 feet of bedded chert. The conclusion then seems inescapable either that the beds were originally much chertier here than elsewhere or that at least some of the bedded chert has been formed by the replacement of limestone, the silica-bearing waters possibly having percolated downward from the overlying glacial till.

A similar explanation has been suggested as the origin of some Ordovician cherts in Missouri.[21] However, Tarr [22] and Barton [23] in special studies of the nodular chert in the Burlington limestone of central and of eastern Missouri, concluded that the chert was probably formed at the time of deposition of the limestone, or after deposition but before the Pennsylvanian epoch.

Thick accumulations of broken angular fragments of chert in residual red clayey soil might possibly be considered as a third type or mode of occurrence of the chert in the Burlington limestone. These accumulations are from 10 to 40 feet thick and without obvious bedding and they mantle the Burlington limestone on upland surfaces outside the limits of Illinoian glaciation. They are especially well developed on the narrow uplands near Coon Creek and Williams Hollow in southwestern Jersey County. These accumulations of chert are clearly the result of long-continued weathering and leaching of the cherty limestone, and they are not properly considered as a part of the Paleozoic limestone. (See p. 74.)

Chemical analysis of a sample (p. 157) collected from the lower 70 feet of the Burlington limestone exposed along the road on Rocky Hill in the SE¼SE¼ sec. 28, T. 10 S., R. 2 W., indicates that the rock consists of 96 percent of fairly pure calcite, about 2 percent of silica—probably disseminated chert—between 0.5 and 1.0 percent of clay, less than 0.5 percent iron oxide, and an almost negligible amount of iron sulfide. (See pp. 16–17.)

Partial analysis of a sample collected near the same locality by Lamar [24] indicates a slightly larger proportion of impurities in the limestone. The analysis given here is similar to partial analyses of the Burlington limestone in St. Louis County,[25] at Hannibal,[26] and in Pike and Ralls Counties,[27] Mo., and to an average of several analyses of the Burlington limestone in Illinois.[28] Physical tests of samples of Burlington limestone from Calhoun, Greene, and Jersey Counties [29] show that the rock varies considerably in its porosity and is less resistant to abrasion than most of the other limestones of the region.

The wide distribution and relative purity of the Burlington limestone makes it one of the most valuable mineral resources in the Hardin and Brussels quadrangles. It is well adapted to grinding for agricultural use, and many small quarries have been opened in the formation by residents of the region and operated for a short while.

Stratigraphic relations.—The contact of the Sedalia and Chouteau limestones is nearly everywhere sharply defined and in several places is a slight erosional unconformity. A short distance east of Brussels quadrangle, along the general line of the Cap au Grès flexure, as in the NE¼ sec. 4 and the SE¼ sec. 13, T. 6 N., R 12 W., the contact between the Chouteau and overlying beds, here referred to the Sedalia, is a slight but unmistakable angular unconformity.

In many exposures the Sedalia limestone seems to grade imperceptibly through 5 or 10 or even more feet of transitional beds into the overlying typical Burling-

[21] Bain, H. F., and Ulrich, E. O., The copper deposits of Missouri: U. S. Geol. Survey Bull. 267, pp. 27, 29, 1905.

[22] Tarr, W. A., Origin of the chert in the Burlington limestone: Amer. Jour. Sci., vol. 44, pp. 409–452, 1917.

[23] Barton, D. C., Notes on the Mississippian chert of the St. Louis area: Jour. Geology, vol. 26, pp. 361–374, 1918.

[24] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. Inv. no. 8, p. 14, 1926.

[25] Ladd, G. E., The clay, stone, lime, and sand industries of St. Louis City and County: Missouri Geol. Survey Bull. 3, p. 77, 1890.

[26] Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2 ser., vol. 2, p. 208, 1904.

[27] Buehler, H. A., The lime and cement resources of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 6, p. 237, [1907].

[28] Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, p. 311, 1925.

[29] Krey, Frank, and Lamar, J. E., op. cit., pp. 47, 51, 52.

ton limestone. In other exposures, however, the contact between the Sedalia and Burlington is sharp and well defined.

Near Chautauqua and Grafton several geologists [30] have recognized the Fern Glen formation [31] between the Chouteau and Burlington limestones or, if a lower bed in this Fern Glen be considered Sedalia,[32] between the Sedalia and Burlington limestones. At Chautauqua the Fern Glen consists of about 40 feet of thin-bedded cherty argillaceous limestone that is greenish in the lower part and buffy in the upper part. The chert occurs in thin concretionary beds and is similar to that in the Chouteau and Sedalia limestones in this region. The layers of limestone contain calcite geodes and many small fragments of crinoid stems.

South of Chautauqua in east-central Missouri [33] the Fern Glen is a widespread formation of green and red argillaceous cherty limestone. Well records indicate [34] that it thickens eastward from Chautauqua along the axis of the Troy-Brussels syncline. Northward and westward from Chautaqua the Fern Glen disappears or becomes unrecognizable within a few miles. The northwesternmost exposure at which it was seen by the writer is in Mason Hollow in the north center NE¼ sec. 4, T. 6 N., R. 12 W., 3 miles east of the Brussels quadrangle. There it consists of approximately 40 feet of thin and somewhat nodular bedded, greenish and reddish-gray crinoidal limestone and some chert and calcite geodes. No Fern Glen was recognized within the Hardin and Brussels quadrangles unless the thin-bedded somewhat argillaceous layers found locally in the Sedalia limestone may represent the Fern Glen.

This is rather abrupt disappearance of the Fern Glen formation north and west of Chautauqua and Grafton and has been interpreted as lateral gradation into the Burlington limestone.[35] Moore [36] also interprets the Fern Glen formation, or at least the lower part of it, as grading laterally into the Sedalia limestone.

The precise stratigraphic relations of the Sedalia, the Fern Glen, and the Burlington formations in and immediately east of the Hardin and Brussels quadrangles have not yet been established. In some exposures each of the three formations seems to be conformable or even completely gradational into each of the others, but at a few exposures the different formations or lithologic units appear to be separated from one another by sharp contacts that may represent important breaks in sedimentation.

It is perhaps worth noting that the area in which there is angular unconformity between the Chouteau and the Sedalia limestones and the region where the Fern Glen disappears abruptly are each near the line of the Cap au Grès flexure. This evidence, combined with that afforded by the variations in thickness and the stratigraphic relations of the Kinderhook formations, indicates strongly that minor movements were taking place along this fold during early and middle Mississippian time.

The Burlington limestone seems to be conformable throughout and the gradual change to softer, more coarsely crystalline, more highly crinoidal, and somewhat thinner-bedded layers in the upper part seems to show that the formation is essentially one lithologic unit.

Along the Cap au Grès flexure and in the northeastern part of the area the Burlington limestone is overlain by the Keokuk limestone, but in the intervening area it forms the uplands and is the youngest Mississippian formation. In this area the Burlington limestone is overlain unconformably by local remnants of Pennsylvanian and Tertiary rocks (pl. 10*A*; fig. 3*D*) and by a more or less continuous mantle of Pleistocene deposits.

The contact of the Burlington with the Keokuk limestone seems to be conformable and gradational, and the line between the two formations in this area must be drawn almost solely on the basis of the contained faunas.

Fossils.—The Sedalia and Burlington limestones are abundantly fossiliferous, but by far the greater proportion of these organic remains comprises broken fragments of crinoid stems. In fact, some thick layers of limestone in the formation appear to be made up almost solely of crinoid stems. However, brachiopods and a few bryozoans and corals may be found throughout both formations. The collections made during the field work on which this report is based (see table on p. 172) are therefore barely more than indicative of the faunas of these beds. In general, the Sedalia limestone in this area was recognized more by its lithologic character than by its fauna.

Names.—The early workers in the geology of this general region, like Potter [37] in Lincoln County, Mo., called these beds the "Encrinital" limestone [38] from the abundance of crinoid fragments that they contain. But the name Burlington limestone had also been used by Owen

[30] Weller, Stuart, Kinderhook faunal studies, V, The fauna of the Fern Glen formation: Geol. Soc. America Bull., vol. 20, p. 268, 1909. Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Mo., to Nauvoo, Ill.: Illinois Geol. Survey Bull. 45, p. 38, 1924. Moore, R. C., Early Mississippian formations in Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 21, p. 147, 1928.

[31] Weller, Stuart, Kinderhook faunal studies, IV, The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, p. 438, 1906.

[32] Moore, R. C., op. cit., pp. 146, 150–151; also, personal communication.

[33] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, pp. 19–20, 1911.

[34] Collingwood, D. M., Manuscript report in files of Illinois Geological Survey.

[35] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Missouri, to Nauvoo, Illinois: Illinois Geol. Survey Bull. 45, p. 38, 1924. Moore, R. C., op. cit., pp. 145–146, 253.

[36] Moore, R. C., op. cit., pp. 144, 146, 150, 166, 253–254.

[37] Potter, W. B., Geology of Lincoln County, in Preliminary report on the iron ores and coal fields: Missouri Geol. Survey, pp. 250–253, 1873.

[38] Owen, D. D., Report of a geological survey of Wisconsin, Iowa, and Minnesota and incidentally of a portion of Nebraska territory, Philadelphia, p. 92, 1852

and by Hall [39] for rocks exposed in Iowa, and this name was applied by Worthen [40] to the beds above the Kinderhook group and below the Keokuk limestone in Calhoun, Jersey, and Greene Counties, Ill. Later writers have followed this usage, but Moore recognized the Sedalia limestone [41] as a separate formation made up of beds that have been included with the Burlington in Illinois and with the Chouteau in Missouri. The Sedalia is thus a restriction of the Burlington as it has been mapped in parts of western Illinois, and at the same time it is a restriction of the Chouteau in Missouri. Moore stated that "on the east side of Mississippi River in Jersey, Calhoun, and Pike Counties, Ill., it is well developed and may be observed with all characteristic features in the bluffs of Mississippi River as far north as Kinderhook." [42]

Because of the thinness of the Sedalia limestone and the indefinite boundary that in many places separates it from the overlying Burlington limestone, the two formations are shown as one unit on the geologic map. (See pl. 1.)

KEOKUK LIMESTONE

Along the Cap au Grès flexure (from sec. 32, T. 12 S., R. 2 W., east to sec. 13, T. 6 N., R. 13 W.) and in the northeastern part of the Hardin quadrangle the Burlington limestone is overlain by the lithologically very similar beds that constitute the Keokuk limestone. At all its exposures in the area this formation seems to be uniformly between 60 and 70 feet thick.

Lithologic character.—The rocks that make up the Keokuk limestone are so nearly identical in their lithologic character with those of the Burlington limestone that one description might well serve for both formations. In general, the Burlington limestone becomes more coarsely crystalline, more highly crinoidal, softer, and thinner-bedded above. Broadly speaking, the Keokuk limestone likewise is softer and thinner-bedded above, but it is more coarsely crystalline and more highly crinoidal in its lower beds. The Keokuk contains brown to gray, somewhat calcareous clay or mudstone, in layers from less than 1 inch to several feet thick, interlaminated with the limestone beds, and the limestone is commonly darker gray where weathered and browner on weathered surfaces than the Burlington. However, the rocks are so variable that none of these general differences serve to distinguish the lower part of the Keokuk from the upper part of the Burlington.

The lower and middle parts of the Keokuk limestone contain abundant nodules of chert like those in the Burlington. Most of this chert in the Keokuk seems to be slightly darker gray in color than the chert in the Burlington, but the chert also is so variable in its character that it cannot be relied upon to mark the contact between the two formations. It is in fact only by their contained faunas that the Burlington and Keokuk limestones can be distinguished.

The limestone beds in the upper part of the Keokuk and the calcareous shale in the overlying Warsaw formation contain cherty concretions of a very different and distinctive type. These concretions are mammillary nodules or hollow geodes that are commonly from 3 to 5 inches in maximum diameter and 2 to 2½ inches thick. In fresh exposures these geodes are made up almost entirely of coarsely crystalline calcite; where somewhat weathered they have a dense siliceous shell and a lining of small quartz crystals around the interior cavity; and in residual accumulations they seem to be made entirely of silica. (See p. 47.)

Seventy feet of the Keokuk limestone and also the underlying and overlying formations are well exposed along the steeply dipping Cap au Grès flexure in the NW¼NW¼ sec. 32, T. 12 S., R. 2 W., at the river's edge south of Dogtown Hollow. Approximately 60 feet of the Keokuk limestone is well exposed in the creek bed in the NW¼ sec. 13 and the NE¼ sec. 14, T. 9 N., R. 13 W., near the northeast corner of the Hardin quadrangle.

Stratigraphic relations.—Although its lower contact is rarely well exposed in the Hardin and Brussels quadrangles, the Keokuk limestone is apparently conformable and completely gradational into the underlying Burlington. Lithologic similarity and conformable relations between the two formations have been reported in many nearby regions.[43]

The upper limit of the Keokuk limestone, though marked by a sharper lithologic change than that at the base of the formation, also seems to be conformable.

Fossils.—The Keokuk, like the Burlington limestone, contains many fragments of crinoid stems. This highly crinoidal character of the limestone is especially pronounced in the lower part of the Keokuk and the upper part of the Burlington and in these adjacent parts of the two formations many of the crinoid stems are very large. The most readily recognized faunal distinction between the two formations is the greater abundance and variety of bryozoans in the Keokuk limestone. A few of the peculiar corkscrew bryozoans, *Archimedes*, which occur also in younger formations, may be found in the Keokuk. (See p. 172.) However, it is said that the general faunal composition of the Keokuk is clearly

[39] Hall, James, Observations upon the Carboniferous limestones of the Mississippi Valley: Amer. Jour. Sci., 2d ser., vol. 23, p. 190, 1857.

[40] Worthen, A. H., Geology of Illinois; Jersey County: Illinois Geol. Survey, vol. 3, pp. 113–115, 1868; Greene County: idem, pp. 129–130; Calhoun County: idem, vol. 4, pp. 12–14, 1870.

[41] Moore, R. C., op. cit., pp. 84, 149, 151.

[42] Moore, R. C., op. cit., p. 149, and fig. 2.

[43] Weller, Stuart, The geological map of Illinois: Illinois Geol. Survey Bull. 6, p. 24, 1907. Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, p. 20, 1911. Krey, Frank, op. cit. pp. 38–39. Weller, Stuart, and St. Clair, Stuart, op. cit., pp. 173, 183–185. Moore, R. C., op. cit., pp. 143–144, 228.

related to that of the Burlington and that the faunal change from one formation to another is neither abrupt nor conspicuous.[44] (See p. 41.)

At one locality, in the SE¼SE¼ sec. 23, T. 8 N., R. 13 W., poorly preserved plant remains were found in a bed of noncalcareous shale 2½ feet thick in the lower part of the Keokuk.

Name.—The Keokuk limestone was named from beds in southeastern Iowa.[45] Worthen [46] applied the name to the rocks overlying the Burlington limestone in Jersey, Greene, and Calhoun Counties, Ill., but he apparently included in the same formation the beds of overlying shale here referred to the Warsaw formation. Weller [47] and Krey [48] in their reports on this area restricted the Keokuk limestone to the strata between the Burlington and the Warsaw.

In the geologic map (pl. 1) the Keokuk is shown separately from the underlying Sedalia and Burlington limestones. It might more accurately have been included with those formations as the Osage group for, except in the southern part of the area, where the beds are steeply dipping and a fairly dependable subdivision may be made by thicknesses and on purely lithologic grounds, the separation was based almost solely on the fossil content. As diagnostic fossils cannot be found in all small exposures and as it is impracticable to make collections at every exposure, the contact shown on plate 1 is necessarily exceedingly generalized.

MERAMEC GROUP

The youngest Mississippian rocks exposed in the Hardin and Brussels quadrangles are the lower units of the Meramec group: [49] the Warsaw, Spergen, and St. Louis formations. The Ste. Genevieve limestone, which overlies the St. Louis limestone at Alton, Ill.,[50] and is included in the Meramec group by Weller and some other geologists, was not recognized in the area. This group consists dominantly of limestone but it includes in its lower part many argillaceous layers and at its top some sandy beds. Its total thickness ranges from about 200 to 320 feet and probably averages about 300 feet.

No strata belonging to the Chester group (late Mississippian) were recognized in the area. The Meramec rocks are immediately overlain by Pennsylvanian beds.

[44] Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser. vol. 22, p. 183, 1928. Moore, op. cit., p. 228.

[45] Owen, D. D., in Hall, James, Observations upon the Carboniferous limestones of the Mississippi Valley: Amer. Jour. Sci., 2d ser., vol. 23, pp. 188–190, 1857.

[46] Worthen, A. H., Illinois Geol. Survey, vol. 3, pp. 112–113, 128–129, 1868; idem, vol. 4, pp. 14–15, 1870.

[47] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, pp. 227–228, 1907.

[48] Op. cit., pp. 38–39.

[49] Ulrich, E. O., in Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines 2d ser, vol. 2, p. 110, 1904.

[50] Weller, Stuart, The Mississippian Brachiopoda of the Mississippi Valley Basin: Illinois Geol. Survey Mon. 1, p. 22, 1914.

WARSAW FORMATION AND SPERGEN LIMESTONE

The Keokuk limestone is overlain near the northeastern corner of the Hardin quadrangle by the Warsaw formation and in a narrow zone along the Cap au Grès flexure by the Warsaw formation and the Spergen limestone. The rocks in these formations are somewhat softer and less resistant to erosion than those of the underlying Burlington and Keokuk and the overlying St. Louis limestones, and they are consequently poorly exposed and difficult to measure. However, in the zone of steeply dipping rocks along the Cap au Grès flexure the Warsaw seems to range in thickness from 50 to 65 feet and the Spergen to be rather uniformly about 70 feet thick.

Lithologic character.—The Warsaw formation is made up largely of soft somewhat calcareous platy shale and massive clay that is light gray to greenish gray where fresh and pale buff to tan on weathered surfaces. Interlaminated with these soft argillaceous beds, especially in the lower and upper parts of the formation, are thin layers commonly less than 1 foot thick of rather hard, brown, dense to crystalline, argillaceous and somewhat dolomitic limestone.

Throughout the formation both the argillaceous and the limestone beds contain many scattered mammillary concretions or geodes like those in the upper part of the Keokuk limestone. These geodes, which range from 2 to 10 inches in diameter, commonly consist of coarsely crystalline calcite surrounded by a thin layer of dense chert. Locally, however, they contain fragments of dense dolomitic limestone; where weathered they are more siliceous and small quartz crystals line the interior cavities. (See p. 46.)

The Spergen limestone consists dominantly of rather hard, massive to thin-bedded, granular to fine-grained, more or less dolomitic limestone. On fresh surfaces this rock is dark gray or dull brown; where weathered, it is dark brown. In general, this brown dolomitic limestone is harder, thicker-bedded, and more dolomitic and porous in the lower part of the formation. Interlaminated with it in the upper part and at the base of the formation are thin argillaceous layers, and, especially in the upper part, beds of gray fine-grained limestone very similar to that in the overlying St. Louis limestone. A few of the layers of dolomitic limestone are somewhat oolitic and others are obscurely cross-bedded with oblique laminations that dip southwestward.

Chert occurs sparingly in the Spergen limestone, both in thin gray and brown nodular beds and in calcite geodes similar to those in the underlying Warsaw and Keokuk formations.

Samples, presumably from the Spergen limestone, that were core-drilled between depths of 87 and 95 feet at the proposed site of a railroad bridge over Illinois River, 1 mile east of the Brussels quadrangle, consist of fine-grained, gray and brown, cherty, fossiliferous, dolomitic limestone and gray oolite. The spherules or oolite grains occur in both the limestone and the chert, and they range from one-quarter to three-quarters of a millimeter in diameter. Many of these spherules have nuclei of white angular and pale-greenish fragments of oolite and nuclei of shells of the foraminifer, *Endothyra*—according to Dr. G. H. Girty, an *Endothyra* of a form smaller than *E. baileyi*. A few of the spherules have small gastropod shells as nuclei. Sponge spicules are exceedingly abundant in one piece of the chert. The limestone itself contains a few small pyrite grains and very thin glauconitic (?) laminae and is marked by stylolitic sutures. Some pieces of the limestone are porous and highly fossiliferous with foraminifers, gastropods, and brachiopods.

No samples of either the Warsaw formation or the Spergen limestone were collected in the Hardin and Brussels quadrangles for chemical analysis. However, two analyses of samples collected by A. H. Worthen [51] from the Spergen limestone—included by him in the St. Louis limestone—in Greene County indicate that the rock contains a large proportion of insoluble clay or sand and is highly dolomitic.

The Warsaw and Spergen formations are well exposed with a total thickness of 140 feet in the zone of steeply dipping rocks at the river's edge, south of Dogtown Hollow, in the west center NW¼ sec. 32, T. 12 S., R. 2 W.

Stratigraphic relations.—Although nowhere found sufficiently well exposed to afford satisfactory evidence, the Warsaw formation seems to lie conformably upon the Keokuk limestone. In fact, the presence of beds of brown calcareous clay in the Keokuk suggests that there may be a gradual transition from one formation to the other, but at all exposures examined a fairly definite contact can be drawn between the crystalline limestone below and the thick series of poorly exposed softer argillaceous beds with thin layers of brown dolomitic limestone above.

The contact between the Warsaw and Spergen, though rarely well exposed, seems definitely to be transitional through a few feet of alternating shale and dolomitic limestone that here is assigned more or less arbitrarily to the underlying Warsaw formation.

At one locality, in the NE¼SE¼ sec. 9, T. 6 N., R. 13 W., the Spergen limestone contains a small erosional unconformity within its limits. This small but definite unconformity separates the hard massive brown dolomitic limestone (Coll. 92) that makes the lower 20 feet of the Spergen from the overlying alternation of thinner-bedded brown dolomitic limestone and gray fine-grained limestone (Coll. 91).

[51] Worthen, A. H., Geology and paleontology of Illinois: Illinois Geol. Survey, vol. 3, p. 573, 1868.

The contact of the Spergen limestone and the overlying St. Louis limestone is, in most exposures, sharply defined but apparently conformable.

Fossils.—Organic remains are neither abundant nor well preserved in the Warsaw and Spergen formations. The thin beds of brown dolomitic limestone interlaminated with the shale in the Warsaw formation contain fragments of small crinoid stems; in some layers in the Spergen limestone bryozoans are numerous, but brachiopods were found in only a few localities. (See table on p. 172.) These two formations were differentiated from one another and from the overlying St. Louis limestone largely on lithologic rather than faunal grounds.

Names.—The Warsaw formation was named by James Hall [52] in 1857 from exposures at Warsaw in western Illinois. In 1901, Cumings [53] proposed the name Salem limestone for beds in Indiana equivalent to those here referred to as the Spergen limestone. In 1904, Ulrich [54] renamed these beds in Indiana the Spergen Hill limestone and recognized their presence in eastern Missouri. In 1905 [55] this name was shortened to Spergen limestone.

In his reports on the geology of Jersey, Greene, and Calhoun counties, Ill., Worthen [56] included the Warsaw formation in the upper part of the Keokuk limestone and the Spergen limestone in the lower part of the St. Louis limestone. Weller [57] recognized the Warsaw formation and Spergen limestone in southern Calhoun County and later writers on the geology of the region have followed his usage.

In the geologic map (pl. 1) that accompanies this report the Warsaw and Spergen are grouped together as one cartographic unit, not because they are especially difficult to separate—in fact, they can be distinguished much more readily than the Keokuk and Burlington limestones—but because they dip steeply; their zone of outcrop is therefore very narrow.

ST. LOUIS LIMESTONE

Over a wide area in the southern part of the region, at and south of the zone of steeply dipping rocks that make the Cap au Grès flexure, the Spergen limestone is overlain by a thick series of beds here referred to as the St. Louis limestone.

[52] Hall, James, Observations upon the Carboniferous limestones of the Mississippi Valley: Amer. Assoc. Adv. Sci. Proc., vol. 10, pt. 2, pp. 54–56, 1857.

[53] Cumings, E. R., The use of Bedford as a formational name: Jour. Geology, vol. 9, pp. 232–233, 1901.

[54] Ulrich, E. O., in Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 2, p. 110, 1904.

[55] Ulrich, E. O., and Smith, W. S. T., The lead, zinc, and fluorspar deposits of western Kentucky: U. S. Geol. Survey Prof. Paper 36, p. 28, 1905.

[56] Worthen, A. H., Geology and paleontology of Illinois: Illinois Geol. Survey, vol. 3, pp. 111–113, 127–129, 1868: idem. vol. 4, pp. 14–15, 1870.

[57] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 228, 1907.

Thickness.—This formation thickens very irregularly from less than 75 feet at some of the westernmost exposures to approximately 185 feet at the eastern margin of the Brussels quadrangle. The variations in thickness appear to be caused chiefly by a pronounced erosional unconformity which in several places cuts down steeply 75 feet or more below the top of the formation. However a part of the variation is caused by a gradual eastward thickening across the quadrangle which amounts to nearly if not quite 50 feet.

Topographic expression.—Because the St. Louis limestone is relatively hard and resistant to erosion, it crops out in steep bluffs, hills, and broad uplands. The rock is fairly pure limestone and, where it is flat lying, especially along the trough of the Troy-Brussels syncline, many sinkholes have been formed in it. In two areas, centering around sec. 3, T. 13 S., R. 2 W., and SW¼ sec. 33, T. 12 S., R. 2 W., these sinkholes are especially numerous and a characteristic karst topography has been developed in the overlying Pleistecene loess.

Lithologic character.—The St. Louis limestone embraces a wide variety of lithologic types, the more characteristic and distinctive of which are a very dense dove-colored limestone that breaks with a conchoidal fracture, some conglomerates or breccias that contain large boulders of limestone, and a clastic sandy limestone made up largely of small rounded fragments of limestone.

About 170 feet, or virtually the entire maximum thickness of the formation, is well exposed in the Cap au Grès flexure south of Twin Springs in the NW¼SE¼ sec. 9, T. 6 N., R. 13 W.

Along the bluff of Mississippi River from Dogtown Hollow south and southeast to Calhoun Landing, the formation is well exposed, and individual beds may be traced throughout this distance. Along these bluffs the lower 50 or 60 feet of the St. Louis is exposed only in the Cap au Grès flexure just below Dogtown Landing. There these lower bends consist of hard, gray to brown, dense limestone that in the lower part is massive and cherty and contains limestone boulders and pebbles and in the upper part is thin-bedded and argillaceous. The bedding surfaces of the thinly laminated portions of the limestone are made irregular or crenulated by current marks and ripple marks. The largest distinct ripple marks noted by the writer were perfect oscillation or symmetrical ripples 3 inches from crest to crest and three-quarters of an inch deep, which trend about N. 35° E. Some of the largest and most perfect ripples have minor intermediate crests. Thin layers, less than 1 inch thick, of pale-greenish gray gritty calcareous shale separate some of the limestone beds. A thin section of a sample of this shale examined by the writer consists chiefly of clay crystals and subordinately of carbonates and angular quartz silt grains from 0.015 to 0.040 millimeter in diameter. Some massive beds of limestone contain small pebbles of this shale from 5 to 15 millimeters in diameter.

The 40 feet of rocks that overlie these basal beds are exposed in many places along the Mississippi River bluffs south and southeast of Dogtown Hollow. (See pl. 8*A*.) They are similar to the underlying beds but are in part softer; where weathered, they are more thinly and irregularly laminated in layers a few inches or even less than 1 inch thick and in part interlaminated with and gradational into more massive, brown, somewhat dolomitic layers. The layers of greenish calcareous shale are more abundant and thicker than those in the lower beds. Gray and brown dense chert is locally common, and the bedding of some of the layers of limestone is contorted. Pebbles and boulders of limestone in a limestone matrix and suboolitic or fragmental limestone occur locally but are much less common than in the higher beds of the formation.

Above these lower rather soft beds and about 100 feet above the base of the formation is a persistent very hard and massive bed or unit of beds from 25 to 35 feet thick that forms a steep cliff at most of its outcrops. Locally this unit contains layers of thin-bedded ripple-marked limestone, greenish shale, and brown dolomitic beds but for the most part it is light buffy gray, massive, dense to fine-grained, and more or less oolitic and conglomeratic limestone. The conglomeratic fragments of limestone are local and irregular in their distribution and apparently more abundant in the northern exposures near the Cap au Grès flexure. These fragments are commonly somewhat rounded and less than 3 inches in diameter, but much larger angular boulders up to 4 or 6 feet in diameter may be seen at several exposures. At a few localities the suboolitic or fragmental limestone is cross-bedded. In places the limestone is stylolitic, and joint surfaces in it are covered with small crystals of pyrite. Small nodules and nodular beds of brown chert occur sparingly in nearly every exposure.

The softer beds overlying this hard massive conglomeratic limestone are not continuously exposed and cannot be traced from one exposure to another in Calhoun County. They appear to consist dominantly of rather thin-bedded, dense, buffy gray limestone like that in the lower part of the formation but locally the highest beds of the formation are crystalline to dense, somewhat cherty, oolitic, and conglomeratic gray limestone that is mottled with purple, red, or green.

The exposures of St. Louis limestone in southwestern Jersey County are more difficult to correlate with one another than those in Calhoun County. The general character of the rocks is similar to that in Calhoun County, but beds of conglomeratic and oolitic limestone are thicker and more abundant throughout the formation, and very sandy limestone is present in the upper 15 or 20 feet of the formation.

Dense pale buffy gray limestone that breaks with a conchoidal fracture is the most common lithologic type in the Jersey County exposures (see pl. 9*A*), but thin irregularly bedded layers, some of which show north-south oscillation ripples, occur in some exposures and nodules of brown chert are abundant in some layers. There are at least two and probably three or more horizons at which conglomeratic limestone occurs locally. (See pl. 9*B*.) In these conglomeratic beds angular pebbles and boulders of dense limestone are set in a granular clastic limestone matrix which in most places is massive but in some exposures is well bedded. The oolitic beds contain relatively few perfect spherules; the grains are made up largely of somewhat angular fragments of limestone coated with a thin layer of calcite.

The upper sandy strata are exceedingly variable in their lithologic character. Locally as in the NW¼SE¼ sec. 9 and the NE¼NW¼ sec. 14, T. 6 N., R. 13 W., beds of pure sandstone are interlaminated with sandy limestone. Elsewhere sand grains are not common; the rock is conglomeratic, oolitic, and made up largely of small fragments of limestone, or it is a hard dense limestone. In a few places the clastic limestones are irregularly cross-bedded with many of the oblique laminations dipping northward. These sandy and oolitic beds vary greatly in their color; though commonly brownish to very light gray, they are locally red or mottled green and brown. (See pl. 8*B*.)

In the samples examined by the writer the sand grains in these upper beds of the St. Louis limestone (pl. 8*C*) are of two distinct sizes: angular grains of fine sand from 0.05 to 0.15 millimeter in diameter and well-rounded grains of medium and coarse sand from 0.25 to 0.75 millimeter in diameter. The coarser sand consists almost entirely of quartz and chert; but the finer sand, though chiefly quartz, contains numerous angular and rounded grains of orthoclase, zircon, garnet, hornblende, tourmaline, and ilmenite(?) These minerals from igneous and metamorphic rocks, although not abundant, are certainly much commoner in the St. Louis limestone than in any of the earlier Paleozoic formations of this region. Hence their presence suggests that some new source began to contribute sediments to the region during the deposition of the St. Louis limestone. However until careful studies have been made of the mineralogical peculiarities of each of the land areas that might have contributed to these seas, it is hazardous to guess what geographical changes were taking place at that time. The quartz grains are commonly very murky and are filled with small inclusions and bubbles and with needles of rutile.

The oolitic and fragmental limestone associated with these sandy beds seems almost always to contain some grains of quartz sand but the rock consists chiefly of small rounded fragments of limestone, most of which are about one-half millimeter in diameter, though the size ranges through wide limits. Perfect spherules or oolite grains make up only a small part of the rock, for most of the fragments are somewhat angular and covered by a thin film of dense calcite. The more perfect spherules have rounded nuclei of clear calcite or dense limestone. Locally these fragmental limestones contain angular fragments of white chert.

No beds of sandstone like those in the upper part of the St. Louis limestone in Jersey County were found by the writer in Calhoun County, but Weller[58] reported that, at the time of his field work in the area, a light-gray or nearly white highly calcareous sandstone, which he tentatively referred to the Rosiclare sandstone member of the Ste. Genevieve limestone, was exposed in an old quarry "in the rim of a large sink-hole just north of the Beechville post office." On the west side of Mississippi River, in Lincoln County, Mo., the writer found fine-grained brown and green sandstone and gray oolite in several exposures of the upper part of the beds here referred to the St. Louis limestone.

Chemical analysis of a sample (p. 157) of St. Louis limestone, collected by T. B. Root and assistant from the 39 feet of rocks that underlie the hard massive bed in the quarry face in the NE¼SW¼ sec. 6, T. 14 S., R. 1 W., Calhoun County, indicates that the limestone consists of about 96 percent of fairly pure calcite. The impurities are almost entirely quartz and clay. (See pp. 16–17.) Physical tests (p. 157) of this sample indicate that the limestone is dense and more resistant to abrasion than most of the other limestones of the area.[59]

Partial analyses of 64 samples of St. Louis limestone from St. Louis County, Mo.,[60] indicate that the composition of individual beds ranges through wide limits above and below the average composition. Some layers are highly dolomitic; others contain large percentages of insoluble matter—silica and alumina.

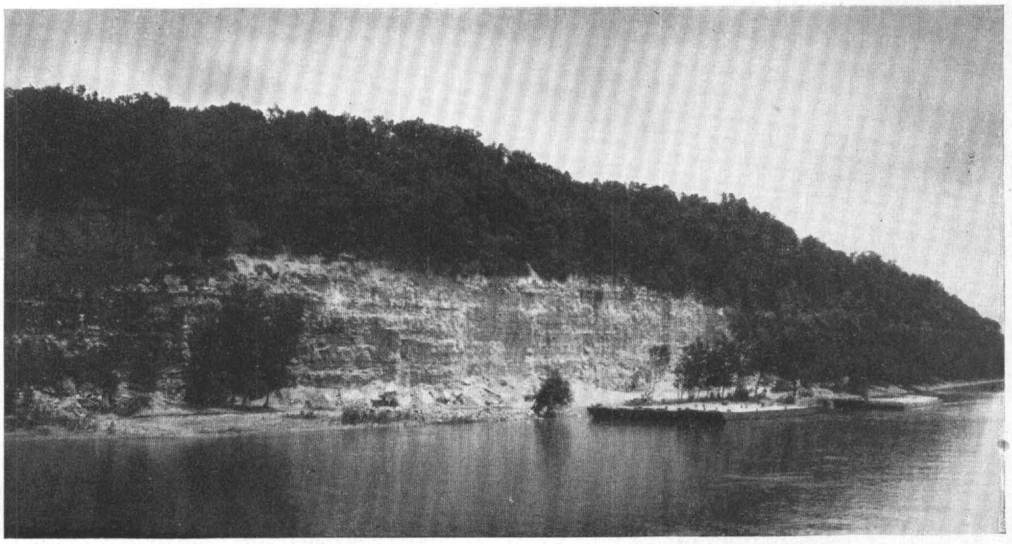
At present the St. Louis limestone is one of the leading mineral resources of the area. This limestone and the Burlington limestone are quarried more extensively than any other formations in the region. Several large quarries in southern Calhoun County along Mississippi River are furnishing St. Louis limestone for rip-rap in river control work.

Stratigraphic relations.—In good exposures the lower limit of the St. Louis limestone is distinct but, where partially covered, the beds of fine-grained gray lime-

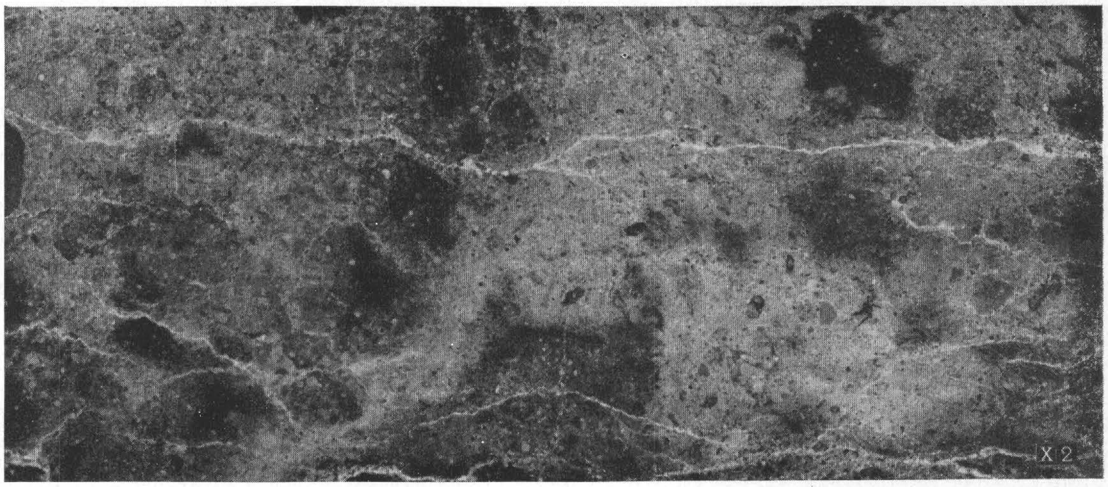
[58] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, pp. 228–229, 1907.

[59] Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, p. 31, 1925.

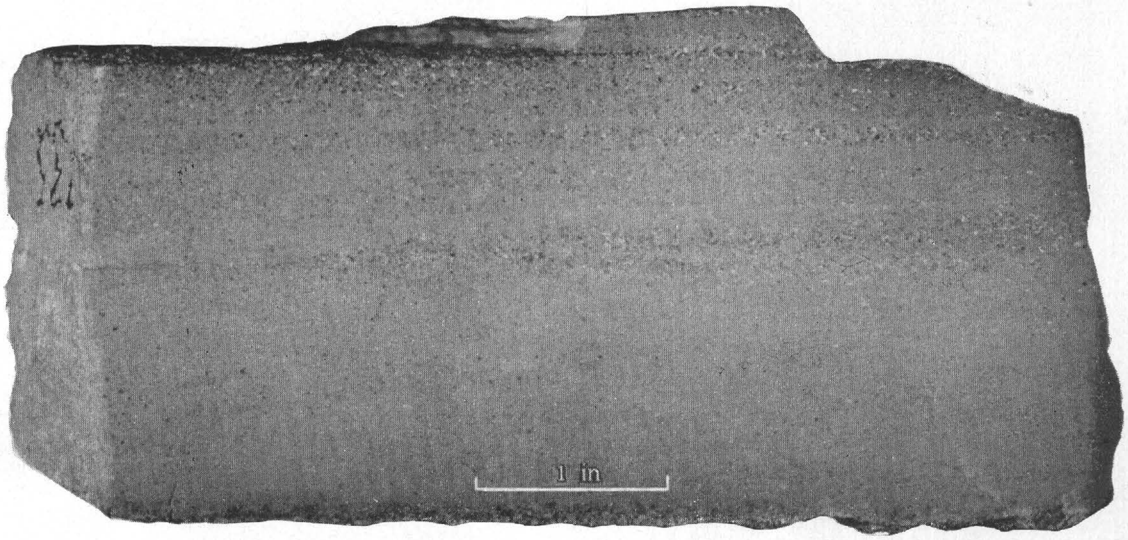
[60] Ladd, G. E., The clay, stone, lime, and sand industries of St. Louis City and County: Missouri Geol. Survey Bull. 3, pp. 76–77, 1890. In part, also republished in Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geol. and Mines, 2d ser., vol. 2, pp. 309–310, 1904; and in Buehler, H. A., The lime and cement resources of Missouri: Missouri Bur. Geol. and Mines, 2d ser., vol. 6, pp. 237–239, [1907.]



A. QUARRY ALONG MISSISSIPPI RIVER IN ST. LOUIS LIMESTONE.
NW¼NW¼ sec. 27, T. 13 S., R. 2 W.



B. MOTTLED CLASTIC LIMESTONE IN UPPER PART OF ST. LOUIS LIMESTONE.
SE¼SE¼ sec. 9, T. 6 N., R. 13 W. Enlarged 2 times.



C. SANDY LIMESTONE AT TOP OF ST. LOUIS LIMESTONE.
Obscurely cross-bedded. NW¼SE¼ sec. 9, T. 6 N., R. 13 W. Natural scale (no enlargement).

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A. ST. LOUIS LIMESTONE DIPPING 26° SOUTHWARD.
NW¼SE¼ sec. 9, T. 6 N., R. 13 W.

B. CONGLOMERATIC BEDS IN ST. LOUIS LIMESTONE.
NW¼SE¼ sec. 9, T. 6 N., R. 13 W.

stone that are interlaminated in the upper part of the Spergen limestone seem to be completely gradational into the St. Louis. In the exposures just south of Dogtown Landing and those in the NE¼ sec. 33, T. 12 S., R. 2 W., the basal beds of the St. Louis limestone are coarsely conglomeratic and hence suggestive of unconformable relations.

The conglomeratic or brecciated layers in the St. Louis limestone have been the subject of much discussion, and many very diverse theories have been proposed to account for their origin.[61] These discussions demonstrate that the names, "breccia" and "conglomerate," have meant many things to many writers. Some of the proposed explanations are clearly inapplicable to the conglomeratic layers in the Brussels quadrangle. Excluding those fragmented portions of the limestone that are obviously related to talus and sinkhole accumulations, to jointing, and to faulting and folding, the remaining true conglomerates are obviously depositional features. However, it is not known whether these conglomerates represent subaerial erosion caused by withdrawal of the sea, or wave erosion on the sea floor, or subaqueous gliding.

If these pebbles and boulders of limestone are taken as evidence of an unconformity, then at least two and probably more than three unconformities should be drawn within the limits here used for the St. Louis limestone. The layers of conglomeratic limestone vary greatly within short distances in the amount of pebbles and boulders that they contain and, except for the basal one, these conglomeratic layers are not sharply defined below. The fragmental, oolitic, and sandy limestones and the ripple marks and cross-bedding indicate that much of the St. Louis limestone was laid down in shallow water. It therefore does not seem essential to the writer that each of the irregular conglomeratic layers must have been formed as the result of an actual emergence of the area above sea level. Instead it seems possible that they may have been formed on the floor of a shallow sea by local warping, by storm waves, or by submarine slides. Whichever explanation is adopted as most probable, it seems that the folding and uplift that followed the Mississippian and preceded the Pennsylvanian deposition (p. 145; fig. 3 *B*, *C*) was well started by the time the St. Louis limestone was being laid down.

However, no evidence of unconformable relations between the uppermost sandy beds and the rest of the formation was noted. In fact, where best exposed, the sandy beds seem to be completely transitional into the underlying limestone.

The evidence bearing on the stratigraphic relations within the series of strata here referred to the St. Louis limestone is thus somewhat contradictory, but the contact between these rocks and the overlying Pennsylvanian beds is clearly marked by one of the most conspicuous unconformities in the entire stratigraphic section in this region.

Fossils.—Well preserved organic remains are not common in the St. Louis limestone. Bryozoans seem to be the most common fossils but in some layers brachiopods, crinoid stems, and several kinds of corals may be found. (See p. 172–173.) The compound coral *Lithostrotion canadensis* is locally abundant in the lower part of the formation.

Name.—The St. Louis limestone was named by Engelmann [62] in 1847. Worthen [63] in his reports on the geology of Jersey, Greene, and Calhoun counties, included the underlying Spergen limestone in the beds which he referred to the St. Louis limestone. He also mistook an exposure of St. Louis limestone near Brussels for beds in the lower part of the Kinderhook group.[64] Weller [65] recognized the Spergen limestone as a separate formation below the St. Louis limestone, and he tentatively referred the upper beds of sandstone to the Rosiclare sandstone [66] member of the Ste. Genevieve limestone.[67]

The Ste. Genevieve limestone has been recognized by Weller [68] at Alton, Ill., 16 miles east of the Brussels quadrangle. Its lithologic character there and elsewhere [69] is similar to that of some of the beds in the Brussels quadrangle. It therefore seemed not unlikely that the upper part of the St. Louis limestone in the Brussels quadrangle might really be part of the Ste. Genevieve limestone. However, Dr. J. M. Weller reports that none of the fossils collected by the writer in these uppermost beds (Colls. 93, 104, 105, 111, 112, 184b, 193, and 194) are characteristic of the Ste. Genevieve, and the entire unit is therefore referred to the St. Louis limestone.

CARBONIFEROUS (PENNSYLVANIAN SERIES)

The Pennsylvanian rocks of the Hardin and Brussels quadrangles consist of shale, clay, sandstone, limestone,

[61] Gordon, C. H., On the brecciated character of the St. Louis limestone: Amer. Naturalist, vol. 24, pp. 305–313, 1890. Van Tuyl, F. M., Brecciation effects in the St. Louis limestone (abstract): Geol. Soc. America Bull., vol. 27, pp. 122–124, 1916. Morse, W. C., The origin of the coarse breccia in the St. Louis limestone: Science, new ser., vol. 43, pp. 399–400, 1916. Grawe, O. R., Some breccias of the St. Louis formation in the St. Louis, Missouri, region: Washington Univ. [St. Louis] Studies, vol. 13, pp. 45–62, 1925.

[62] Engelmann, George, Remarks on the St. Louis limestone: Amer. Jour. Sci., 2d ser., vol. 3, pp. 119–120, 1847.

[63] Worthen, A. H., Geology and paleontology, Illinois: Illinois Geol. Survey vol. 3, pp. 111–112, 127–128, 1868; idem, vol. 4, p. 15, 1870.

[64] Worthen, A. H., op. cit., vol. 4, pp. 11–12.

[65] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, pp. 228–229, 1907.

[66] Ulrich, E. O., and Smith, W. S. T., The lead, zinc, and fluorspar deposits of western Kentucky: U. S. Geol. Survey Prof. Paper 36, p. 40, 1905.

[67] Shumard, B. F., Observations on the geology of the County of Ste. Genevieve: St. Louis Acad. Sci. Trans., vol. 1, p. 406, 1859.

[68] Weller, Stuart, The Mississippian Brachiopoda of the Mississippi Valley Basin: Illinois Geol. Survey Mon. 1, p. 22, 1914. Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 22, p. 183, 1928.

[69] Weller and St. Clair, op. cit., pp. 219–221. Lamar, J. E., The oolite of the Ste. Genevieve formation: Illinois Geol. Survey Rept. Inv. no. 10, pp. 409–413, 1926.

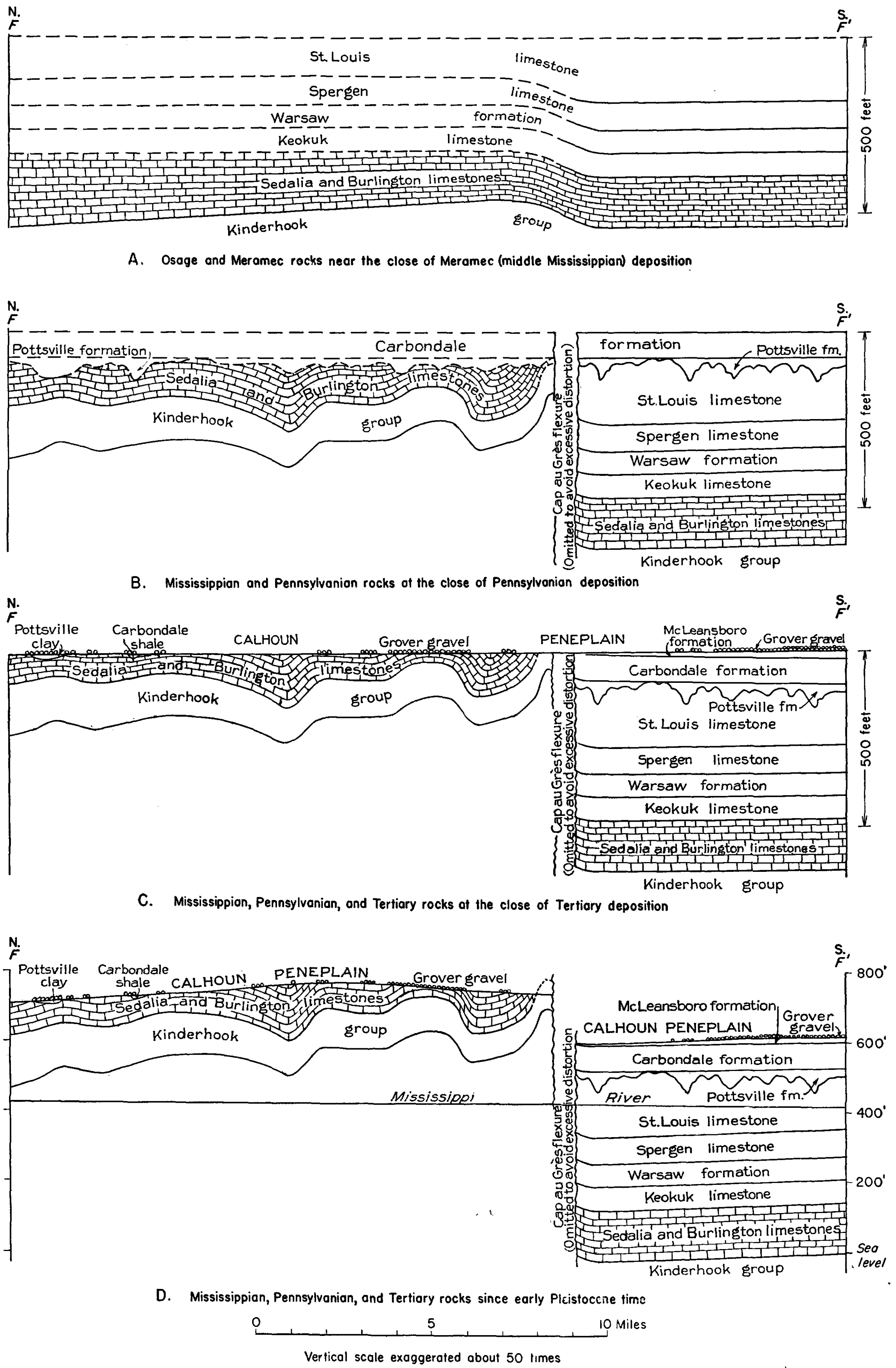


FIGURE 3.—Generalized cross sections along line shown in figure 14 showing approximate structural relations.

and coal, listed in the order of their relative abundance. These different kinds of rocks occur in many thin, fairly persistent beds that have been grouped together into three rather comprehensive formations—the Pottsville at the base, the Carbondale in the middle, and the McLeansboro at the top. These formations cover a fairly wide area in the Brussels quadrangle south of the Cap au Grès flexure, but they are restricted to small remnants on the uplands in the Hardin quadrangle.

In southern Calhoun County where the Pennsylvanian rocks are most continuously exposed they lie upon the St. Louis limestone, and their thickness increases very irregularly southwestward from less than 70 to more than 200 feet. Throughout most of this southern area the Pennsylvanian rocks are between 100 and 125 feet thick. Before erosion these beds may have been several hundred feet thicker than they are now. Most of the present irregularity in thickness is caused by a pronounced erosional unconformity at the base of the series.

Traced westward from this area across Missouri [70] and eastward to central Illinois,[71] the Pennsylvanian rocks thicken notably both by interlamination of strata and by the presence of successively older beds at the base. This thickening indicates that this area, like the Ozark Highlands to the southwest, remained longer and emerged more often above stream and sea level than the coal basins to the west and to the east.

Yet it seems reasonably certain, from the continuous outcrops of Pennsylvanian rocks only a few miles northeast of the Hardin quadrangle and from the recognition of small remnants of these rocks in depressions or sinkholes in northern Calhoun County, Ill., and in Lincoln County, Mo., that Pennsylvanian strata were once much more widespread in the Hardin and Brussels quadrangles than they are now and that they then overlapped northward from the Troy-Brussels syncline onto the older Mississippian formations on the Lincoln anticline. (See pl. 2; and fig. 14.) The implications of this relationship seem clear. Although it is not known whether the Ste. Genevieve limestone or any of the overlying Chester formations was once present in the area, it seems certain that, some time after or perhaps during the deposition of the St. Louis limestone and before the Pennsylvanian formations were laid down, the region immediately north of the Cap au Grès flexure, essentially the present Lincoln anticline, was sharply folded and uplifted. Streams then cut deeply into the limestone uplands, removing at least locally a thickness of 400 feet or more of the Burlington, Keokuk, Warsaw, Spergen, and St. Louis formations. At this time streams also cut narrow gorges in the southern part of the area below a flat tableland that had developed or remained upon the upper surface of the St. Louis limestone. However, the quantity of rock removed from the southern synclinal area was much less than that removed from the northern anticlinal area. This work of erosion was eventually halted by a change to conditions of deposition and the Pennsylvanian continental and marine sediments were laid down. These Pennsylvanian sediments very probably were deposited over the entire area, for, not only are there scattered remnants still on the upland north of the Cap au Grès flexure, but, furthermore, if high limestone uplands and bluffs had remained above stream and sea level, the Pennsylvanian sediments immediately south of the flexure should now contain many large boulders of limestone and chert and the Pennsylvanian limestones should be far less pure than they are. Since the time of the Pennsylvanian deposition, the Lincoln anticline has been subjected to other and smaller uplifts and to long-continued erosion, until at present all but a few relatively small remnants of the Pennsylvanian deposits have been removed from the area north of the Cap au Grès flexure.

[70] Knight, J. B., The Pennsylvanian outlier of St. Louis, Missouri, and its corrrelations [abstract]: Geol. Soc. America Bull., vol. 40, no. 1, p. 190, 1929. Weller, J. M., Cyclical sedimentation of the Pennsylvanian period and its significance: Jour. Geology, vol. 38, p. 109, 1930.

[71] Henbest, L. G., Pre-Pennsylvanian surface west of the Duquoin anticline: Ill. Acad. Sci. Trans., vol. 20, pp. 265–268, 1928.

Generalized section of Pennsylvanian strata

	Feet
Unconformity.	
McLeansboro formation (about 28 feet).	
12. Limestone, gray; weathers brown. Dense, massive, fossiliferous. Forms a prominent ledge	5+
11. Calcareous clay, pale-buff	15±
10. Limestone, dark-gray. Dense, massive below, thin-bedded above, fossiliferous. Somewhat conglomeratic	8±
Carbondale formation (65–90 feet).	
9. Calcareous clay, pale greenish gray with thin carbonaceous zones at top and bottom. Contains irregular masses of white calcareous powder	4–12+
8. Limestone, light-gray. Fine-grained, massive below, nodular above. Somewhat conglomeratic. Weathers to an irregular knobby surface and forms a prominent ledge	6±
7. "Fire" clay, pale-gray to white, mottled with yellow, brown, red, maroon, and purple and with thin carbonaceous zone at top	3–15
6. Shale and siltstone, sandy, micaceous. Greenish to buffy gray, brown, and maroon. Noncalcareous, platy to massive. Grades laterally into very fine grained argillaceous sandstone	50±
5. "Bony coal" or "roof slate". Hard black laminated shale or very argillaceous coal. Locally pyritic, fossiliferous, and with ferruginous nodules and layers of dense gray limestone less than 1 inch thick	up to 4
4. Coal, locally with a parting of clay shale and ferruginous concretions near top	up to 3
Pottsville formation (0–85+ feet, commonly 10–35).	
3. "Fire" clay, gray to white. Locally pyritic and contains concretionary masses of pisolitic or phosphatic limestone near top. On uplands of central and northern Calhoun County is interlaminated with lenses of hard, nonplastic, somewhat carbonaceous "flint" clay	0–12+

Generalized section of Pennsylvanian strata—Continued

Pottsville formation—Continued	
2. Sandy clay, dark shale, and argillaceous sandstone Poorly exposed	0–12+
1. Sandstone, locally conglomeratic and cross-bedded	0–20+
Unconformity.	

The most completely exposed section of Pennsylvania rocks found within the area is in the north center section 1, T. 14 S., R. 2 W., and extends from the open pit at the old Winneberger or Golden Eagle brick plant northeastward up an old road nearly to the upland.

		Feet
	Covered.	
12	Limestone, heavy ledges, dense, massive. Medium to dark gray where fresh, weathers brown on and for some distance from surface. Fragments of fossils on weathered surface	5±
11 (b)	Covered	8
11 (a)	Calcareous clay, massive, somewhat plastic, slightly gritty. Pale buffy gray with some maroon beds	7
10 (c)	Limestone, mottled with irregular patches of very pale buffy gray fine-grained limestone in a denser darker-gray limestone matrix. Denser and darker colored above. No chert. Irregular weathering surface	3. 2
10 (b)	Covered	2. 2
10 (a)	Limestone, massive, fine-grained, medium gray. Large nodules of medium- to light-gray chert, which weathers pale tan. Many crinoids on weathered surface	2. 5
9 (d)	Covered	5
9 (c)	Calcareous clay with soft lumps of chalk(?). Pale gray green below; becomes whiter and chalkier above	3. 5
9 (b)	Calcareous clay, massive, deep-purple. Contains some irregular lumps of white chalk(?) powder	1. 3
9 (a)	Calcareous clay or marl, massive, pale greenish gray	. 4
8	Limestone, mottled gray and tan. Lower part makes heavy massive ledge. Upper 2 feet consists entirely of limestone nubbins. Some light-tan chert. Fossils—*Productus, Spirifer*, crinoids, bryozoans	5
7 (b)	Covered	11
7 (a)	Clay, massive, bright ochre below, white streaked with bright red above	4
6 (b)	Siltstone and shale, massive to platy below, platy to fissile above. Gray, buffy-gray, and greenish-gray below, mottled greenish and maroon above. Very slightly gritty, noncalcareous, nonplastic	34
6 (a)	Covered	12
5 (b)	Ferruginous concretions in poorly exposed shale	1
5 (a)	Fissile shale, buff to gray	1. 9
4 or 5 (c)	Coal	. 3
(b)	Sandstone and clay, highly ferruginous	1. 1
(a)	Shale, fissile black, noncalcareous, plastic	. 5
4	Coal	2. 1
3 (b)	Clay, massive, noncalcareous, gray with yellow stains	2. 4
3 (a)	Covered.	

Some of these rocks, especially those of marine origin, are highly fossiliferous and the faunas of these Pennsylvanian formations are probably less perfectly represented by the small number of collections made by the writer and assistant than are those of any other formations in the area. These collections were studied by Dr. J. M. Weller and supplemented by his own collections made in 1930. His reports are given in tabular form. (See p. 173.)

POTTSVILLE FORMATION

The Mississippian rocks are overlain unconformably by the Pottsville formation, a variable unit composed chiefly of clay, sandstone, and shale. This formation comes to the surface over a wide area in southern Calhoun County south of the Cap au Grès flexure, but it is very soft and is not well exposed anywhere. No exposures of the Pottsville were found in southwestern Jersey County, but well records indicate that it may be present there south of the flexure at shallow depths. A few isolated outcrops on the uplands of Calhoun County, north of the flexure—clay in secs. 8 and 17, T. 10 S., R 2 W., Hardin quadrangle, and secs. 6, T. 8 S., R 3 W., and 1, T. 8 S., R. 4 W., Nebo quadrangle; and sandstone associated with Carbondale shale in sec. 23, T. 8 S., R. 3 W., Pearl quadrangle—are believed to be beds of the Pottsville formation.

Thickness.—In southern Calhoun County, where the Pottsville formation is best developed, its thickness ranges from more than 85 feet to a feather edge. In this region the normal thickness appears to increase very irregularly westward or southwestward from about 10 feet to about 35 feet, but in several places the formation cuts down steeply into the St. Louis limestone and reaches thicknesses of 50 to 85 or more feet. In central and northern Calhoun County the Pottsville seems to be very local in its distribution, but in a few places it attains thicknesses of at least 15 feet.

Lithologic character.—Except in the local depressions where its thickness is greatest, the Pottsville formation seems to consist dominantly of fire clay—the underclay of the No. 2 coal. In southern Calhoun County, thicknesses of 5, 8, and even 12 feet of this clay are exposed in many places. In fresh exposures the clay is gray, massive, slightly calcareous, and locally pyritic, but where weathered it is white with yellow and red stains and very soft and plastic. In the exposures on the uplands north of the Cap au Grès flexure this regularly stratified soft plastic clay is either interlaminated with or else both overlies and underlies lenticular masses of a harder, somewhat darker gray, nonplastic "flint" clay.

Thin sections cut from 12 samples of these clays collected by the writer in the Hardin and Brussels quadrangles and by J. E. Lamar in northern Calhoun County were examined by C. S. Ross and the writer. These thin sections seem to show that the plastic fire clays of both the northern and southern areas are made up of large crystals of the clay mineral beidellite with a few scattered sand grains and that the hard flint clays of the northern uplands consist of very finely crystalline kaolin and halloysite. A small amount of diaspore was recognized as a minor constituent of one sample of the kaolin or flint clay from sec. 6, T. 8 S., R. 3 W.

Perhaps the most striking characteristic of the beidellite or fire clay samples is the presence of highly angular sand and silt grains that are commonly from 0.025 to 0.165 millimeter in diameter and average about 0.070 millimeter. These grains are dominantly angular fragments and slivers of quartz, but they also include many partially decomposed grains of orthoclase and a few crystals of muscovite, zircon, and apatite. The presence of the undecomposed grains of feldspar indicates that although the clay may have been formed partly by residual weathering and thorough decomposition in place, as commonly supposed, it also contains significant amounts of unweathered material.

In several places in southern Calhoun County the fire clay contains a discontinuous bed of nodular or concretionary limestone a few feet below the top of the formation. Locally these nodules or concretions have a pisolitic or spherulitic structure on weathered surfaces. A fragment of this concretionary pisolitic limestone collected from a mine dump in sec. 1, T. 14 S., R. 2 W., was examined microscopically in the expectation that the rock might contain the mineral diaspore. However no diaspore was found and the rock seems to consist entirely of calcite with a lesser amount of clay and scattered pyrite crystals and sand grains. At other places, as for example in the SW¼NE¼ sec. 26, T. 13 S., R. 2 W., these nodules of argillaceous limestone contain subangular pebbles less than 2 inches in diameter of dense black (possibly phosphatic) limestone.

Ceramic tests by the Department of Ceramic Engineering of the University of Illinois of several samples from the Hardin and Brussels quadrangles indicate that the fire clay is refractory and might be of commercial value for several purposes. (See pp. 158–160.) These clays give promise of becoming one of the most important mineral resources of the area.

Where the clay lies directly upon the Mississippian limestones, as in the local deposits on the uplands in the SW¼ sec. 6, T. 8 S., R. 3 W., and the SE¼SE¼ sec. 8, T. 10 S., R. 2 W., it is somewhat intermixed in its lower portion with accumulations of residual chert.

In several places in southern Calhoun County where the Pottsville formation is thickest, the clay is underlain by sandstone that fills irregularities in the upper surface of the underlying St. Louis limestone. The sandstone consists almost entirely of rounded quartz grains and sharply angular, secondarily enlarged quartz crystals from 1/6 to 2/3 millimeter in diameter, but magnetite, zircon, garnet, biotite, muscovite, and hornblende are also present. The undecomposed minerals, especially the biotite flakes, seem to show clearly that the land masses from which the basal Pottsville sediments were derived were not everywhere deeply decayed by long-continued weathering, a conclusion that seems consistent with the character of the old pre-Pennsylvanian erosion surface. Minerals from igneous rocks have been reported in Pennsylvanian sandstones in other parts of western Illinois.[72]

Locally, as in sec. 26, T. 13 S., R. 2 W., and in sec. 1, T. 14 S., R. 2 W., this sandstone is conglomeratic and contains rounded pebbles of chert and sandstone 1 inch or less in diameter. In other areas in Illinois the basal sandstone of the Pennsylvanian is reported to be coarsely conglomeratic.[73]

At one locality, at the river level in the center NE¼ sec. 5, T. 14 S., R. 1 W., a thickness of 20 feet or more of cross-bedded sandstone fills a channel only 9 feet wide in the St. Louis limestone. The lowest exposure of this sandstone is 60 feet below the top of the St. Louis limestone scarcely 100 feet away and more than 75 feet below the highest limestone exposures several hundred feet to the west. The narrow channel trends N. 20° E.—approximately at right angles to the Cap au Grès flexure and hence possibly a widened joint crack or fissure—and the cross-bedded laminae dip southward.

Poorly sorted argillaceous sandstone and sandy clay are associated with the clay and the sandstone of the Pottsville formation in many places but, as only partial exposures could be found, the thickness of these beds is unknown. Worthen[74] and Weller[75] report that a thickness of 10 or 12 feet of dark shale separates the clay from the basal sandstone at the old Golden Eagle or Winneberger coal mine and brick plant in sec. 1, T. 14 S., R. 2 W., but at the time of the writer's field work these beds were not exposed.

Stratigraphic and physiographic relations.—The Pottsville formation lies with marked unconformity on the limestones of Mississippian age. In southern Calhoun County the variations in thickness of the formation are a direct measure of the ancient relief on the old erosion surface. Above the hills on this old surface the Pottsville is very thin or even absent, but locally, as in secs. 5, 16, 17, and 21, T. 13 S., R. 2 W., sec. 1, T. 14 S., R. 2 W., and sec. 5, T. 14 S., R. 1 W., it cuts down steeply into the St. Louis limestone and reaches thicknesses of 50 to 85 feet or more. The more northern of these irregularities or depressions, those in secs. 5, 16, and 17, T. 13 S., R. 2 W., are at least partially filled with Pottsville clay, and they may possibly be ancient sinkholes on the old erosion surface. But the more

[72] Poor, R. S., and Willman, H. B., in Weller, J. M., Cyclical sedimentation of the Pennsylvanian period and its significance: Jour. Geology vol. 38, pp. 111–112, 1930.

[73] Poor, R. S., The character and significance of the basal conglomerate of the Pennsylvanian system in southern Illinois: Ill. Acad. Sci. Trans., vol. 18, pp. 371–374, 1925.

[74] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey vol. 4, p. 16, 1870.

[75] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 230, 1907.

southern depressions contain sandstone which is locally cross-bedded and these seem clearly to represent stream channels on the pre-Pennsylvanian surface.

The exact contact between the Pottsville formation and the St. Louis limestone is not sufficiently well-exposed in this area to permit the construction of an accurate map of the topography of this pre-Pennsylvanian erosion surface. However, the scattered exposures indicate that this surface is a relatively flat tableland and that the irregularities on it are narrow elongated depressions that seem to deepen southward and westward in a manner that strongly suggests that they were once converging stream courses.

In southern Calhoun County the bedding in the Pennsylvanian formations lies very nearly parallel to that of the underlying Mississippian limestone; in fact, the upper contact of the Pottsville formation seems to be approximately 40 feet above the top of the hard massive brecciated bed in the St. Louis limestone throughout this area. However, in middle and northern Calhoun County the Pennsylvanian overlaps onto older formations and the local deposits of Pottsville and Carbondale on the uplands lie upon the Burlington limestone or in depressions in its upper surface. McQueen [76] has reported similar occurrences of high alumina clay "in depressions in the chert conglomerate marking the base of the Pennsylvanian series" in central Lincoln County and farther south in Missouri.

No beds of undoubted marine origin were found in the Pottsville formation in this area, and, so far as the evidence goes, the sandstone and the clay may all have been laid down upon the land. Yet the basal sandstone contains some mineral grains that must originally have come from a distant source. Judged by the composition of these minerals and by the probable direction of land slopes suggested by the local thickening of Pennsylvania sediments and the possible drainage pattern then, it seems very unlikely that the igneous rocks of the nearby Ozark Highlands could have been a competent source. These minerals conceivably might have been swept by marine longshore currents directly from some more distant source into the area, but this possibility does not accord well with the topography of the old pre-Pennsylvanian surface. The sandy beds in the upper part of the St. Louis limestone seem to be the only rocks now left in the immediate vicinity that might have contributed the minerals. (See p. 50.) They may therefore have been deposited first in the St. Louis limestone or possibly in the Ste. Genevieve limestone or overlying Chester rocks [77] by marine currents and later reworked by weathering and streams into the basal Pennsylvanian clay and sandstone.

Whether or not the Pottsville formation is made up entirely of continental deposits in this area, the thickness of the formation varies systematically so as almost exactly to fill all irregularities in the old erosion surface before the accumulation of the overlying coal. The striking relationship may be no more than accidental, but it suggests that conditions were not suitable for the formation of coal until the region had been silted up to a nearly level plain of deposition.

The contact between the top of the Pottsville formation and the coal bed at the base of the Carbondale formation is apparently conformable.

Fossils.—In many places in southern Calhoun County the clay beds in the Pottsville formation contain poorly preserved plant remains that consist chiefly of fragments of roots known as *Stigmaria.* No other fossils were found in the formation.

Two collections of these plant remains were made from somewhat carbonaceous "flint" clays on the uplands in northern and central Calhoun County. These collections were studied by Dr. David White and reported on as follows:

Lot 74, collected at the Guthrie clay pits, SW¼ sec. 6, T. 8 S., R. 3 W., includes—

Stigmaria verrucosa, detached scars.
Cardiocarpon sp.
Asterophyllites? leaf fragments.
Megaspores of some lepidophyte.

Lot 183, from the SE¼SE¼ sec. 8, T. 10 S., R. 2 W., has comminuted and generally much macerated plant fragments in silts. I am able to identify only—

Stigmaria verrucosa.
Scraps of roots.

This material is Carboniferous. There is little doubt as to its Pennsylvanian age; it is probable that the deposit is of Pottsville date.

Name and members.—The name Pottsville was first used in Pennsylvania [78] and later applied to the lower part of the Pennsylvanian rocks of Illinois by David White.[79] For convenience the upper limit of the Pottsville formation in Illinois has in recent years been drawn more or less arbitrarily [80] at the base of the Murphysboro (No. 2) coal in some reports and in other reports at the base of the underlying clay bed. The name is here applied to the rocks in the Hardin and Brussels quadrangles on the advice of Drs. David White and J. M. Weller, both of whom visited the writer in the field and examined some of the exposures.

[76] McQueen, H. S., Geologic relations of the diaspore and flint fire clays of Missouri: Amer. Ceramic Soc. Bull., vol. 12, pp. 696–697, 1929.

[77] Lamar, J. E., Sedimentary analysis of limestones of the Chester series: Econ. Geology, vol. 21, pp. 583–584, 1926.

[78] Platt, W. G., and Platt, F., Report of progress in the Cambria and Somerset district of the bituminous coal fields of western Pennsylvania; Part 1, Cambria: 2d Geol. Survey Pa., Rept. 1875, p. 26, 1877.

[79] White, David, Report of the field work in the coal districts of the State: Illinois Geol. Survey Bull. 4, pp. 201–203, 1907; Report on field work done in 1907: Idem, Bull. 8, pp. 268–272, 1908; Paleobotanical work in Illinois in 1908: Idem, Bull. 14, pp. 293–295, 1910. De Wolf, F. W., Studies of Illinois coal: Illinois Geol. Survey, Bull. 16, p. 180, 1910.

[80] Culver, H. E., Coal resources of District III (Western Illinois): Illinois Geol. Survey Cooperative Min. Ser., Bull. 29, p. 16, 1925. Wanless, H. R., Geology and mineral resources of the Alexis quadrangle: Illinois Geol. Survey Bull. 57, pp. 47–48, 1929.

The Pottsville formation of Illinois has been correlated [81] with the lower part of the Cherokee shale [82] of Missouri and Kansas and the clay at the top of the Pottsville with [83] the Cheltenham clay bed [84] of St. Louis County, Mo. The sandstone in the lower part of the Pottsville formation is probably the same as the "Ferruginous Sandstone," which Potter [85] recognized in Lincoln County, Mo.

CARBONDALE FORMATION

The Pottsville formation is overlain conformably by a unit of shale, clay, limestone, and coal, which makes up the Carbondale formation. The Carbondale crops out on hill slopes below the uplands in southern Calhoun County, in a small area in southwestern Jersey County, and in a few small isolated exposures on the uplands north of the Cap au Grès flexure. Like the Pottsville, the Carbondale formation is made up largely of soft and unresistant rocks but because it contains thin beds of hard limestone in its upper part and is overlain by other limestones it is commonly much better exposed than the Pottsville.

Where overlain by the McLeansboro formation in southern Calhoun County, the Carbondale ranges from 65 to 90 feet thick, apparently becoming thicker southwestward. According to D. M. Collingwood,[86] the formation again thickens gradually northward and eastward from southwestern Jersey County.

The Carbondale formation is made up of several persistent members. Listed in their stratigraphic order, these are (1) a basal thin coal bed from a few inches to nearly 3 feet thick, (2) sandy shale and siltstone approximately 50 feet thick, (3) fire clay about 3 to about 15 feet thick, (4) limestone about 6 feet thick, and (5) an uppermost member of calcareous clay from 4 to 12 feet thick.

Coal.—The basal coal bed is the only coal of commercial value in the area. It crops out at an elevation of about 520 feet at numerous places on the west side, and at a few places on the east side, of the divide in southern Calhoun County. It is near the surface, and it may actually crop out in the SE¼SE¼ sec. 9, T. 6 N., R. 13 W., Jersey County. In a nearby well in the NE¼NW¼ sec. 15, T. 6 N., R. 13 W., it is reported at a depth of 24 feet. No exposures of the coal were found north of the Cap au Grès flexure, but there are persistent reports by residents of the area of small pockets of coal on the upland somewhere on St. Andrew Ridge in T. 7 N., R. 13 W. Although not verified, this report is made plausible by the local occurrence of Pottsville and Carbondale clay and shale on the upland in Calhoun County and by the presence of coal in sinkholes in limestones of the Osage group in Lincoln County, Mo.[87]

The coal apparently becomes thicker southwestward and reaches its maximum thickness of 30 inches or slightly more in secs. 15, 22, and 27, T. 13 S., R. 2 W. Northward and eastward the bed is either thinner or else so divided by partings of dark clay shale in its upper part that it appears thinner. Exposures and scattered well records indicate that north of sec. 9, T. 13 S., R. 2 W., and east of sec. 32, T. 13 S., R. 1 W., there is less than 1 foot of pure coal.

Proximate analysis (p. 161) of a sample collected from an old prospect pit in the center SW¼NW¼ sec. 26, T. 13 S., R. 2 W., indicates that the coal is of good quality. Analyses published by earlier writers [88] show that the coal formerly mined in sec. 1, T. 14 S., R. 2 W., is of similar character. This mine, which is now abandoned, is the only large-scale development of the coal ever attempted in the region. The coal was mined for firing the excellent brick made there from the Pottsville and Carbondale clays.

The black laminated shale or "roof slate" that immediately overlies the coal is more appropriately considered as part of the coal member than of the overlying sandy siltstone. This rock, which ranges from a few inches to nearly 4 feet thick and apparently thickens southwestward, consists of highly carbonaceous clay or very argillaceous coal—the "bony coal" of some miners—and thin layers of dense gray limestone less than 1 inch thick which contain small crystals of pyrite and irregular algal(?) markings. Locally the black shale contains small nodules of pyrite and abundant more or less pyritized shells of marine invertebrates (Colls. Nos. 31 and 90, p. 173). At several exposures this black shale contains hard nodules or concretions of highly ferruginous sandy clay from a few inches to more than 1 foot in diameter. A few of the freshest and least weathered of these nodules contain masses of pyrite at their centers. At the old Golden Eagle or Winneberger brick plant these ferruginous concretions occur not only above the coal but also in a parting of clay shale

[81] White, David, in Hinds, H., and Greene, F. C., The stratigraphy of the Pennsylvanian series in Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 13, p. 262, 1915. Hinds and Greene, idem., p. 41. Savage, T. E., Marine invertebrate fossils as horizon markers in the Pennsylvanian rocks of Illinois: Jour. Geology, vol. 32, p. 581, 1924; Significant breaks and overlaps in the Pennsylvanian rocks of Illinois: Amer. Jour. Sci., 5th ser., vol. 14, pp. 315–316, 1927. Knight, J. B., The Pennsylvanian outlier of St. Louis, Mo., and its correlations (abstract): Geol. Soc. America Bull., vol. 40, no. 1, p. 190, 1929. Weller, J. M., personal communication.

[82] Haworth, E., and Kirk, M. Z., The Neosho River section: Kans. Univ. Quart., vol. 2, p. 105, 1894.

[83] Knight, J. B., Op. cit.

[84] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle: U. S. Geol. Survey Bull. 438, pp. 28, 49–53, 1911.

[85] Potter, W. B., Geology of Lincoln County, in Preliminary report on the iron ores and coal fields: Missouri Geol. Survey, pp. 250–253, 1873.

[86] Manuscript report in files of Illinois Geological Survey.

[87] Potter, Op. cit., pp. 258, 263–281.

[88] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, p. 21, 1870. Culver, H. E., Coal resources of District III: Illinois Geol. Survey, Coop. Min. Ser., Bull. 29, p. 23, 1925. Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. of Inv. no. 8, p. 19, 1926.

2 feet thick that separates the lower 25 inches of coal from an upper layer 4 inches thick.

Shale.—The coal and black laminated shale is overlain by the thickest member of the Carbondale formation. This member consists entirely of noncalcareous platy shale, massive sandy siltstone, and soft thin-bedded very fine grained sandstone. The color of these rocks commonly ranges from greenish gray through light buffy gray to deep brown and maroon and in some places, especially in the upper part of the member, they are mottled with green and red. Locally, as in sec. 26, T. 13 S., R. 2 W., the fine-grained argillaceous sandstone makes up nearly all the member. Elsewhere it occurs as thin layers a few inches thick interbedded with the shale and siltstone. This fine-grained sandstone is poorly sorted, and the largest grains are rarely more than one-tenth millimeter in diameter.

Both the siltstone and the sandstone contain numerous small flakes of muscovite, a characteristic that with the maroon colors serves to distinguish these rocks from any others in the region. Hence the micaceous and maroon platy shale found in a depression which seems to be a remnant of a sinkhole in the Burlington limestone in the SE¼ sec. 28, T. 10 S., R. 2 W., is referred with considerable assurance to the Carbondale formation. Somewhat similar siltstone associated with sandstone thought to be part of the Pottsville formation was noted in sec. 23, T. 8 S., R. 3 W.

Chemical analysis of a sample (p. 158) collected from the upper 30 feet of this member of the Carbondale formation in the open pit at the abandoned Golden Eagle or Winneberger brick plant in sec. 1, T. 14 S., R. 2 W., indicates that the rock there consists of more than 80 percent of clay, less than 10 percent of quartz, and a small amount of pyrite and iron oxide. The analysis also indicates that the sample contains 6 percent or less of magnesite and dolomite—an amount much greater than the behavior of the shale with concentrated hydrochloric acid would lead one to estimate. (See pp. 16–17.) In its high percentage of clay and low percentage of quartz the rock is much more similar to the calcareous Maquoketa shale (p. 22) than it is to the quartzose Hannibal shale (p. 38).

Ceramic tests of this sample (pp. 160–161) indicate that the Carbondale, like the Hannibal shale, might be used for the manufacture of some kinds of brick and tile. In fact, the shale was formerly quarried at the pit from which this sample was taken and mixed with the underlying Pottsville and overlying Carbondale fire clays for the manufacture of face brick.

Fire clay.—The shale member of the Carbondale formation is overlain by a variable thickness of fire clay. This clay resembles that in the Pottsville formation, but it is commonly somewhat paler gray or almost white and more heavily mottled with brighter tints of yellow, brown, red, maroon, and purple. The fire clay is massive, plastic, slightly calcareous, and somewhat gritty. Locally it contains thin layers of fissile shale and fine-grained argillaceous sandstone and, in sec. 1, T. 14 S., R. 2 W., nodules of calcareous argillaceous iron oxide are present in the lower foot of the member. In many places the upper few inches of the clay is dark gray or purplish and may be a thin carbonaceous zone or "coal smut" that represents a thicker coal bed in other regions.

A thin section of a sample from the open pit at the abandoned brick plant in sec. 1, T. 14 S., R. 2 W., shows that this clay, like that in the Pottsville formation, is made up of large crystals of the clay mineral beidellite and a few scattered quartz grains.

Ceramic tests (p. 160) of a sample collected at the same locality show that this clay, which formerly was used in the manufacture of brick, is very similar in its physical properties to the clay in the Pottsville formation.

Limestone.—The fire clay member of the Carbondale formation is overlain by a thin but hard bed of limestone. In southern Calhoun County this bed is very resistant to erosion and forms a prominent ledge from which heavy blocks break off and strew the slopes made by the soft underlying clays and shales. This hard limestone may possibly cap the narrow terrace or bench along the southern line of sec. 10 T. 6 N., R. 13 W., Jersey County, but if so it is obscured by the heavy mantle of loess there.

Where well exposed the bed is commonly about 6 feet thick but the upper 1 or 2 feet consists of nodular layers or concretionary beds of limestone imbedded in calcareous clay, and these softer upper layers are not everywhere exposed. The limestone is fine-grained to dense and commonly light gray to pale buffy gray. The rock is somewhat conglomeratic or brecciated and contains small pebbles of gray dense limestone imbedded in a matrix of light-gray, fine-grained limestone. Where weathered, these limestone pebbles stand out from the matrix and give the rock a very irregular knobby surface. In some places the limestone contains a few small nodules of brown chert.

Chemical analysis of a sample (p. 157) taken to represent the 5½ feet of this limestone and the lower 2¼ feet of the limestone at the base of the McLeansboro formation as exposed in the SW¼SW¼ sec. 14, T. 13 S., R. 2 W., indicates that the rock consists of about 98 percent of relatively pure calcite. The impurities are probably almost all clay and silica. (See pp. 16–17.) This analysis indicates that, in their high total content of calcium carbonate and their low percentage of silica and alumina, these two Pennsylvanian beds are to be classed with the very purest limestones of the region.

Physical tests of this sample (p. 157) indicate by the high bulk density and low absorption and loss by abrasion that these beds are probably the most dense and compact limestones in the region.[89]

Calcareous clay.—The uppermost member of the Carbondale formation is a plastic calcareous clay that somewhat resembles the underlying fire clay in the Carbondale and Pottsville formation. However, it is much more calcareous than these underlying clays, and it commonly contains, especially in its middle and upper parts, irregular patches of a white calcareous powder. It is also characteristically pale greenish gray and streaked in its upper and lower parts with thin yellow, red, and purplish layers. Furthermore it commonly contains, at both top and bottom, thin dark-gray and purplish carbonaceous zones or coal smuts. In the NE. ¼NW.¼ sec. 6, T. 14 S., R. 1 W., the upper few inches of the member contains small nodules of dark, perhaps phosphatic limestone and fragments of wood. The thickness of the member varies irregularly from 4 to 12 feet or more.

Stratigraphic relations.—No evidence of a stratigraphic break was recognized either at the top or bottom or within the Carbondale formation. The coal at the base of the formation is sharply separable from but seems to lie conformably upon the fire clay of the Pottsville. At least locally the coal appears to grade upward into the black laminated shale which in turn is not sharply separated from overlying sandy shale member. No evidence of a stratigraphic break was detected within the thick sandy shale member. The fine-grained argillaceous sandstone, which locally makes up nearly all the member, appears to grade laterally by interlamination into the more usual shale and siltstone. In some exposures the bed of fire clay overlies this member with sharp contact but elsewhere the contact is not abrupt. The lower limit of the limestone member is everywhere sharp but apparently conformable. The uppermost member of calcareous clay seems to be almost completely gradational into the underlying limestone and, in the best exposures, it appears also to grade into the overlying limestone at the base of the McLeansboro formation.

However this appearance of conformity may be misleading. Marine fossils were found in the black laminated shale, in the thick shale member, and in the limestone member. Yet it is generally thought that coal, such as that in the basal bed of the formation, accumulated in swamps that were above sea level or at least some distance landward from the shore. If the thin carbonaceous zones in the fire clay and calcareous clay members represent other coal beds, the area may have emerged above sea level several times during the accumulation of the Carbondale formation. Unconformities within continental deposits have much less stratigraphic significance than unconformities within or upon marine sediments. Similarly, the absence of unconformities of any kind within continental deposits does not prove that the area has not moved up and down several times.

Fossils.—The basal coal bed and the upper clay members of the Carbondale formation contain poorly preserved plant remains. In a few localities the black laminated shale above the coal contains abundant marine invertebrates (Colls. 31 and 90), the thick shale member a few small unidentified pelecypods, and the limestone a few fossils, most of which are brachiopods. (See p. 173.)

Name and members.—The Carbondale formation was named from exposures near Carbondale in Jackson County, Ill.,[90] In some reports this formation has been taken to include all the beds between the base of the Murphysboro (No. 2) coal and the top of the Herrin (No. 6) coal.[91] In other reports, however, its base has been drawn at the base of the underclay of No. 2 coal. It here is drawn more or less arbitrarily at the base of the coal instead of at the base of the underclay. The name Carbondale is here used for the rocks in the Hardin and Brussels quadrangles upon the advice of Dr. J. M. Weller who visited the writer in the field and who examined all the fossil collections.

Worthen [92] early correlated the bed of coal mined in southern Calhoun County with the Murphysboro or Colchester (No. 2) coal. Culver [93] referred to the bed as coal No. 2, and J. M. Weller [94] believes that it certainly correlates with the Colchester and very probably with the Murphysboro coals of Illinois and with the Bevier coal of Missouri.

The thick sandy shale member (unit 6 of generalized section, p. 53) that overlies the coal bed may possibly be equivalent to Savage's Ipava [95] shale and sandstone or the Pleasantview sandstone of Wanless,[96] or to both these members.

It seems reasonably certain that the bed referred to by Culver [97] as "the Golden Eagle limestone, well known in Calhoun County" is the limestone member of the Carbondale (unit 8 of generalized section, p. 53) and not one of the two higher limestones (units 10 and 12). It is true that Culver referred his Golden Eagle limestone to the McLeansboro formation. However, this reference seems very improbable because (1) the lower of

[89] Krey, Frank, and Lamar, J. E., Limestone resources of Illinois; Illinois Geol. Survey Bull. 46, p. 31, 1925.

[90] Shaw, E. W., and Savage, T. E., U. S. Geol. Survey Geol. Atlas, Murphysboro-Herrin folio (no. 185) p. 6, 1912. Lines, E. F., Portland cement resources of Illinois: Illinois Geol. Survey Bull. 17, p. 74, 1912.

[91] Culver, H. E., Coal resources of District III: Illinois Geol. Survey Coop. Min. Ser. Bull. 29, p. 16, 1925. Wanless, H. R., Geology and mineral resources of the Alexis quadrangle: Illinois Geol. Survey Bull. 57, pp. 47–48, 78, 1929.

[92] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, p. 22, 1870.

[93] Culver, H. E., op. cit., p. 23.

[94] Personal communication.

[95] Savage, T. E., Significant breaks and overlaps in the Pennsylvanian rocks of Illinois: Amer. Jour. Sci. 5th ser., vol. 14, p. 309, 1927.

[96] Wanless, H. R., Geology and mineral resources of the Alexis quadrangle: Illinois Geol. Survey, Bull. 59, pp. 90–91, 1929.

[97] Culver, H. E., op. cit., p. 20.

the two limestone members of the McLeansboro in Calhoun County is less resistant and hence not so conspicuously developed as the limestone member of the Carbondale and (2) the more resistant upper limestone member of the McLeansboro is restricted to a very few exposures in Calhoun County and so probably was not the bed he referred to. Furthermore, in the stratigraphic section quoted by Culver[98] from Worthen, the only bed of limestone included is the one in the upper part of the Carbondale formation.

J. M. Weller[99] is inclined to think that the bed referred to in this report as the limestone member of the Carbondale (unit 8 of the generalized section, p. 53) actually contains the representatives of two different limestones that are well developed in other parts of Illinois. By this interpretation the lower fine-grained massive portion is equivalent to the "No. 4 cap" limestone and the upper nodular portion is equivalent to the "No. 5 cap" or the St. David shale and limestone of Savage.[1]

According to J. M. Weller,[2] Knight,[3] and, less specifically, Savage,[4] the coal, shale, and fire clay members of the Carbondale formation are equivalent to the upper part of the Cherokee shale and the limestone and calcareous clay members to the lower and middle parts of the Fort Scott limestone[5] of Missouri and Kansas.

M'LEANSBORO FORMATION

The youngest Paleozoic rocks remaining uneroded in the Brussels quadrangle are some thin beds of limestone and clay that belong to the McLeansboro formation. These beds cap the narrow remnants of upland in southern Calhoun County and they have a maximum exposed thickness of about 28 feet. A much greater thickness of the McLeansboro formation may have been deposited in this area and later eroded away. The formation is more than 1,000 feet thick in southern Illinois and beds of equivalent age in northwestern Missouri are also more than 1,000 feet thick. Inasmuch as the older Pennsylvanian formations thin toward the Hardin and Brussels quadrangles, it seems improbable that the McLeansboro formation was ever 1,000 feet thick in this area. However, it may well have been several hundred feet thick before erosion.

Like the Carbondale formation the McLeansboro can conveniently be subdivided into several members. These are a basal limestone, a middle clay, and an upper limestone.

The basal limestone bed is widespread in southern Calhoun County. It is commonly a dense, dark somewhat buffy gray, highly fossiliferous limestone that is massive in the lower part and thinner-bedded above. Locally it contains a few large nodules of gray chert, which upon weathering become tan or brown. Like the limestone bed in the upper part of the Carbondale, this bed contains small limestone pebbles but, unlike those in the lower limestone, these pebbles are lighter gray and coarser-grained than the groundmass that contains them. The bed can usually be distinguished from the limestone in the Carbondale by its denser texture, darker color, and greater abundance of fossils and by the fact that it is less resistant to erosion. In a few places in the southern part of the area the full thickness of this limestone is exposed and at those places the bed is about 8 feet thick; throughout most of its area of outcrop, however, only the lower 1 or 2 feet is exposed.

At a few exposures along the line of outcrop in sec. 1, T. 14 S., R. 2 W., the basal limestone is overlain by 15 feet of pale-buff, massive, somewhat gritty and plastic, calcareous clay. This clay in turn is overlain at these few exposures by a hard, dense, massive, fossiliferous limestone 5 feet thick, which is gray on fresh surfaces but brown where weathered. This upper limestone is extremely resistant to erosion and, like the limestone member of the Carbondale but unlike the lower limestone of the McLeansboro formation, it forms a prominent ledge from which large blocks break off and strew the slopes below.

Fossils.—The two beds of limestone in the McLeansboro formation are commonly much more highly fossiliferous than the limestone of the Carbondale formation (see p. 173). No organic remains were observed in the middle clay member of this formation.

Name and members.—The McLeansboro formation was named from exposures in Hamilton County, Ill.,[6] to embrace all Pennsylvanian strata in Illinois above the Herrin (No. 6) coal. The name McLeansboro is here applied, on the advice of Dr. J. M. Weller, to the uppermost Pennsylvanian rocks exposed in the Brussels quadrangle.

The lower limestone member of the McLeansboro formation probably corresponds to the Brereton limestone of Savage.[7] This basal bed has been correlated by Knight[8] and Weller[9] with the upper part of the Fort Scott limestone of Missouri and Kansas. These two

[98] Culver, H. E., op. cit., p. 39.

[99] Personal communication.

[1] Savage, T. E., Significant breaks and overlaps in the Pennsylvanian rocks of Illinois: Amer. Jour. Sci., 5th ser., vol. 14, p. 309, 1927.

[2] Weller, J. M., Cyclical sedimentation of the Pennsylvanian period and its significance: Jour. Geol., vol. 38, pp. 108–109, 1930; also, personal communication.

[3] Knight, J. B., Some Pennsylvanian ostracodes from the Henrietta formation of eastern Missouri: Jour. Paleontology, vol. 2, p. 229, 1928; Pennsylvanian outlier at St. Louis, Mo., and its correlations [abstract]: Geol. Soc. American Bull., vol. 40, no. 1, p. 190, 1929.

[4] Savage, T. E., Marine invertebrate fossils as horizon markers in the Pennsylvanian rocks of Illinois: Jour. Geology, vol. 32, p. 581, 1924.

[5] Swallow, G. C., Preliminary report of Geological Survey of Kansas, pp. 25–26, 1866.

[6] DeWolf, F. W., Studies of Illinois coal: Illinois Geol. Survey Bull. 10, p. 181, 1910. Savage, T. E., The geology and coal resources of the Herrin, Illinois, quadrangle: Idem., pp. 271, 274.

[7] Savage, T. E., Significant breaks and overlaps in the Pennsylvanian rocks of Illinois: Amer. Jour. Science, 5th ser., vol. 14, p. 309, 1927.

[8] Knight, J. B., The Pennsylvanian outlier of St. Louis, Missouri, and its correlations [abstract]: Geol. Soc. America Bull., vol. 40, no. 1, p. 190, 1929.

[9] Weller, J. M., Cyclical sedimentation of the Pennsylvanian and its significance: Jour. Geology, vol. 38, pp. 108–109, 1930.

workers have also correlated the overlying argillaceous beds with the Labette[10] shale and the succeeding limestone (the Piasa[11] limestone of Culver) in western Illinois with the Pawnee limestone[12] of Missouri and Kansas. According to these correlations the beds of the McLeansboro formation that are exposed in the Brussels quadrangle are all embraced in the Henrietta formation of Missouri.

CENOZOIC

TERTIARY

After the Pennsylvanian seas withdrew, large areas of the North American continent because dry land and, so far as present information goes, the central Mississippi Valley region has remained above sea level since that time. However, the record of the geologic events in this region after the Pennsylvanian and before the Pleistocene is very meager. In other parts of the world, during a period of time estimated at several hundred million years, sediments accumulated to thicknesses of many thousands of feet.[13] In the Hardin and Brussels quadrangles the only stratigraphic record of this vast length of time consists of a few thin remnants of an old stream gravel. Yet during this period, much of the framework and the present geography of the region were blocked out. Consequently, in a description of the geology of the region these thin remnants of the old stream gravel assume an importance out of all proportion to their present thickness. The very fact that there is almost no record of Mesozoic and Tertiary stratigraphy in this region makes it all the more necessary to describe carefully the meager records that can be found.

However these gravels, taken alone, tell almost nothing about the intervening history. It is necessary to supplement their testimony by that of the physiographic record of Tertiary events. Even then the available information affords only the barest outline of the complete history. Much that is included in the description and discussion of the Grover gravel might more logically have been restricted to the section of this report entitled "Physiography." However, it is almost essential to bring the two types of evidence together into one discussion, and it seems more convenient from the reader's viewpoint to introduce the pertinent physiographic data along with the regular stratigraphic description.

GROVER GRAVEL

At several places on the narrow uplands in the Hardin and Brussels quadrangles a thin layer of gravel lies between the highest Mississippian or Pennsylvanian formations and the overlying Pleistocene deposits. The pebbles in this gravel—formerly called the "Lafayette"—are marked by a number of distinctive characteristics and, in many places where the gravel cannot be found exposed, its presence beneath the loess mantle on the uplands is demonstrated by an abundance of these pebbles in the upper parts of small stream courses nearby.

North of the Cap au Grès flexure, the gravel occurs in several small remnants in the Calhoun County part of the Hardin quadrangle and in a few places in southwestern Jersey County. In the area of Illinoian glaciation, east of Illinois River and north of Otter Creek, this gravel could not be recognized, but the presence in the Illinoian till of a few pebbles apparently identical with those characteristic of the gravel indicates either that the gravel was once present there or that the ice sheet advanced across deposits of this gravel elsewhere and incorporated them within its debris.

Northward from the northern limit of the Hardin quadrangle to the southwestern limit of Illinoian glaciation, the upland surface is somewhat wider and the remnants of upland gravel correspondingly larger than they are in the Hardin quadrangle. In the eastern part of the T. 8 S., R. 3 W., especially along Farmer's Ridge, from 7 to 10 miles north of the Hardin quadrangle, remnants of this gravel are numerous and widespread.

The most abundant and the thickest exposures of the gravel within the area covered by this report are in the Brussels quadrangle south of the Cap au Grès flexure, along the ridge from sec. 15, T. 13 S., R 2 W., south and east to sec. 32, T. 13 S., R. 1 W. However, the most numerous and widespread and the best exposed remnants of these deposits near the Hardin and Brussels quadrangles are those on the flat upland in the western part of St. Louis County, Mo., about 20 miles south of the Brussels quadrangle. In this region thick remnants of the formation clearly display the original bedding and structure of the deposits, and it is from exposures near Grover, Mo., that the name Grover gravel is proposed for these beds. (See p. 67.)

Thickness.—Throughout most of the area of the Hardin and Brussels quadrangles the Grover gravel seems to be merely a thin veneer of pebbles, and in a number of places it is definitely absent. However, the exposures are poor, and it may be much thicker beneath the loess mantle that everywhere covers the uplands. In northern Calhoun County, north of the Hardin quadrangle, and in southern Calhoun County, in the southern part of the Brussels quadrangle, the formation is commonly from 2 to 5 and in a few places 10 feet thick, and it may be much thicker where covered by loess. In western St. Louis County, Mo., the formation is more than 10 feet thick at many exposures, and in sec. 3, T. 44 N.,

[10] Haworth, E., Stratigraphy of the Kansas Coal Measures: Kansas Univ. Geol. Survey, special repts., vol. 3, pp. 36–37, 92, 94, 100, 1898.
[11] Culver, H. E., op. cit., p. 20.
[12] Swallow, G. C., Preliminary report of the Geological Survey of Kansas, pp. 9, 28, 1866.
[13] Wilmarth, M. G., The geologic time classification of the United States Geological Survey: U. S. Geol. Survey Bull. 769, pp. 5–6, 1925.

R. 3 E., a thickness of slightly more than 30 feet of these deposits is exposed.

The evidence afforded by these scattered remnants is not sufficient to prove whether or not these deposits once extended as a continuous sheet over the upland throughout this area. They may once have been continuous, for the upland has been subject to long-continued weathering and erosion since the formation was deposited, and it is precisely where the largest remnants of this upland surface remain that the gravel is likewise best preserved. The formation may thus have been much thicker and much more widespread than the accidental remnants of today would indicate. However, the gravel may not be erosion remnants, preserved in these places merely because the upland surface remains intact. In fact, it is possible that the gravel has acted as a protective covering [14] and helped to preserve these remnants of the upland surface.

It is interesting to note that the remnants of Grover gravel in Calhoun and St. Louis Counties lie in a relatively narrow belt 60 miles long that coincides roughly with the general course of Mississippi River. It is true that in these two counties the remnants all lie in the narrow "driftless area" between the regions of Illinoian and Kansan glaciation (see fig. 4) and therefore that the linear distribution may be more apparent than real. Yet upland gravels have been reported as lying below glacial till in each of the countries along the Illinois side of Mississippi River from Calhoun north to Hancock County. These preglacial gravels and those capping the divides far outside the limits of glaciation from St. Louis County south through Franklin, Washington, and St. Francois Counties, Mo., have been thought to be equivalent to the upland gravels in Calhoun County. (See references on p. 66.) Should these correlations prove correct, the narrow north-south belt in which the gravels occur is about 175 miles long and entirely independent of the limits of glaciation.

Topographic expression.—The Grover gravel occurs only upon the uplands. Wherever found it caps the high narrow remnants of an old and once much more extensive upland surface. The scattered pebbles and a few small accumulations of redeposited gravel in small streams and on hillsides are more widespread, but they were moved to their present position long after the deposition of the original gravel, and they do not constitute a part of the Grover gravel.

In the eastern part of St. Louis County, Mo., the gravel caps low hills that rise about 50 feet above the general upland surface. Similar relations were not observed in Illinois, but these low hilltops may correspond to the Calhoun peneplain, and the general upland surface near St. Louis may be a partial peneplain equivalent to the poorly-defined intermediate upland surface in the Hardin and Brussels quadrangles (pp. 109–110).

Lithologic character.—Poorly sorted gravel, sand, and clay in varying proportions make up the formation. Although clay and sand are probably everywhere the chief constituents of the unit, they are much less conspicuous than the gravel in all natural exposures.

This gravel consists dominantly of pale brown, polished, and rounded pebbles of chert, quartzite, and quartz. The pebbles are commonly from ¼ to 2 inches in diameter but numerous boulders more than 6 inches across and a few from 1 to 2 feet in maximum dimension may be found in southern Calhoun County, Ill., and western St. Louis County, Mo. Generally speaking, the gravel seems to become coarser southward across Calhoun County and westward across St. Louis County.

Subrounded chert pebbles are more numerous than all other constituents of the gravel. Commonly the surface of this chert is pale brown and somewhat glazed, but where freshly broken the interior of most of the pebbles is light gray. However, the chert is of many different colors and textures. Some pebbles contain Paleozoic fossils, and these and many others probably were derived from chert nodules in Paleozoic formations. But much of the chert has textures which suggest that the original rock was limestone or even metamorphic schist that subsequently has become silicified into a fine-grained chert. Pebbles of oolitic chert or silicified oolite are rather common in the formation. Thin sections cut from several samples of this oolite and of intimately veined and probably schistose pebbles show that, whatever the original composition, a secondary silicification has completely transformed the rocks into finely crystalline quartz. A few pebbles of well-rounded and polished fine-grained jasper were found at nearly every exposure examined.

Although less abundant than the chert, quartzite is probably the most conspicuous element in the gravel of the formation. It is present as subrounded to well-rounded, more or less polished pebbles and boulders of purple, red, pink, and gray, medium-grained to coarse-grained and conglomeratic quartzite. The largest boulders in the formation—those from 9 to 18 or 24 inches in maximum diameter—seem everywhere to be well-rounded red or purple quartzite. Some of the fragments show distinct lamination, and in a few of them this lamination is made conspicuous by alternate white and purple layers. A few of the quartzite pebbles are obviously the result of secondary silicification—when broken they are found to be friable sandstone inside. Thin sections indicate that in some of the pebbles the coloring matter, presumably iron oxide, is restricted to a coating on the rounded quartz grains, but in others it fills the finely crystalline quartz matrix between small chert sand grains. In a thin section of a dark purple quartzite pebble from sec. 2, T. 8 S., R. 3 W., Calhoun

[14] Rich, J. L., Gravel as a resistant rock: Jour. Geology, vol. 19, pp. 492–506, 1911.

County, every quartz grain has a shadowy extinction and seems to be granulated and elongated parallel to a general schistose structure. This particular pebble seems almost certainly to be a metamorphosed quartzite.

Small very well rounded and highly polished quartz pebbles represent another conspicuous rock type that is common among the pebbles. These quartz pebbles, which range from pale brown, through gray and white, to clear and colorless, are commonly from 10 to 15 millimeters or about ½ inch in diameter. Thin sections indicate strongly that this quartz is of igneous origin. A clear and nearly colorless pebble 20 millimeters in diameter from sec. 2, T. 8 S., R. 3 W., Calhoun County, consists of a single quartz crystal that is traversed by many fine lines made by minute liquid inclusions that contain gas bubbles. Another pebble from the same locality seems to be a fragment of vein quartz that has been sheared. A quartz pebble from the NE¼ sec. 11, T. 6 N., R. 13 W., Jersey County, has the allotriomorphic texture, shadowy extinction, and lines of inclusions characteristic of the mineral as it occurs in quartz veins and in pegmatite.

A fourth and less common type of rock among the pebbles is represented by subangular to rounded fragments of conglomerate in which well-rounded quartz pebbles are set in a matrix of dark-brown ferruginous sandstone. In some exposures a ferruginous conglomerate apparently identical with that in these fragments has been formed within the Grover by the deposition of a ferruginous cement, and it is possible that the fragments themselves have had the same origin. However, they greatly resemble fragments of the conglomeratic sandstone in the Pottsville formation. (See p. 55.)

In a few exposures distinct pebbles several inches in diameter may be found that are of massive tan clay like that occurring in beds in other parts of the Grover and of maroon siltstone like that in the underlying Carbondale formation.

Pebbles composed of other rocks are very rare. A decomposed pebble 4 inches in diameter collected in the SE¼ sec. 1, T. 44 N., R. 3 E., St. Louis County, Mo., seems to be a highly altered volcanic breccia. It is made up of angular clastic fragments set in a microcrystalline matrix that shows a lathlike and apparently a perlitic structure. No volcanic glass was recognized in this rock; both the fragments and the matrix seem to have been silicified, perhaps sericitized, and subsequently kaolinized.

Careful search was made at many exposures, but no rock types other than those mentioned could be found. It is perhaps worthy of notice that the dominant types—chert, quartzite, and quartz—are an assemblage of quartzose rocks. Feldspathic igneous rocks and carbonate sedimentary rocks appear to be absent. The softer rocks, which would not withstand long-continued abrasion, and the more soluble rocks, which would decompose most readily under long continued weathering, are both rare.

The distinctive polished surface so noticeable on many of the pebbles is not present on all of them. The quartz and the finer-grained chert pebbles are most conspicuously polished or glazed, but some of the more granular cherts, the coarser-grained quartzites, and the ferruginous conglomerates seem to be totally without this peculiar surface. Some of the pebbles are much more shiny on one side than on the other, thus suggesting that the polish was originally developed upon an exposed side or that it was subsequently destroyed on the more weathered side of the pebble. On some of the most shiny pebbles, the polish extends into minor depressions and small grooves much like a varnish. However, microscopic examination seems to show clearly that the glazed surface is not caused by a superficial varnish. Although microscopic examination shows that the surfaces of many of the finer-grained pebbles are checked by small crescentic cracks that record the blows struck by other pebbles, it reveals almost no evidence of the fine striations that might be left by a polishing agent. The origin of this glazed surface is unknown; it may possibly be the result of polish by wind-blown dust or of combined solution and abrasion by water-borne silt.

The clay and sand associated with the gravel were found well exposed in relatively few places. In most exposures the gravel is set in a matrix of poorly sorted, very sandy, plastic, noncalcareous clay that is blue gray where fresh and red and tan where weathered. In a few places, however, a horizontal layer about 6 inches thick of gray or green massive clay or platy siltstone was found interstratified with the gravel.

The best exposure of the formation seen by the writer was pointed out to him by R. B. Cozzens of St. Louis. This exposure, in the south center sec. 3, T. 44 N., R. 3 W., 2 miles west of Grover, St. Louis County, Mo., is a quarry face 150 feet long. The formation is more than 30 feet thick, and it overlies with sharp contact the hard massive maroon siltstone of the Pennsylvanian, which in turn lies above the fire clay quarried there. The lower half of the formation is composed of massive gravel and poorly sorted, essentially unstratified pink argillaceous sandstone. This lower unit is terminated above by a distinctly bedded layer of greenish-gray silty clay about 6 inches thick. This thin layer is succeeded by conspicuously cross-bedded gravel and clayey sand. The cross-bedded layers dip regularly southward in long sweeping curves that extend through a vertical thickness of about 12 feet. It is perhaps worth noting that this large-scale cross bedding and the southward dip of the cross-bedded layers seem to accord with the distribution of the formation in a narrow north-south belt roughly parallel to the general course of Mississippi River. (See p. 62.) The overlying and uppermost unit is massive gravel, sand, and clay like that at the base of the formation.

Samples of sandy clay from several exposures in St. Louis County, Mo., and Calhoun County, Ill., were examined microscopically. The sand is made up almost entirely of grains of quartz and chert, but in each of 6 samples examined numerous grains of orthoclase and ilmenite (?) were found. The sand is poorly sorted, fine- to coarse-grained, and well-rounded. In contrast to the abundant evidence of silicification in the gravel pebbles, very few if any crystal faces formed by secondary silicification were seen on any of the sand grains. This evidence seems to show that the silicification of the pebbles was accomplished before the pebbles and sand were brought together—that is, sometime before deposition. The surfaces of the sand grains are conspicuously glazed and shiny; very few of the "groundglass" or frosted surfaces found commonly on the grains in Paleozoic sandstones of this region were noted. This glazed surface is said to be produced by abrasion under water;[15] it is quite unlike the minutely etched surface of grains in glacial tills that are undergoing solution and decomposition.

Most of the quartz grains are murky with rutile, apatite, magnetite, and liquid inclusions, although a few are transparent. The chert grains are brown, gray, and white and are finely crystalline. Some of the grains of orthoclase are partially decomposed, but others appear to be totally unaltered. In a sample from northern Calhoun County and another from St. Louis County, fresh grains of microcline, the largest of which was 2.3 millimeters in diameter, were found. A sample from sec. 3, T. 44 N., R. 3 E., St. Louis County, Mo., included a few grains of tourmaline and zircon. The widespread presence of some grains of potash feldspar in this sand seems to show conclusively that the formation has not been subjected to extreme decomposition since it was deposited. Large pebbles of feldspathic rock should resist decomposition much longer than small grains of feldspar, and the absence of any feldspathic and carbonate pebbles seems to demand that all but the most quartzose rocks were lost either by decomposition or by trituration long before the sand and gravel were deposited.

There are thus two important and probably significant differences in the composition of the pebbles and the sand—the pebbles show abundant evidence of silicification, but feldspathic rocks are very rare or absent; the sand grains show no evidence of silicification, but fresh feldspars are commonly present. These differences suggest that the pebbles and the sand may have had very different histories.

[15] Galloway, J. J., The rounding of grains of sand by solution: Amer. Jour. Sci., 4th ser., vol. 47, pp. 272–273, 1919; Value of physical characters of sand grains in the interpretation of the origin of sandstones (abstract): Geol. Soc. America Bull., vol. 33, pp. 104–105, 1922.

The thin bed of silty clay in the middle of the formation in sec. 3, T. 44 N., R. 3 E., St. Louis County, Mo., consists dominantly of clay, but it also contains numerous sharply angular grains and thin slivers of quartz and orthoclase less than 0.05 millimeter in diameter and flakes of muscovite up to 0.25 millimeter in diameter. Other angular grains and euhedral crystals of hornblende, zircon, chert, biotite, magnetite (?), albite, microcline, tourmaline, and apatite were recognized in this material.

A thin section of the sandy clay matrix in which the gravel is imbedded in sec. 2, T. 8 S., R. 3 W., Calhoun County, shows two types of material: very finely crystalline silty and sandy clay, which probably was deposited as such, and lesser amounts of coarsely crystalline brown clay filling cracks and veinlets, which probably was formed during the processes of weathering.

Stratigraphic and physiographic relations.—The formation, here called the Grover gravel, everywhere lies upon the old upland surface or, as it is called in this report, the Calhoun peneplain (see pp. 102–103) and hence it may rest unconformably upon all formations truncated by that peneplain. Within the Hardin and Brussels quadrangles the Grover gravel was found in actual contact with only the Burlington, Pottsville, and McLeansboro formations. However, the peneplain locally truncates or once did truncate the Maquoketa shale, the Silurian and Devonian and the Kinderhook and later Mississippian formations in this area. Hence, in this and immediately adjacent regions, remnants of the formation may be looked for wherever these Paleozoic rocks form the local uplands.

The uplands and the thin veneer of gravel immediately north of the Cap au Grès flexure now stand higher than the uplands and the thicker remnants of Grover gravel in southern Calhoun County. It seems fairly certain, however, from several lines of evidence, that both the upland deposits and the peneplain upon which they rest were once continuous across the flexure and that they have been deformed into their present position by subsequent uplift of the Lincoln anticline. This conclusion might perhaps rest safely on the identical character of the upland deposits north and south of the flexure and their presence on a widespread flat surface that bevels rock structures in both areas. However, this conclusion is greatly strengthened by an examination of alternative explanations that might conceivably account for the present distribution of the upland gravel.

The three alternative hypotheses that seem to merit discussion are (1) that the highest part of the uplands immediately north of the Cap au Grès flexure may have stood as hills above the old peneplain, (2) that the gravel may have been laid down upon two separate levels or peneplains, and (3) that the gravel may have been laid down on some still higher and older surface, from which it was let down as a residual deposit upon the peneplain.

The first alternative, at least insofar as it relates to the origin of the gravel, seems to be eliminated by the presence of remnants of gravel on the highest part of the uplands north of the flexure in secs. 2 and 11, T. 6 N., R. 13 W., Jersey County. These remnants appear to show conclusively that a stream, or some other agent of transportation competent to move the material, once extended over or above what are now the highest parts of the old surface.

The second alternative, that deposition on two different peneplains may account for the present distribution of the gravel, seems highly improbable. The gradual slope of the peneplain and of the remnants of gravel upon it from these highest points near the flexure northward across Calhoun County and from St. Louis County northward to southern Calhoun County (see pl. 10*A*; fig. 3*D*) proves that the gravel has been tilted if not deformed and that its present elevation is no sound basis for correlation. Also, if the gravel that caps the uplands south of the flexure were part of a second and lower bed, it should continue at accordant levels below and on the side of the higher uplands north of the flexure, yet no remnants of such a lower level of gravel were found along the slopes on either side of Mississippi or Illinois rivers. Furthermore, an intermediate post-mature upland surface is present below the Calhoun peneplain both north and south of the flexure (pp. 109–110; pls. 10 *B*, *C*, 20), and this intermediate surface helps to identify the peneplain throughout the region.

The third alternative, that the gravel is a residual deposit let down upon the upland from some postulated higher and older surface, is considered elsewhere in this report (p. 70). It seems sufficient for this particular purpose to point out that the largest and best-preserved remnants of the upland deposits—those that seem most likely to have been deposited by large streams and that are not merely residual accumulations—are below and well north and south of the parts of the old surface that now stand highest. If the more scanty remnants of gravel on the upland in central Calhoun and southwestern Jersey counties are residual accumulations, they were probably let down from a surface once continuous with the present upland surface of northern and southern Calhoun County. Hence this alternative, even if it appeared probable, would lead back to the conclusion that the peneplain has been deformed; in fact, it would indicate that the deformation along the Cap au Grès flexure was even greater than that indicated by the present remnants of the peneplain.

At every exposure examined, the Grover gravel underlies Pleistocene loess. In southern Calhoun County, the overlying loess, according to M. M. Leighton,[16] is of late Sangamon age. (See p. 89.) In northwestern Jersey County, the upland surface and apparently some reworked remnants of the gravel on this surface underlie the Illinoian till. In Pike County, Ill., Worthen [17] and Salisbury [18] found the upland gravel underlying Illinoian till.

The gravels in the Batchtown channel and the Kansan till(?) were laid down in western Calhoun County in valleys that had been trenched far below the old upland surface and the deposits of upland gravel. Similarly, the valleys near Winchester, Ill., 25 miles north of the Hardin quadrangle, in which Bell and Leighton [19] found Illinoian, Kansan, and Nebraskan tills, were cut long after the Grover gravel was deposited. (See also pp. 76, 78, 80, 81.)

Age.—No fossils other than those in fragments of Paleozoic rocks were found in the Grover gravel in the Hardin and Brussels quadrangles. Josiah Bridge,[20] when at the Missouri School of Mines, found fossil wood in the formation near Eureka, 5 or 6 miles south of Grover, St. Louis County, Mo., which was reported by the late Dr. F. H. Knowlton, of the United States National Museum, to be of Tertiary age. No other floral or faunal evidence of the age of the formation is known to the writer.

The stratigraphic relations within the Hardin and Brussels quadrangles show that the Grover gravel is younger than the lower part of the McLeansboro formation and older than the Illinoian (middle Pleistocene) till. The topographic position of the Kansan and Nebraskan tills nearby show furthermore that the formation is older than the earliest Pleistocene. Local evidence thus indicates clearly that the Grover gravel is post-Pennsylvania and pre-Pleistocene in age. This interval—Permian and all of Mesozoic and Tertiary time—was exceedingly long and in other areas it is represented by many thousands of feet of strata.

More strictly physiographic evidence demands some further restriction in the range of possible geologic age. Time must be allowed before the Pleistocene for the development of the intermediate postmature upland surface (see pp. 103–104, 109–110, and pls. 10 *B*, *C*, 20) and for the deep trenching which followed (p. 110). The length of time required for the later trenching is difficult to estimate; it may have happened very quickly at the close of Tertiary and the beginning of Pleistocene time. However, it seems necessary to allow a much longer period for the development of the intermediate post-mature surface—perhaps all the Pliocene epoch. In that case the Grover gravel must have been deposited

[16] Personal communication.

[17] Worthen, A. H., Geology of Illinois; Pike County: Illinois Geol. Survey, vol. 4, p. 37, 1870.

[18] Salisbury, R. D., On the northward and eastward extension of the pre-Pleistocene gravels of the Mississippi Basin: Geol. Soc. America Bull., vol. 3, pp. 184–185, 1892.

[19] Bell, A. H., and Leighton, M. M., Nebraskan, Kansan, and Illinoian tills near Winchester, Ill.: Geol. Soc. America Bull., vol. 40, pp. 481–490, 1929.

[20] Personal communication.

at the beginning of the Pliocene, the end of the Miocene, or even earlier.

The Calhoun peneplain must have been essentially completed before the Grover gravel was deposited upon it. The geologic date at which the land surface was finally reduced to a peneplain is not known, but certain relationships suggest that the lines of original drainage, which finally culminated in the development of this surface, did not become established until after the Mississippi embayment was formed in the Cretaceous period (pp. 108–109). These relationships therefore indicate that the final bevelling down of the land to the peneplain and the deposition of the Grover gravel took place long after the Cretaceous period.

If it should be permissible to correlate the Grover gravel, even approximately, with the similar deposits in southeastern Missouri and southern Illinois, the geologic age of the formation would thereby be fixed as middle or late Tertiary, for in that region the beds that most resemble those of the Grover lie upon the Eocene Jackson formation.[21]

In summary, the evidence seems to narrow down the possible age of the formation to well within the Tertiary period, probably post-Eocene and pre-Pliocene. If the formation was deposited from streams that were being rejuvenated by uplift of the peneplain (pp. 72–73), then it is consistent with present information to interpret the Grover gravel as perhaps late Miocene and the Calhoun peneplain as middle or late Tertiary.

Name.—The beds here referred to the Grover gravel were first recognized in Calhoun County by Salisbury,[22] who correlated them with the "Orange sand"[23] of the southern Mississippi Valley. Years earlier, Worthen[24] had found thin remnants of gravel in Pike and Hancock Counties, Ill., which he had compared with probable Tertiary gravels in the southern part of the State. Salisbury's subsequent discoveries from Calhoun County north through Pike and Adams into Hancock County indicated that this gravel had once been widespread on the uplands along Mississippi River. In a later paper Salisbury[25] reported the presence of scattered remnants of this upland gravel northward from western Illinois into Wisconsin and southward into southern Illinois and suggested its correlation with the high-level gravels of the Driftless Area[26] in the northern part of the Mississippi Valley and the gravels on the crest of Crowley's Ridge in northeastern Arkansas.

Weller[27] also recognized these beds in Calhoun County and correlated them with "the Lafayette[28] gravel as exposed near Glencoe in St. Louis County, Mo.," 20 miles south of the Brussels quadrangle. These "excellent exposures at and west of * * * Grover, 2½ miles north of Glencoe," in St. Louis County, Mo., were assigned to the "Lafayette" gravel by N. M. Fenneman, W J McGee, and R. D. Salisbury.[29] These and other exposures of the gravel in St. Louis County were mentioned by Winslow,[30] Buckley,[31] and Dake.[32] Buckley correlated them with high-level gravels in the adjacent Franklin, St. Francois, and Washington Counties, Mo. Weller and St. Clair[33] report a late Tertiary(?) gravel in Ste. Genevieve County, Mo. A widespread but thin layer of "Lafayette" gravel has been reported to lie on the highest hills in southeastern Missouri,[34] southern Illinois,[35] western Kentucky and Tennessee,[36] and northeastern Arkansas.[37]

Westward and southward from the exposures in St. Louis County, Mo., a few widely scattered remnants of upland gravel have been reported on the northwest slopes of the Ozark Highlands in Morgan County[38] and along Osage River[39] and on the west slopes in southwestern Missouri and southeastern Kansas.[40]

In nearly all of these many widely distributed areas the gravels have been recognized and correlated by their distinctive lithologic characteristics and their physiographic setting. In most of these regions the gravel

[21] Stephenson, L. W., and Crider, A. F., Geology and ground waters of northeastern Arkansas: U. S. Geol. Survey Water Supply Paper 399, p. 86, 1916.

[22] Salisbury, R. D., On the northward and eastward extension of the pre-Pleistocene gravels of the Mississippi Basin: Geol. Soc. America Bull., vol. 3, p. 184, 1892.

[23] Safford, J. M., A geological reconnaissance of the State of Tennessee, pp. 148, 162, 1856.

[24] Worthen, A. H., Geology of Illinois; Hancock County: Illinois Geol. Survey vol. 1, p. 330, 1866; Pike County: Idem., vol. 4, p. 37, 1870.

[25] Salisbury, R. D., Preglacial gravels on the Quartzite Range near Baraboo, Wis.: Jour. Geology, vol. 3, pp. 660–662, 1895.

[26] Trowbridge, A. C., The erosional history of the Driftless Area: Univ. Iowa Studies, vol. 9, pp. 79–80, 112–113, 1921.

[27] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 231, 1907.

[28] (Hilgard, E. W., Orange sand., Lagrange, and Appomattox: Amer. Geologist, vol. 8, pp. 129–131, 1891. McGee, W J, The Lafayette formation: U. S. Geol. Survey 12th Ann. Rept., pt. 1, pp. 500–501, 1891.

[29] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle: U. S. Geol. Survey Bull. 438, pp. 30–31, 1911.

[30] Winslow, Arthur, Lead and zinc deposits; section 2: Missouri Geol. Surveys, vol. 7, pp. 425–427, 1894.

[31] Buckley, E. R., Geology of the disseminated lead deposits of St. Francois and Washington Counties: Missouri Bur. Geology and Mines, 2d ser., vol. 9, pt. 1, pp. 9, 68, 1908.

[32] Dake, C. L., The sand and gravel resources of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 15, p. 190, 1918.

[33] Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 22, pp. 248–249, 1928.

[34] Shepard, E. M., Underground waters of Missouri: U. S. Geol. Survey Water Supply Paper 195, p. 25, 1907.

[35] Glenn, L. C., Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois: U. S. Geol. Survey Water Supply Paper 164, pp. 40–43, 1906. Weller, Stuart. The geological map of Illinois: Illinois Geol. Survey Bull. 6, p. 31, 1907. Lamar, J. E., Preliminary report on the fuller's earth deposits of Pulaski County: Illinois Geol. Survey Rept. Inv. 15, p. 9, 1928; Cretaceous, Tertiary, and Quaternary formations of extreme southern Illinois: Geol. Soc. America Bull., vol. 39 (abstract), pp. 203–204, 1928.

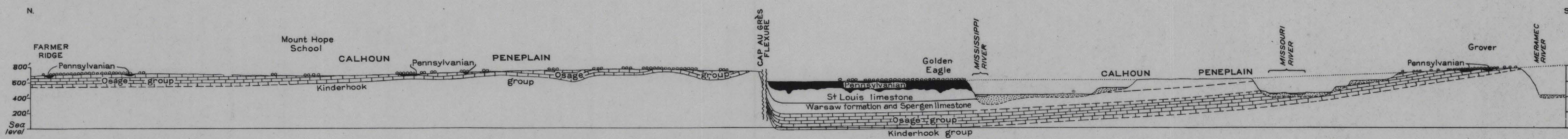
[36] Glenn, L. C., op. cit. Roberts, J. K., Tertiary stratigraphy of west Tennessee: Geol. Soc. Amer. Bull., vol. 39, pp. 442–443, 1928.

[37] Stephenson, L. W., and Crider, A. F., Geology and ground waters of northeastern Arkansas: U. S. Geol. Survey Water Supply Paper 399, pp. 85–100, 1916.

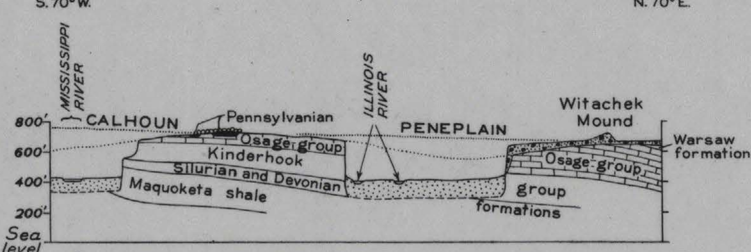
[38] Marbut, C. F., The geology of Morgan County: Missouri Bur. Geology and Mines, 2d ser., vol. 7, pp. 10, 58, 1907.

[39] Winslow, Arthur, op. cit., pp. 425–427.

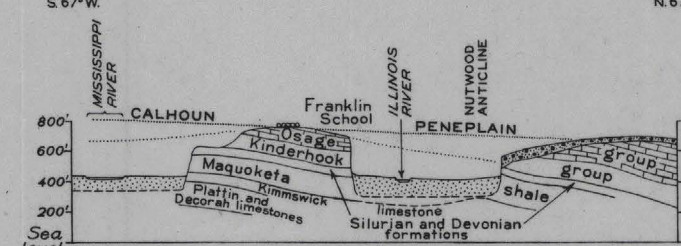
[40] Winslow, Arthur, op. cit., pp. 425–427. Smith, W. S. T., and Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Joplin folio (no. 148), pp. 7–8, 1907.



A. Section from Grover, St. Louis County, Missouri, northward to Farmer Ridge, Calhoun County, Illinois

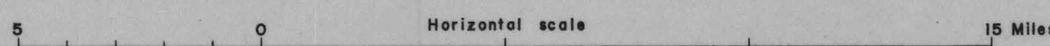


B. Section east-northeastward through Witacheck Mound, Green County, Illinois



C. Section east-northeastward past Franklin School, Calhoun County, Illinois

GENERALIZED CROSS SECTIONS SHOWING STRUCTURAL AND PHYSIOGRAPHIC RELATIONS IN AND ADJACENT TO HARDIN AND BRUSSELS QUADRANGLES



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is said to consist dominantly of somewhat-rounded chert pebbles and cobbles and subordinately of well-rounded and polished quartz and quartzite pebbles. With the exception of the deposits in Ste. Genevieve County, pebbles from other rocks are rare or absent. The gravel is commonly associated with sand, some of which is distinctly cross-bedded, and with beds and occasional pebbles of clay. The sand and clay are commonly stained red, orange, or yellow and in many places the gravel is cemented into a hard conglomerate by dark-brown iron oxide. These beds, which are reported as rarely more than 20 feet thick, occur on the highest hills and ridges in each locality, and they are apparently restricted to the vicinity of large streams.

Whether or not these widespread occurrences of the distinctive upland gravel were ever strictly contemporaneous with one another, their relationships and correlation became badly confused (1) by their too-ready correlation with other gravels far outside the Mississippi River Valley, (2) by the careless application in many regions of the name "Lafayette" to much older gravels from which the upland deposits, in part at least, had been derived and to lower and much younger terraces made up of redeposited gravels from the uplands, and (3) by the resulting conflict of evidence in widely separated regions as to the age of the gravels. Hence, when Berry,[41] by a study of the fossil flora, determined that the "Lafayette formation" at its type locality is a part of the Eocene Wilcox formation, it became evident that the name "Lafayette" must be abandoned, that new names should be applied to the upland gravels in different areas, and that final correlations must wait upon the completion of detailed field studies and tracing of the beds.[42]

In keeping with this modern tendency to apply local names to the upland gravels in different areas and to make correlations more cautiously, the writer here proposes the name of Grover gravel for the beds exposed on the upland near Grover, in St. Louis County, Mo. (See pp. 63–64.) This locality is chosen as the type for this region because it seems to be the best known, and it affords the most complete exposures of the formation near the Hardin and Brussels quadrangles. It is true that the upland gravels near Grover do not extend continuously from there into the area of this report. However, after a study of the lithologic character of the gravel, sand, and clay and of the peneplained surface on which they lie, the writer feels reasonably confident that these upland deposits of St. Louis County, Mo., can be correlated with those of southern, middle, and northern Calhoun County, Ill. (See also pp. 64–65; pl. 10A.) This proposal is made with a recognition that, should it ever become possible to correlate these beds accurately with those in the Mississippi Embayment, better type localities will probably be available there. Nevertheless, until such a correlation becomes possible, it seems highly desirable to have a local name for the gravels of this upper region.

ORIGIN OF GROVER GRAVEL

The upland gravels of the Mississippi Valley have long puzzled geologists. These deposits are exceedingly difficult to explain and yet, as the sole stratigraphic record of a large part of geologic time, they are particularly important in studies of the geologic history of the region. Because of their difficulty and their importance, the upland gravels have been of special interest, and many different theories to account for their origin have been proposed. The present discussion of the origin of the Grover gravel makes no claim to completeness and reaches no very definite conclusions. Yet some new facts were gathered in the studies of the formation in this region, and a review of earlier theories in the light of these facts may mark one step toward the final solution of the problem.

Ultimate source of materials.—Most of the chert pebbles in the Grover gravel doubtless may have been derived from Paleozoic limestone that come to the surface of the old peneplain in the Hardin and Brussels quadrangles or on nearby slopes of the Ozark Highlands, as has been suggested for the deposits of southeastern Missouri and northeastern Arkansas.[43] Yet these dominant chert pebbles might with almost equal likelihood have come from any other area where cherty limestones were exposed to weathering.

However the abundant pebbles of quartz and quartzite and the less common fragments of jasper and metamorphic rocks must originally have come from much more distant sources.

Weller [44] states that "the purple Sioux quartzite is one of the conspicuous materials present" in southern Calhoun County. Fenneman [45] reports that "certain quartzites and jaspilites" in St. Louis County, Mo., "resemble no known formation nearer than the Lake Superior region." He says that "some of the quartzite pebbles are of a purplish color and closely resemble the Baraboo quartzite of Wisconsin and the Sioux quartzite of Iowa and South Dakota" and that "many of the

[41] Berry, E. W., The age of the type exposures of the Lafayette formation: Jour. Geology, vol. 19, pp. 249–256, 1911.

[42] The story of the rise and fall of the concept of the "Lafayette formation" is well summarized in the following reports: McGee, W J, The Lafayette formation: U. S. Geol. Survey 12th Ann. Rept., pt. 1, pp. 498–501, 1891. Stephenson, L. W., and Crider, A. F., Geology and ground waters of northeastern Arkansas: U. S. Geol. Survey Water Supply Paper 399, pp. 85–86, 1916. Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, pp. 167–172, 1916.

[43] Stephenson, L. W., and Crider, A. F., Geology and ground waters of northeastern Arkansas: U. S. Geol. Survey Water Supply Paper 399, p. 88, 1916.

[44] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 231, 1907.

[45] Fenneman, N. M., op. cit., pp. 30, 44.

jasper pebbles strongly suggest the jaspilites of the Lake Superior region."

Shaw [46] has suggested that the quartz pebbles in the gravel on Crowley's Ridge may have come from

> [1] the veins of quartz cutting the crystalline rocks in the northern part of the Mississippi basin, probably not an adequate source; [2] conglomerates in Paleozoic rocks of the upper Mississippi basin; [3] postulated gravel deposits of Cretaceous and Tertiary age in the same basin, now largely though probably not entirely, removed; and [4] the crystalline rocks of the Piedmont area east of the Appalachian Mountains. The ultimate source of the quartz in the Paleozoic and later conglomerates of the upper Mississippi River basin would be either the crystalline rocks of Canada or those of the Piedmont; it seems improbable that any of the quartz has been derived from the Rocky Mountain region. The question of the possible transportation of quartz pebbles from the Piedmont region along the ancient drainage courses or shore lines has not been sufficiently studied.

Barrell [47] suggested that the gravel and sand in the "Lafayette formation" may have been swept eastward from the long gently sloping debris platform, now called the High Plains, that was built east of the Rocky Mountains in Tertiary time.

Prof. W. D. Shipton,[48] of Washington University (St. Louis, Mo.), impressed by the coarsening of quartzite boulders westward across St. Louis County, Mo., and by the presence of chert which resembles that in certain formations exposed in the Ozarks, believes that the apparently foreign pebbles in the Grover gravel may all have come from the Ozark Highlands; that is, the quartzite boulders may possibly have been formed from silicified and iron-stained sandstones, and the quartz pebbles from fragments of secondary quartz in geodes and joints in limestone. A somewhat similar explanation was proposed by Hopkins [49] for the quartzose pebbles in a Pennsylvanian conglomerate in Indiana.

The writer is not sufficiently familiar with the rocks in the different areas mentioned to hazard an independent opinion of the source of the pebbles in the Grover gravel. However, study of materials collected in Calhoun and Jersey Counties, Ill., and St. Louis County, Mo., seems to demonstrate clearly that not all the pebbles could possibly have come from local chert and geodes or even from the small pre-Cambrian areas in the nearby Ozark Highlands. The jasper and colored quartzites and the probable schistose rocks strongly suggest, and the abundant igneous quartz and occasional metamorphosed quartzite and quartz pebbles (see pp. 62–63) seem to demand, a much more distant ultimate source. The Wisconsin and the Southern Appalachian regions are the nearest areas that might possibly have contributed these foreign materials and, as specific identifications of pebbles with rocks of the upper Mississippi Valley region have been suggested by Weller and Fenneman, that general region may be considered as at least one of the most probable ultimate sources of the material.

It is interesting to note here the conflict between two types of evidence bearing on the source of the gravel in the formation. Nearly all the abundant chert pebbles might have come from the nearby Ozark Highlands, and the quartzite boulders seem to become larger southward across Calhoun County and westward across St. Louis County toward this uplift. Yet many associated pebbles and even the quartzite boulders themselves seem to have come originally, not from the Ozarks, but from some more distant source. One of the most probable of the distant sources of these foreign boulders seems to be the northern part of the Mississippi valley, a suggestion that apparently accords well with the linear distribution and direction of cross bedding in the formation. This apparent contradiction is somewhat paralleled by the lithologic evidence that the silicified quartzose pebbles may have had a very different history from the unsilicified, feldspathic sand with which they are associated.

Immediate source of materials.—Yet even if the ultimate source of all the materials were known, it does not necessarily follow that the pebbles were transported the entire intervening distance at the time the Grover gravel was being laid down. They may first have been deposited in some Paleozoic, Mesozoic, or early Tertiary formation and later reworked into the Grover gravel.

The only strata exposed in the Hardin and Brussels quadrangles that contain siliceous pebbles and that are older than the Grover gravel are the beds of sandstone in the Pottsville formation. The pebbles found by the writer in the Pottsville sandstone are well rounded like those in the Grover, but they are scarce and small and apparently composed entirely of chert. (See p. 55.) It seems almost certain that these Pottsville beds, at least those exposed in the Hardin and Brussels quadrangles, could not have furnished either the quantity or all the different kinds of pebbles and boulders now present in the Grover gravel.

However, the Pottsville may be much more conglomeratic in other areas and thereby afford an ampler supply of gravel. In fact, Poor [50] has reported that, locally in southern Illinois, the Pottsville conglomerate contains many small well-rounded pebbles of quartz and numerous boulders of silicified oolitic limestone up to 2 feet in their major dimension "embedded in a matrix of coarse sand colored brown by a limonitic cement." He concluded that these materials came from the highland masses of southern Missouri and Illinois. Poor [51] also

[46] Shaw, E. W., in Stephenson, L. W., and Crider, A. F., op. cit., p. 99.

[47] Barrell, Joseph, Relations between climate and terrestrial deposits: Jour. Geology, vol. 16, p. 376, 1908; Marine and terrestrial conglomerates: Geol. Soc. America Bull., vol. 36, p. 340, 1925.

[48] Personal communication.

[49] Hopkins, T. C., Origin of conglomerates of western Indiana: Geol. Soc. America Bull., vol. 8, pp. 14–15, 1896.

[50] Poor, R. S., The character and significance of the basal conglomerate of the Pennsylvania system in southern Illinois: Illinois Acad. Sci. Trans., vol. 18, pp. 371–372, 374, 1925.

[51] Poor, R. S., op. cit., p. 373.

quotes Stuart Weller as authority for the statement that granite pebbles occur in the Pottsville elsewhere in southern Illinois. According to Weller [52] cross-bedded sandstones that contain "great numbers of smoothly rounded, white, quartz pebbles which vary in size from one-fourth of an inch to nearly an inch in diameter * * * are highly characteristic of the Pottsville formation * * * and widely distributed in the hills of the elevated country crossing Illinois south of Carbondale." Savage and Griffin [53] found pebbles, the largest 4 inches in diameter, of vein quartz, greenstone, granite, schist, and quartzite in a limestone bed in the McLeansboro formation in northern Illinois. They concluded that the crystalline rocks of northern Wisconsin were the most probable source of these pebbles. Savage and Griffin also refer to earlier records of quartzite boulders in Pennsylvanian rocks in Ohio and Tennessee. J. M. Weller [54] reports that, in general, the size of the quartz pebbles in Pennsylvanian rocks increases eastward from southern Illinois and western Kentucky into the Appalachian region.

Yet despite these reports from many regions, the fact remains that pebbles and boulders are neither abundant nor widespread in Pottsville and later Pennsylvanian rocks in the Mississippi valley. Doubtless the scattered Pennsylvanian pebbles contributed somewhat to the gravel in the Grover. Supplemented by local chert gravel and concentrated in narrow zones of deposition, they may even account for all the foreign material in the upland gravels of some areas. However, if Pennsylvanian conglomerates are to be considered the source of all the qualtzite, quartz, jasper, and metamorphic pebbles in the Grover gravel, it becomes almost if not absolutely essential to postulate that the Pennsylvanian rocks which once extended farther up the flanks of the Ozark Highlands were more highly and coarsely conglomeratic than the beds that now remain uneroded. This assumption is probably not an unreasonable one, but it should be noted that it is not founded upon any direct or independent evidence.

In southern Illinois, rocks of Chester (late Mississippian) age are more or less conglomeratic and contain pebbles of chert, quartz, and igneous rock.[55] No rocks of the Chester group were recognized in the Hardin and Brussels quadrangles. However, they are present [56] only 35 miles to the southeast, and they may once have extended into the area or onto the flanks of the Ozark Highlands and thus have contributed to the residual gravels of the region.

Nothing is known about Cretaceous sediments in the central part of the Mississippi Valley; they may or may not have been deposited there, and if so they may or may not have contained conglomeratic material. Cretaceous seas lay south of the Hardin and Brussels quadrangles in the Mississippi embayment and far to the west and northwest in the Western Interior region. At times either of these seas might possibly have extended into the central Mississippi Valley or, somewhat more probably, the region may have been the site of either widespread or very local sedimentation by streams that flowed into these seas. Local deposits of conglomeratic material have been recorded in Cretaceous beds at the head of the Mississippi embayment,[57] in southeastern Minnesota,[58] and in western Iowa.[59] Outliers of gravel in eastern Iowa [60] are thought to be of either Cretaceous or Tertiary age.

Similarly there is no record of either early Mesozoic or early Tertiary deposition in the central part of the Mississippi Valley, and the early Tertiary sediments in the Mississippi embayment region are not reported to be notably conglomeratic. It is of course possible that some Mesozoic or early Tertiary formation may have contributed some of the materials that make up the Grovel gravel but, in the absence of definite evidence that such conglomeratic beds were once present in the central Mississippi Valley, this assumption seems unwarranted.

Agents of transportation.—The means whereby the pebbles and boulders were carried from their distant and ultimate source to their final resting place in the Grover gravel is difficult if not impossible to ascertain. Much depends upon whether the long trip was made as a nearly continuous passage by a single method of transportation or as a series of shorter journeys by several different methods, interrupted by prolonged waits that may have lasted through one or more geologic periods.

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[52] Weller, Stuart. Some events in the geological history of southern Illinois: Illinois Acad. Sci. Trans., vol. 14, p. 30, 1921.

[53] Savage, T. E., and Griffin, J. R., Significance of crystalline boulders in Pennsylvanian limestone in Illinois: Geol. Soc. America Bull. vol. 39, pp. 421–428, 1928.

[54] Weller, J. M., Cyclical sedimentation of the Pennsylvanian period and its significance: Jour. Geology, vol. 38, p. 112, 1930.

[55] Weller, Stuart, The Mississippian Brachiopoda of the Mississippi Valley Basin: Illinois Geological Survey Mon. 1, p. 25, 1914; The Chester series in Illinois: Jour. Geology, vol. 28, pp. 287–290, 1920. Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 22, pp. 230, 232–233, 244, 1928.

[56] Weller, Stuart, The Chester series in Illinois: Jour. Geology, vol. 28, pp. 407, 413–414, 1920.

[57] Glenn, L. C., Underground waters of Tennessee and Kentucky west of Tennessee River and of an adjacent area in Illinois: U. S. Geol. Survey Water-Supply Paper 164, p. 24, 1906. Wade, Bruce, Recent studies of the Upper Cretaceous of Tennessee: Jour. Geology, vol. 28, pp. 380–384, 1920.

[58] Trowbridge, A. C., The erosional history of the Driftless Area: Univ. Iowa Studies, vol. 9, pp. 121–122, 1921.

[59] Bain, H. F., Geology of Guthrie County: Iowa Geol. Survey vol. 7, pp. 451–459, 1897.

[60] McGee, W J, The Pleistocene history of northeastern Iowa: U. S. Geol. Survey, 11th Ann. Rept., pt. 1, pp. 304–308, 1891. Calvin, Samuel, Geology of Delaware County: Iowa Geol. Survey vol. 8, pp. 160–162, 1898. Udden, J. A., Geology of Muscatine County: Iowa Geol. Survey vol. 9, pp. 316–320, 1899. Norton, W. H., Hendrixson, W. S., Simpson, H. E., Meinzer, O. E., and others, Underground water resources of Iowa: U. S. Geol. Survey Water-supply paper 293, p. 87, 1912. Howell, J. V., The iron ore deposits near Waukon, Iowa: Iowa Geol. Survey, vol. 25, pp. 58–59, 62, 1916. Trowbridge, A. C., The erosional history of the Driftless Area: Iowa Univ. Studies in Nat. History, vol. 9, no. 3 pp. 79–80, 112–113, 1921.

Almost the only evidence bearing on the agent or agents of transportation, as contrasted to the final agent of deposition, of the materials in the Grover gravel is the marked degree of rounding of the pebbles and boulders, especially of those composed of quartz and quartzite. The less-pronounced rounding of the chert pebbles may indicate that only the distinctly foreign materials have been transported great distances. However, chert commonly tends to break in angular fragments, and this difference of shape may have no significance. The rounding, together with the regular stratification, the occasional cross bedding, and the absence of the more readily soluble rocks, shows clearly that the materials in the Grover gravel were not transported and deposited by an early Pleistocene glacier, as has been suggested by Leverett.[61] (See also pp. 76, 78.) Furthermore, the rounding very probably could not have been caused by wind abrasion. It almost certainly was accomplished by long-continued abrasion in water that moved in currents swift enough to move the largest boulders and round off their corners. Beyond this, the rounding does not serve to distinguish the exact agent of transportation. Judged solely by the evidence of rounding, currents of water competent to move the boulders might with equal likelihood have been in the sea or in streams. If the pebbles have been reworked into the Grover gravel from Mississippian, Pennsylvanian, or Cretaceous conglomerates, most of their rounding and their long journeys may possibly have been accomplished in the sea. The exact agents, though unknown, might have been either shore currents along beach lines or, in order to account more reasonably for the large quartzite boulders, by being rolled along stream beds and then rafted across open water in floating masses of spring ice or uprooted trees.

Other characters of the pebbles that probably were acquired during some stage of transportation rather than at the time of deposition are the high degree of silicification and polish. The origin of these features is very imperfectly understood at the present time, but some geologists believe that both are indicative of long continued exposure to weathering or perhaps to evaporation and wind blast in arid climates.

Conditions of deposition.—Somewhat more is known about the conditions of final deposition than about the agencies of transportation. Yet no one theory of the conditions of deposition known to the writer is completely satisfactory in all its details.

McGee[62] concluded that the "Lafayette formation" of the Mississippi embayment and Coastal Plain regions was of marine origin. This proposed explanation can with reasonable assurance be eliminated for the Grover gravel. Not only are there no marine fossils to confirm the hypothesis but the large-scale cross bedding and the linear distribution of the remnants of the formation strongly suggest stream deposition. Furthermore, clay pebbles such as those found in some places in the gravel are generally considered good evidence that the beds containing them were exposed to air during at least a part of the time of their deposition.[63]

Pebbles, cobbles, and boulders are transported most effectively and deposited in greatest quantity during the mature stage of a stream's development.[64] In old age the weakened stream destroys the coarsest materials that may get into its channel and is unable to transport more from its headwaters. (See pp. 71–72.) Hence, it is conceivable that the rounded gravel in the Grover might possibly have been deposited in the region by early vigorous streams and let down as residual accumulations onto low divides that were out of reach of those streams that cut the final peneplain. And it is true that the thin veneer of gravel on the upland in central Calhoun County might possibly be a residual accumulation of this sort. However, those remnants of the formation that are stratified, especially the best-preserved remnants like the cross-bedded gravel and sand in western St. Louis County, Mo., clearly were not formed that way. And, inasmuch as the other remnants of the formation seem to lie upon the same peneplained surface as these stratified deposits, it appears most in accord with the data to interpret all these remnants as stream deposits rather than as residual accumulations.

This conclusion obviously leads to the question, "Could an old-age stream like that which bevelled the Calhoun peneplain transport boulders as large as those found in the Grover gravel?" The question cannot be answered categorically, and a number of geologists who have studied the problem seem to have found no satisfactory answer.

It is first necessary to recognize clearly a fundamental difference between peneplains and pediments. The streams that have cut the steeply-sloping but very sharply planed-off pediments[65] at the foot of mountains in arid regions are unqestionably competent to transport gravel and coarse boulders. But this fact in itself is no indication whatever of the transporting power of the streams that have cut the much gentler sloping extensive peneplains or areas of subdued relief in the humid interior lowlands.

[61] Leverett, Frank, Glacial deposits of Missouri and adjacent districts (abstract): Geol. Soc. America Bull., vol. 34, pp. 91–92, 1923.

[62] McGee, W J, The Lafayette formation: U. S. Geol. Survey 12th Ann. Rept., pp. 508–511, 1891.

[63] Grabau, A. W., Principles of stratigraphy, p. 711, 1913. Goldman, M. I., Petrographic evidence on the origin of the Catahoula sandstone of Texas: Amer. Jour. Sci., vol. 39, pp. 283–284, 1915. Matson, G. C., The Pliocene Citronelle formation of the Gulf Coastal Plain: U. S. Geol. Survey Prof. Paper 98, p. 175, 1916. Tieje, A. J., The red beds of the Front Range in Colorado; a study in sedimentation: Jour. Geology, vol. 31, p. 205, 1923. Twenhofel, W. H., Treatise on sedimentation, p. 497, 1926.

[64] Campbell, M. R., Geomorphic value of river gravel: Geol. Soc. America Bull., vol. 40, pp. 518–523, 1929.

[65] Johnson, Douglas, Planes of lateral corrosion: Sci., new ser., vol. 73, pp. 174–177, 1931.

The size of materials moved by a stream depends ultimately upon the velocity of the currents. If fine material is available in great quantities, the stream carries it and in so doing uses up the energy of fall—or velocity—and is unable to transport coarser material.[66] If there is no such excess of fine materials, the stream carries the largest of the pebbles available to it that its velocity will allow. This velocity in turn depends upon the slope or the fall of the stream, the quantity of water and of load that is being carried, and the amount of friction between the moving water and the stream bed. On equal slopes, shallow streams, or streams laden with much sediment, move less rapidly than relatively deep streams or streams of clear water. Large rivers, because they are relatively less retarded by bed friction, can flow faster and transport coarser material on flatter slopes than small creeks, which are compelled to expend much of their energy in contact with their stream beds. Hence, gradient alone is no measure of the size of material that can be carried. Even the observation that large streams seem unable to carry coarse gravel and cobblestones on slopes of less than 5 or 10 feet [67] or 2 or 3 feet [68] to the mile must therefore be used cautiously in any attempt to interpret conditions in the geologic past.

However, analogy with present large rivers of the area affords some enlightening information. Barrell [69] cites observations that boulders weighing 2,500 grams (approximately 5 inches in diameter) are not moved until the current at river bottoms attains a velocity of 1.80 meters (5.9 feet) per second and those weighing 1,000 grams (approximately 3½ inches in diameter) until the velocity reaches 1.59 meters (5.2 feet) per second. Other empirical relationships [70] that have been found between grain size and stream velocities indicate that the velocities required to move boulders 3½ to 5 inches in diameter are from 10 to 17 feet per second. The swiftest average velocities recorded on Illinois River and on Mississippi River above St. Louis, Mo., are 5.18 feet per second at Havana, Ill., and 5.19 feet per second at Hannibal, Mo.[71] Both of these average velocities were gaged at flood stages when the mean depth of water in the streams was more than 18 feet. It is well known that stream velocities tend to be greatest near the upper surface of the water and near the middle of the channel; they decrease notably downward toward the stream bed and laterally toward the two banks. Hence, the velocities near the beds of the Illinois and Mississippi Rivers were certainly much less than the average velocities of the entire streams and far from competent to transport boulders. Doubtless in some places and at exceptional flood stages, higher velocities are attained and some coarse material is moved, but from these velocity measurements alone there is no evidence that the Illinois or Mississippi rivers are competent to transport boulders for great distances.

This conclusion seems to be confirmed by examination of the materials actually being carried by Mississippi River. (See pp. 99–101.) Although Mississippi River falls less than 0.5 foot a mile between St. Paul, Minn., and St. Louis, Mo.,[72] this river, in one important respect, is greatly unlike streams that have cut peneplains. It flows through a young, deep, trenchlike valley from the sides of which steep tributaries bring in much coarse chert and glacial material. Many of these tributaries build small deltas at their mouths, but from time to time this material is swept away by floods and becomes, at least temporarily, a part of the river's load. In a study of the sediments in the Mississippi River, Lugn [73] found pebbles and boulders up to 4 or 6 inches in diameter near the mouth of many tributaries. Yet of the 235 samples for which he gives mechanical analyses more than half are composed entirely of materials less than 4 millimeters in diameter, and only 14 contain any pebbles larger than 16 millimeters in diameter. (See also pp. 99–100.)

Littlefield [74] also found gravel near the mouths of Arkansas and Red Rivers and where Mississippi River crosses the outcrop of the conglomeratic Citronelle formation but farther downstream gravel was absent. Trowbridge [75] reports that the largest grains carried to the Gulf by Mississippi River are from ½ to ¼ millimeter in diameter.

Considering the great quantities of coarse material brought to the river by tributaries and the abundant supplies of Pleistocene gravels in and on the flood plains (see p. 101), it is indeed surprising that so little coarse material can be found. Boulders probably move only short distances even at times of exceptional floods, and hence they are subjected to great abrasion from the continuous blast of sand grains swept over and past them at all times of the year.[76] As stated on page 101, the rapid disappearance of gravel downstream from the tributaries of Mississippi River may be caused by this

[66] Gilbert, G. K., Report on the geology of the Henry Mountains, pp. 106–108, 110–111, U. S. Geog. & Geol. Survey Rocky Mountain Region, 1877.

[67] Barrell, Joseph, Relations between climate and terrestrial deposits: Jour. Geology, vol. 16, pp. 256–257, 1908.

[68] Barrell, Joseph, Marine and terrestrial conglomerates: Bull. Geol. Soc. America, vol. 36, pp. 324–325, 1925.

[69] Barrell, Joseph, op. cit., p. 317, 1925.

[70] Gilbert, G. K., The transportation of débris by running water: U. S. Geol. Survey Prof. Paper 86, pp. 163, 216, 1914.

[71] Mississippi River Commission, Results of discharge observations, Mississippi River and its tributaries and outlets, 1838–1923, pp. 227, 47, St. Louis, Mo., 1925.

[72] Gannett, Henry, Profiles of rivers in the United States: U. S. Geol. Survey Water Supply Paper 44, pp. 39–40, 1901.

[73] Lugn, A. L., Sedimentation in the Mississippi River between Davenport, Iowa, and Cairo, Illinois: Augustana Library Pubs. no. 11, pp. 20, 30–32, 34–35, 41–43, 46, 49, 52, 55, 57, 60, 71, 77, 81, 83, 86–87, 90, 1927.

[74] Littlefield, Max, Mississippi River gravels below the mouth of the Arkansas River (abstract): Geol. Soc. America Bull., vol. 38, p. 147, 1927.

[75] Trowbridge, A. C., Disposal of sediments carried to the Gulf of Mexico by Southwest Pass, Mississippi River (abstract): Geol. Soc. America Bull., vol. 38, p. 148, 1927.

[76] Barrell, Joseph, Marine and terrestrial conglomerates: Geol. Soc. America Bull., vol. 36, pp. 330–331, 335–336, 338, 1925.

wearing away of pebbles by the constant stream of passing sand.

Whatever the explanation, it seems certain that the present Mississippi River, despite its bluff-bordered valley, is carrying much smaller pebbles and a tremendously greater proportion of fine material than the streams that deposited the Grover gravel. It thus seems fair to conclude that, in order to transport the materials of the Grover gravel, the early stream or streams must have been less choked with fine sediment, have flowed on steeper gradients, or have carried a larger volume of water than the present Mississippi River.

Yet under the conditions and at the time when the upland peneplain was being cut, it seems extremely improbable that any one of these three alternatives could account satisfactorily for the deposition of the Grover gravel. On the reduced slopes of an old-age topography, weathering is deep, and therefore even finer-grained sediment would be expected on streams flowing upon the peneplain than in the present river. Also, if long through-flowing streams that rose in or beyond the ultimate sources of the gravel must be assumed, then gradients much steeper than that of the present Mississippi are out of the question, both because of the excessive elevations demanded and the approximate parallelism of the surface on which the upland gravels lie and the gradient of the present streams. Nor do rivers much larger than the present ones seem at all probable. The Mississippi River, even that part of it above the mouth of the Missouri, is one of the largest rivers of the continent and there seems to be no reason to think that before Pleistocene time it ever carried a greater volume of water than it does today. In fact, if the Grover gravel is of Tertiary age, our knowledge of geologic history, deduced from rocks of this age in other areas, would lead us to expect smaller rather than larger streams.

Deposition by rejuvenated streams.—The difficulties just mentioned of accounting for the transportation of boulders and pebbles by the streams that fashioned the peneplained surface have led a number of geologists to believe that the upland gravels must have been deposited upon this surface by streams, the transporting power of which had been rejuvenated by climatic change or by crustal warping.

Several writers [77] have called attention to the fact that crustal warping is especially likely to affect different areas in different ways but that climatic changes will have a very similar effect upon broad tracts of country. Barrell,[78] in particular, pointed out that a change from a relatively arid to a relatively humid climate would increase the transporting power of streams and cause them to pick up coarser detritus in the upper reaches and sweep it far out over the lower flood plains. Noting that evidence in the eastern and western parts of the continent indicates a change near the close of the Tertiary and the beginning of Pleistocene time from a dryer to a wetter climate and accepting the wide correlations of the "Lafayette formation" that had been made, Barrell [79] suggested that the upland gravels may have been deposited during this climatic change.

The proposal is an ingenious one that seems to fit nicely the concept of a widespread gravel of very late Tertiary age. The chief difficulty met with in attempting to apply this explanation to the Grover gravel is the apparent corollary that sets the age of the formation at or immediately following the change to a colder and more rainy Pleistocene climate. So late a date seems to the writer very improbable; it appears to leave altogether too little time for the development of the intermediate postmature surface (see pp. 103–104, 109–110) and for the cutting of the trench in which earliest Pleistocene deposits have been found (see pp. 65, 76, 80–81, 103).

Similarly influenced by the widespread correlation of the "Lafayette formation" then current, Chamberlain and Salisbury [80] interpreted the upland gravels as the result of a series of gentle uplifts that spread gradually down the streams from the headwaters to the coast line. This explanation was apparently accepted by Fenneman [81] for the upland deposits of St. Louis County. The conception of gradually advancing uplifts accounts for widespread remnants of gravel upon the uplands, and at the same time it successfully avoids the great elevations demanded by continuous steep gradients. However, the type of uplift postulated is an exceedingly special case for which, so far as the writer is aware, there is no independent evidence in this or other regions.

A modification of this theory of uplift may possibly explain the present distribution of the Grover gravel. If it should prove true that the upland gravels were once correlated over much too great an area and if, as seems possible, the foreign pebbles and boulders were derived from nearby Paleozoic or Mesozoic conglomerates, then

[77] Johnson, W. D., The High Plains and their utilization: U. S. Geol. Survey 21st Ann. Rpt., pt. 4, pp. 626, 628–630, 1901. Davis, W. M., A journey across Turkestan, in Pumpelly, Raphael, Explorations in Turkestan: Carnegie Institution of Washington Pub. no. 26, p. 53, 1905. Huntington, Ellsworth, A geologic and physiographic reconnaissance in central Turkestan, in Pumpelly, Raphael, Explorations in Turkestan: Carnegie Institution of Washington Pub. no. 26, pp. 203–208, 1905; The basin of eastern Persia and Sistan, in Pumpelly, Raphael, Explorations in Turkestan: Carnegie Institution of Washington Pub. no. 26, p. 254, 1905. Barrell, Joseph, Relations between climate and terrestrial deposits: Jour. Geology, vol. 16, p. 373, 1908. Huntington, Ellsworth, The climatic factor as illustrated in arid America: Carnegie Institution of Washington Pub. no. 192, pp. 23–24, 28–33, 1914. Barrell, Joseph, Marine and terrestrial conglomerates: Geol. Soc. America Bull., vol. 36, p. 339, 1925.

[78] Barrell, Joseph, Relations between climate and terrestrial deposits: Jour. Geology, vol. 16, pp. 368, 372, 382, 1908; Marine and terrestrial conglomerates: Geol. Soc. America Bull., vol. 36, pp. 337–338, 1925.

[79] Barrell, Joseph, Relations between climate and terrestrial deposits: Jour. Geology, vol. 16, pp. 376–377, 1908; Marine and terrestrial conglomerates: Geol. Soc. Bull., vol. 36, pp. 339–340, 1925.

[80] Chamberlain, T. C., and Salisbury, R. D., Geology, vol. 3, pp. 305–306, 1906.

[81] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle: U. S. Geol. Survey Bull. 438, p. 44, 1911.

it is no longer necessary to seek some climatic change or wave of advancing uplifts that would affect the entire Mississippi valley equally. A simple uplift of the Ozark Highlands might thus account for the deposition of the Grover gravel.

How might this simple concept fit the detailed facts? Pebbles and boulders transported somehow from a distant ultimate source were first deposited in Mississippian, Pennsylvanian, and possibly in Cretaceous sediments. During later uplift, erosion, and weathering, these pebbles and abundant chert from the underlying limestones accumulated upon the broad area that constitutes the present Ozark Highlands. And during this weathering any feldspathic pebbles may have been decomposed and the residual quartzose gravels further silicified. To the east and northeast a large southward-flowing stream had become established in approximately the same position as the present Mississippi River. If at this time the Ozark Highlands were gently uplifted, the eastward and northeastward flowing tributaries would be steepened, and they would sweep great quantities of the residual gravel into the large stream.[82] Thus might the linear north-south distribution of the formation, the southward dip of the cross bedding, and the unsilicified feldspathic sand, on the one hand, and the silicified quartzose gravel, the poor sorting of the materials, and the apparent coarsening toward the Ozarks, on the other, be consistently explained.

If the assumed uplift took place during the Tertiary period, ample time would be allowed for the cutting of the intermediate upland surface and the deep pre-Pleistocene trench. The assumption of gentle movements in the Ozark region as recently as the Tertiary period is supported by abundant evidence. (See pp. 104–105, 145–146.) The greatest weakness of this hypothesis of local uplift seems to be the assumption that the quantity of foreign pebbles and boulders in Paleozoic or Mesozoic rocks was adequate to supply all those present in the Grover gravel.

Preservation.—Even after the Grover gravel was deposited upon the peneplained surface, conditions must have changed in some way so as to permit its preservation until the present time. Most sediments, whether of continental or marine origin, will not be preserved unless they are soon buried by later accumulations. If uplifted above the site of deposition, they are soon carried away by erosion; if not uplifted, the depositing agent itself gradually grinds them away and removes them. Burial is required to protect most newly deposited sediments. According to one geologist, "in order that grăvel may remain as conglomerate formations, either of terrestrial or marine origin, it must be progressively buried below the zone of erosion."[83] By this reasoning, it would follow that the Grover gravel must have been buried beneath later sediments in order to protect it from abrasion by the streams in which it was deposited. But, if ever present, any such overlying sediments must have been removed after later uplift, for there is no record of their former presence in the remnants of upland deposits left today.

It is by no means certain that any such protecting mantle of sediments was ever deposited upon the Grover gravel. Gravel is in one important respect quite unlike other sediments. It may be preserved not only by burial but also by uplift. It is doubtless true that the gravel would have been ground small by rolling or filed away by passing sand if the depositing streams had continued to flow at the same level. But if shortly after the gravel was laid down, the rejuvenated streams began cutting deeper into the peneplain, the gravel would be left above water level, exposed, it is true, to weathering and erosion, but out of reach of the continuous rasp of the river's sediment. With additional uplift or deeper trenching of the streams, the abandoned gravel would be left farther above water level upon the uplands. Because gravel is more porous than most other rocks and is made up of larger fragments, small streams do not readily gain a foothold nor develop rapidly in it. Furthermore, quartzose gravels are a concentrate of the most chemically resistant rock types and they decompose very slowly under long-continued weathering. Hence quartzose gravels that lie upon an upland surface are especially resistant to erosion and weathering,[84] and it is not until the larger streams have cut into and removed the upland surface itself that the deposits of gravel disappear.

In other words, the fact that remnants of the Grover gravel have been preserved on the uplands certainly indicates, and probably proves, that the formation either was protected by a mantle of sediments or was deposited by streams that were rapidly intrenching themselves. Inasmuch as there is no evidence of a former protecting mantle but much independent evidence that the gravel was deposited by rejuvenated streams (p. 72), the second alternative seems much more probable.

Or, reversing the argument, the fact that remnants of the Grover gravel are preserved on the present uplands converges with other evidence in indicating that the gravels were deposited by rejuvenated streams.

Summary of origin.—Scattered remnants of the Grover gravel, ranging from a few feet to 30 feet in thickness, have been reported in a relatively narrow north-south zone more than 100 miles long and roughly parallel to the course of the present Mississippi River. The thickest and best exposures known are on the remnants of the upland peneplain in western St. Louis County, Mo., where cross-bedded layers dip steeply

[82] Smith, W. S. T., and Siebenthal, C. E., U. S. Geol. Survey Geol. Atlas, Joplin folio (no. 148), p. 8, 1907.

[83] Barrell, Joseph, Marine and terrestrial conglomerates: Geol. Soc. America Bull., vol. 36, p. 341, 1925.

[84] Rich, J. L., Gravel as a resistant rock: Jour. Geology, vol. 19, pp. 492–497, 1911.

southward. Gravel, the most conspicuous constituent of the formation, consists entirely of quartzose pebbles and boulders with maximum diameters of 1 to 2 feet—chiefly "bronzed" chert, well-rounded quartzite, and polished quartz but also some silicified sedimentary and metamorphic rocks. The sand grains associated with the gravel are composed chiefly of quartz and chert, but, unlike the gravel, they include also some fresh feldspar and they show no evidence of secondary silicification. Stratigraphic and physiographic evidence shows that the formation is clearly post-Pennsylvanian, pre-Pleistocene, probably post-Eocene, pre-Pliocene, and possibly late Miocene in age.

A discussion of the origin of the Grover gravel is taken up under the headings of ultimate and immediate sources of the materials, agents of transportation, and conditions of deposition and preservation. The nearest original source of the foreign materials that has been suggested is the northern Mississippi Valley, but the immediate source of some of these materials may have been pebbles deposited first in Pottsville or late Mississippian rocks and reworked into later gravels. Otherwise, the apparent coarsening of the pebbles and boulders in the Grover southward toward the Ozarks contradicts the evidence of their original source and the direction of cross bedding. The rounding of the pebbles indicates long-continued abrasion in water, and the silicification and the polish may possibly suggest exposure to weathering or an arid climate. A marine, a glacial, or a residual origin appears out of the question and streams seem the only competent agent of final deposition. But it seems highly improbable that streams flowing normally on a nearly flat peneplain, such as that on which the formation rests, could have carried such coarse materials. Even large rivers, like the present Mississippi, which flow in trenches between steep tributaries, carry no boulders as large as those in the Grover gravel. And, furthermore, the apparent absence of a protective cover suggests that this formation was preserved by uplift immediately after deposition. Hence, for these two reasons, deposition by rejuvenated streams seems very probable. To account for the presumed widespread deposition of the "Lafayette" gravel, Barrell suggested increased rainfall at the beginning of the Pleistocene, and Chamberlin and Salisbury postulated a neatly adjusted series of uplifts that spread gradually downstream. Barrell's explanation makes the formation much too young and, if the upland gravels are not so widespread as once thought, Chamberlin and Salisbury's very special type of wavelike uplift is not demanded. An uplift of the Ozarks alone might have been sufficient. Pebbles deposited first in late Paleozoic rocks could have been mixed with residual cherts during the long period of Mesozoic and Tertiary weathering on the Ozark Highlands. A gentle uplift at that time would have swept these gravels northeastward into the ancestral Mississippi, a stream that apparently flowed southward along the line of the present Grover remnants. Feldspathic and unsilicified sand might thus be deposited along with weathered and silicified gravel.

PLEISTOCENE AND TERTIARY

RESIDUAL CHERT AND CLAY

Lying upon many of the Paleozoic formations, above and below the Grover gravel, and below the Pleistocene loess is an irregular covering of residual chert and clay. This covering attains a maximum thickness of about 40 feet on the Burlington uplands near Williams Hollow and Coon Creek (p. 44) and a thickness of 5 to 10 feet on uplands and intermediate benches and in sinkholes in many other places. In parts of the area it is absent below the Illinoian till.

The material consists of nodules and broken fragments of chert, from less than 1 inch to more than 1 foot in diameter, set in a structureless matrix of red, gritty, noncalcareous, plastic clay.

This residual chert and clay is the product of long-continued weathering of the underlying rocks, and it therefore grades almost imperceptibly into each of the formations that it overlies. Almost certainly it was not all formed at the same time. Its accumulation probably began before the completion of the Calhoun peneplain (pp. 102–104) and continued until the uplifted and dissected peneplain was buried by loess. The mode of formation of this material was identical with that of the local accumulations of residual chert in the lower part of the Pottsville clay (p. 55) and with the "gumbo" formed on Pleistocene gravel, till, and loess (pp. 75–76, 80, 89). Where this residual chert and clay have been transported very short distances by streams or by soil creep, they grade insensibly into the materials here classified as Recent and Pleistocene stream deposits, slope wash, and talus. In many places these residual accumulations appear to grade into the overlying loess.

PLEISTOCENE

The divisions of Pleistocene time most widely used in North America are listed below:[85]

Recent time.
Pleistocene time.
- Wisconsin glacial stage.
  - Peorian interglacial stage.
- Iowan glacial stage.
  - Sangamon interglacial stage.
- Illinoian glacial stage.
  - Yarmouth interglacial stage.
- Kansan glacial stage.
  - Aftonian interglacial stage.
- Nebraskan glacial stage.

Pliocene time.

[85] Wilmarth, M. G., The geologic time classification of the United States Geological Survey; U. S. Geol. Survey Bull. 769, p. 46, 1925.

Probably all the Pleistocene stages except the Nebraskan, Aftonian, and Iowan are represented by deposits in the Hardin and Brussels quadrangles. These deposits consist of glacial till, wind-blown loess, and gravel, sand, silt, and clay laid down in rivers, small streams, and ponds.

These varied Pleistocene deposits record a history of two ice advances into but not across the Hardin and Brussels quadrangles and of varying levels of river deposition and cutting at different times. The area lay near the margin of two or three great continental ice sheets, but the movement of these sheets had been so retarded that further advance was barred by the deep trenches of Mississippi and Illinois Rivers and by the uplands of the Lincoln anticline; hence, the Hardin and Brussels quadrangles were not overspread by glaciers as were the regions to the west, north, east, and southeast. (See fig. 4.) The Kansan ice sheet advanced southeastward and eastward to and around the Lincoln Ridge in Missouri and into the Mississippi River trench; there it lay for a time along part of the western edge of the Hardin and Brussels quadrangles. The Illinoian ice sheet advanced southwestward to the uplands in southwestern Jersey County and into the Illinois River trench, but it did not encroach upon the uplands of Calhoun County. During both the glacial and the interglacial stages, the area outside the limits of glaciation was profoundly affected by the changing regimen of the rivers and streams. At times the rivers were filled with sediment to elevations as much as 100 feet or more above their present level; at other times they probably cut to depths equally far below their present level.

As in the case of the stratigraphic discussion of the Grover gravel, much that follows on the stratigraphy of the Pleistocene deposits might more logically have been included in the section of the report on Physiography. However so many of the questions of correlation, age relationships, and origin depend upon physiographic facts and interpretations that it seemed more convenient, both for the reader and the writer, to discuss these physiographic relations in places where their significance is most readily apparent.

Fossils collected from Pleistocene stream deposits and loess in the Hardin and Brussels quadrangles were studied and identified by Dr. F. C. Baker. Dr. J. P. E. Morrison, associate curator, United States National Museum, kindly brought the nomenclature up to date in 1948 and arranged the names in biologic order as given on pages 174–175.

KANSAN GRAVEL AND TILL (?) NEAR BATCHTOWN

The earliest Pleistocene deposits in the Hardin and Brussels quadrangles that can be dated with any degree of assurance are some deeply weathered stream-laid sediments here called the gravels in the Batchtown channel. These deposits crop out on the western side of Calhoun County for about 6 miles along an old valley that is now crossed and dismembered by present-day streams. This old valley runs north and south through the town of Batchtown and essentially parallel to the strike of the Paleozoic rocks. It is the belt of Maquoketa lowlands (see pp. 21–22), and it lies between the uplands made by the Kimmswick limestone on the west and the Silurian, Devonian, and Mississippian formations on the east. At a few places immediately west of this old valley there are poor exposures of some bouldery deposits that may be either deeply weathered gravel or glacial till.

This gravel was found well exposed in only four places. The best of these is in a small eastward-draining gully in the NE¼SW¼NE¼ sec. 17, T. 12 S., R. 2 W., slightly less than 1 mile south of Batchtown, where the gravel extends up to an elevation of about 540 feet. The gravel is also exposed about 400 feet south of this locality in the west bank of the creek and again about one-half mile to the south on the east side of the road in the SE¼NW¼SE¼ sec. 17. The only other good exposure found by the writer was in the NE¼SW¼NW¼ sec. 32, T. 11 S., R. 2 W., 2¼ miles north of Batchtown. Fragmentary exposures and partially reworked deposits of the gravel at numerous other places indicate a more general distribution of the formation.

At the best exposures the material consists of indistinctly bedded gravel and sand which seems to grade upward into a sticky sandy clay or "gumbo." The gravel consists dominantly of chert, but there are also many pebbles of igneous and metamorphic rocks. Quartz pebbles and fragments of coarse- and medium-grained ferromagnesian igneous rocks are conspicuous, but quartzite, schist, and phyllite also are present. However, silicic igneous rocks are noticeably uncommon. The pebbles range from well-rounded to highly angular, but most of them are somewhat rounded, many are distinctly facetted, and a very few are striated. Nearly all the fragments are pebbles less than 3 inches in diameter, but some are boulders with a maximum diameter of 1½ or 2 feet. The sand grains between the pebbles range from coarse to medium in grain size and well-rounded to subangular in form. Nearly all the sand grains seem to be made of quartz.

The material was clearly deposited by streams, yet the igneous and metamorphic rocks and the numerous facetted pebbles and the occasional striated pebbles virtually prove that the materials were carried by ice, probably to within a short distance of the site of deposition.

The gravel and sand is overlain by 8 to 12 feet of gray to brown sandy clay that contains thin gravelly layers and scattered pebbles. In the lower part of this clay the pebbles are indistinguishable from and nearly as abundant as those in the underlying gravel but they become scarcer, smaller, and finer-grained above, and in the upper part they are difficult to find. This more or less pebbly sandy clay grades in turn into brown clayey silt that is indistinguishable from loess.

As pointed out to the writer by M. M. Leighton, the gravel and the overlying sandy clay in these exposures correspond to horizons 3 and 2 in a "poorly drained profile of weathering."[86] On this interpretation, the 8 to 12 feet of sandy clay is "gumbo gravel"; it and perhaps some of the overlying loesslike silt were formed by the long-continued weathering and nearly complete decomposition of the original gravel. Thicknesses of 8 to 12 feet of horizon 3 have been found in the central Missisipi Valley region only on early Pleistocene deposits.[87]

Wells drilled in the old valley in the town of Batchtown failed to reach bedrock at depths of 65 and 70 feet. According to local reports these wells penetrated from 20 to 36 feet of loess and then encountered water-bearing sand, gravel, and clay. They thus indicate that these gravels in the Batchtown channel probably filled the old valley to a thickness of more than 45 feet or to an elevation of about 560 feet above sea level.

The deposits immediately west of the old valley, such as those in the NW¼SW¼ sec. 5, T. 12 S., R. 2 W., are so thoroughly decomposed that no bedding is preserved. This structureless but bouldery gumbo is poorly exposed, and it is not known whether it was originally stream gravel or glacial till.

Reconnaissance examinations in northern St. Charles County, Mo., by M. M. Leighton and the writer and in eastern Lincoln County, Mo., by the writer indicate that Kansan till, continuous with that which forms the widespread till plains of northern Missouri, mantles the uplands eastward to the river bluffs in southeastern Lincoln County, only 4 miles west of the Hardin and Brussels quadrangles. The eastern margin of the Kansan ice sheet here was distinctly lobate, and a large lobe extended into the ancient trench of Mississippi River west of Batchtown. (See also p. 117.) This lobe probably lay for a time along or against the western bluffs of Calhoun County. (See fig. 4.) It seems highly probable, therefore, that the facetted and striated igneous and metamorphic pebbles of the gravels near Batchtown were deposited by a marginal glacial stream that was diverted eastward into the old north-south valley by this Kansan ice lobe. The southern outlet of this old Batchtown channel is not known. The diverted waters may have crossed Calhoun County over the col in the NW¼ sec. 34, T. 12 S., R. 2 W., or they may have turned back westward in sec. 33, T. 12 S., R. 2 W., into the Mississippi River trench. (See fig. 5.)

[86] Leighton, M. M., and MacClintock, Paul, Weathered zones of the drift sheets of Illinois: Jour. Geology, vol. 38, pp. 28–53, 1930.

[87] M. M. Leighton, personal communication.

NEBRASKAN AND OTHER PRE-ILLINOIAN DEPOSITS NEAR THE HARDIN AND BRUSSELS QUADRANGLES

Pre-Illinoian till and gravel have been reported from several localities outside the main area of Kansan glaciation. Of these, the most definite record seems to be the occurrence of Nebraskan and Kansan tills below Illinoian till in a tributary of Illinois River in Scott County, near Winchester, Ill., 25 miles north of the Hardin quadrangle.[88] (See fig. 4.) Leverett and Leighton [89] have found Kansan and probably Nebraskan tills in the trough of Mississippi River near Quincy, Ill., 50 miles northwest of the Hardin quadrangle.

MacClintock [90] has described several other exposures of pre-Illinoian till and loess in Scott County, one in Morgan County, and one in Greene County. (See fig. 4.) This occurrence of Nebraskan or Kansan till in Greene County, only 6 miles east of the Hardin quadrangle, was recognized by the superposition of 15 feet of unoxidized calcareous Illinoian till upon 18 feet of oxidized calcareous till.[91]

MacClintock [92] has further suggested that the extreme flatness of the Illinoian till plain may be due to the presence of pre-Illinoian drift filling all irregularities in the preglacial topography. Under this hypothesis, pre-Illinoian drift might be expected to underlie the flat Illinoian till plain in the eastern part of the Hardin quadrangle. No till or other deposits of pre-Illinoian age sufficient to fill these irregularities were recognized by the writer in this region. Furthermore, it may be noted that this hypothesis to explain the flatness of the Illinoian till plain carries with it the corollary that the flat Kansan till plain of northeastern Missouri should likewise be underlain by pre-Kansan drift, a conclusion which is unsupported by any evidence known to the writer.

Leverett [93] has reported remnants of Nebraskan (?) drift outside the limits of Kansas glaciation in eastern Missouri and western Illinois, including "scattered boulders and smaller erratics" on the highest divides of Calhoun County, Ill., which he thinks "may represent an earlier glaciation than the Kansan and be reduced on that account to a scanty deposit." From detailed examinations in Calhoun County, the writer feels reasonably certain that the pre-Nebraskan (see p. 70) stream deposits of the Grover gravel were mistaken for Nebraskan (?) drift. And from reconnaissance examina-

[88] Bell, A. H., and Leighton, M. M., Nebraskan, Kansan, and Illinoian tills near Winchester, Illinois: Geol. Society America Bull., vol. 40, pp. 481–489, 1929.

[89] Leighton, M. M., Personal communication.

[90] MacClintock, Paul., Recent discoveries of pre-Illinoian drift in southern Illinois: Illinois Geol. Survey Rept. Inv. 19, pp. 51–54, 1929.

[91] MacClintock, Paul, op. cit., p. 51 and fig. 10.

[92] MacClintock, Paul, op. cit., pp. 56–57; Physiographic divisions of the area covered by the Illinoian drift sheet in southern Illinois: Illinois Geol. Survey Rept. Inv. 19, pp. 24–25, 1929.

[93] Leverett, Frank, Glacial deposits of Missouri and adjacent districts (abstract): Geol. Soc. Amer. Bull., vol. 34, pp. 91–92, 1923.

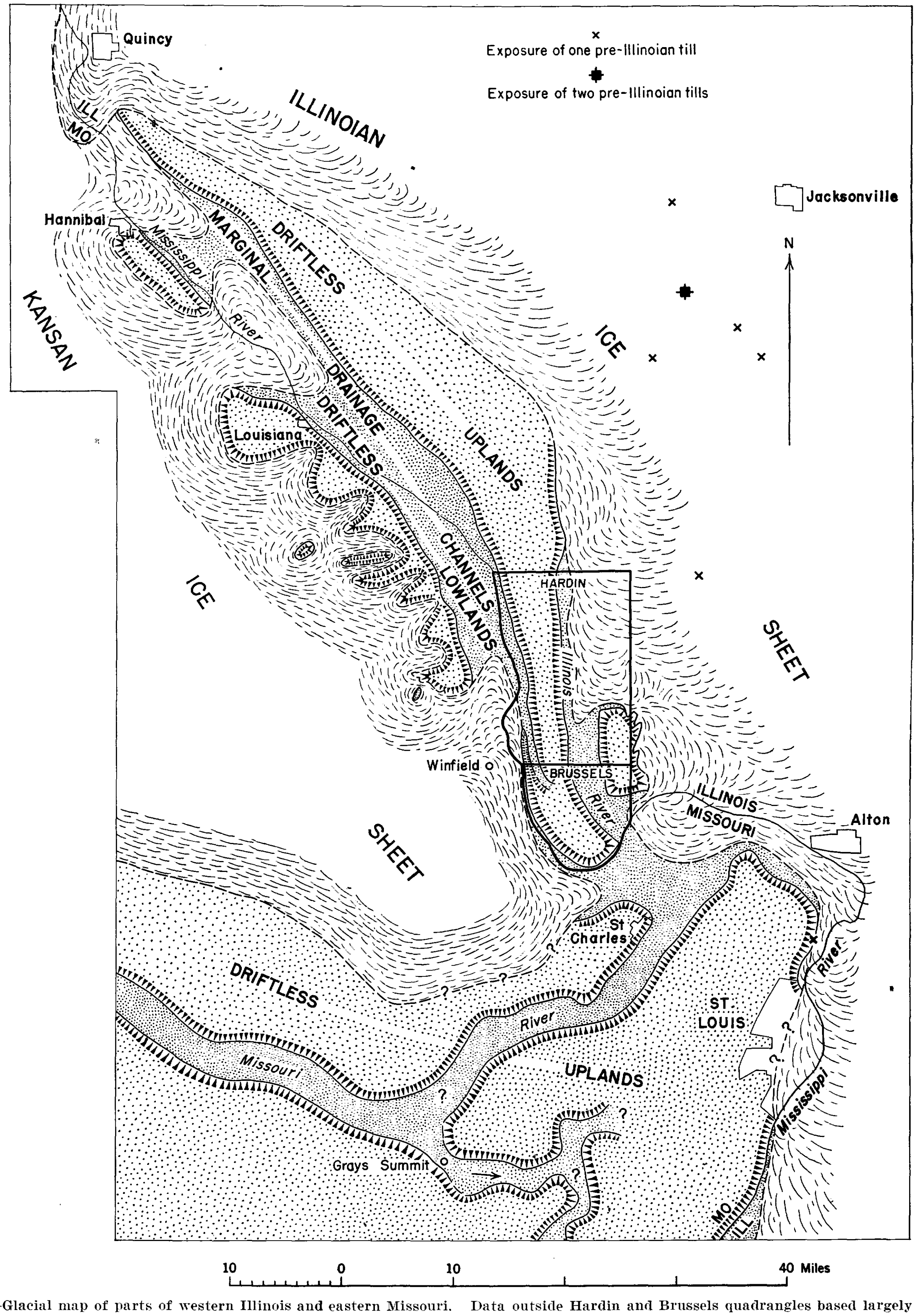

FIGURE 4.—Glacial map of parts of western Illinois and eastern Missouri. Data outside Hardin and Brussels quadrangles based largely on: Todd, J. E., Formation of the Quaternary deposits: Missouri Geol. Survey, vol. 10, pl. 12, pp. 140, 183, 207, 1896. Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pl. 6, 1899; Oldest (Nebraskan?) drift in western Illinois and southeastern Missouri in relation to the "Lafayette gravel" and drainage development (abstract): Geol. Soc. America Bull., vol. 35, p. 69, 1924. Bell, A. H., and Leighton, M. M., Nebraskan, Kansan, and Illinoian tills near Winchester, Ill.: Geol. Soc. America Bull., vol. 40, fig. 1, pp. 484–486, 1929. MacClintock, Paul, Recent discoveries of pre-Illinoian drift in southern Illinois: Illinois Geol. Survey Rept. Investig. no. 19, fig. 1, pp. 51–54, 1929. Antevs, Ernst, Maps of the Pleistocene glaciation: Geol. Soc. America Bull., vol. 40, fig. 6, p. 643, 1929. Modification of Todd's mapping between Winfield and Louisiana, Mo., based on reconnaissance by W. W. Rubey.

tions in western St. Louis County, Mo., it seems possible that a similar misinterpretation was made there. (See also p. 117.)

Fenneman [94] reported three occurrences of pre-Illinoian gravel (and till?) in and below the river bluffs near Chain of Rocks Waterworks north of St. Louis, Mo. (See fig. 4.) Messrs. Leighton and MacClintock and the writer examined two other exposures of partially decomposed pre-Illinoian gravel and silt nearby—one on the west side of Broadway near the east corner of O'Fallon Park, the other on the west side of Riverside Drive, one-half mile north of the Chain of Rocks Waterworks.

EARLY PLEISTOCENE CLAY

In many valleys throughout the Hardin and Brussels quadrangles there are small exposures of a peculiar hard pitted clay 10 feet or more thick that underlies the middle and late Pleistocene loess, the Illinoian drift, and the Brussels formation. This clay is massive in structure and bluish gray to tan in color, depending upon the degree of oxidation. It is essentially noncalcareous and rather poorly sorted; it contains some sand grains and many particles the size of silt.

The distinctive characteristics of the clay are its hardness and its peculiar pitted surface. So hard is it that where its outcrop is crossed by streams it commonly forms a firm rocklike bed and in a few places miniature waterfalls. The peculiar pitted surface is caused by the washing away of soft plastic clay that fills many long cylindrical holes from 1 to 3 inches in diameter in the hard clay. The origin of these numerous cylindrical holes is unknown; in some places they resemble cavities left by the decay of roots, elsewhere they are related to concretionary deposits of iron oxide, but most commonly they resemble the borings of some small animals, such as crayfish.

The sand grains washed from three samples of the hard clay were found to consist chiefly of well-rounded to subangular grains of quartz and chert from 0.1 to 0.6 millimeter in diameter and subordinately of orthoclase and small spherules of calcite. Many of the quartz grains have crystal faces formed by secondary enlargement.

The exact age of this hard massive clay is not known. It underlies and thus is clearly older than the Sangamon(?) loess, the Brussels formation, and the Illinoian till and marginal pond deposits. It is not certainly Yarmouth nor even pre-Illinoian, however, for its relationship to the dark gray, calcareous clay in the base of the Brussels formation (pp. 83, 85) is unknown. It may be the leached equivalent of this calcareous clay or it may be much older.

ILLINOIAN TILL AND ASSOCIATED STRATIFIED DRIFT

East of Illinois River and north of Otter Creek the uplands of the Hardin quadrangle are heavily covered with Illinoian till and some intimately associated beds of stratified drift. South of Otter Creek the western margin of these deposits coincides approximately with the eastern limit of the two quadrangles, thus about 20 square miles of upland in Jersey County east of Illinois River and all of the uplands in Calhoun County west of Illinois River are driftless. (See figs. 4, 5.)

Topographic expression.—These deposits of the Illinoian ice sheet fill depressions in a fairly rugged preglacial topography, and they form the flat, nearly featureless Illinoian till plain that covers about one-half of the State of Illinois. Immediately east of the Hardin quadrangle this till plain is monotonously flat with only a few morainic or drumlinlike mounds scattered here and there upon it.[95] But within the Hardin quadrangle, a few miles from the former margin of the ice sheet, this till plain curves down into minor stream valleys, and, even upon the upland where relatively flat, it is interrupted by fairly numerous small and irregularly shaped drumloidal or kamelike knolls. (See p. 118.)

Within the Hardin and Brussels quadrangles the actual margin of the former ice sheet can be observed only in the area south of Otter Creek, for elsewhere it extended into the lowlands of Otter Creek and Illinois River where all records have been removed by subsequent erosion. Where it can be observed most accurately, the limit of the glacial till is marked by marginal or proglacial ponds (pp. 81–82), but no well-defined terminal moraine can be recognized. The Illinoian till plain merges almost imperceptibly into the remnants of the Calhoun peneplain. (See pl. 20.)

Near the mouth and on the northern side of both Crawford Creek and Kampsville Hollow (Pearl quadrangle), 2½ and 3½ miles north of the Hardin quadrangle, are conspicuous gravel bars that stand 100 or 125 feet above the flood plains. The upper surfaces of these bars slope westward up the two tributary valleys. The reconnaissance nature of the examination of these deposits did not permit a determination of their exact origin; they may represent deltas built into the tributary valleys or bars deposited across the valley mouths. Nevertheless, it seems reasonably certain that the gravel bars were formed immediately in front of if not actually at the Illinoian ice front, and they therefore serve to indicate approximately the eastern margin of the "driftless area" immediately north of the Hardin quadrangle.

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[94] Fenneman, N. M., Physiography of the St. Louis area: Illinois Geol. Survey Bull. 12, pp. 9, 58, 1909; Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, pp. 31–32, 46, 1911. Anonymous, Notes on the geology of St. Louis and vicinity, accommodated to the text of Le Conte's Compend of Geology, St. Louis University, pp. 3–5, 1892.

[95] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 38–39, 744, 746, 1899.

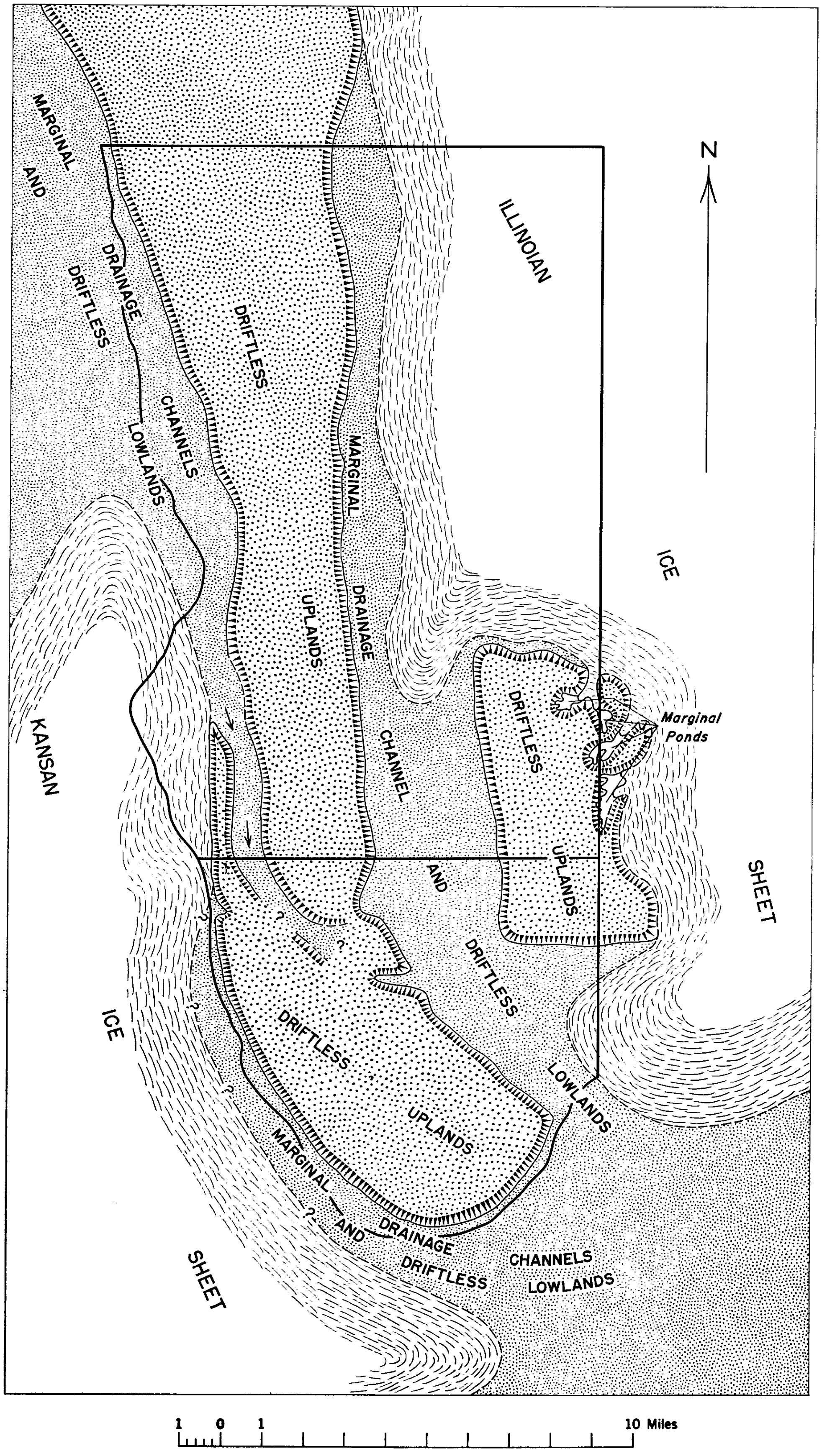

FIGURE 5.—Glacial map of Hardin and Brussels quadrangles, Ill.

Thickness.—The Illinoian till and associated stratified drift vary greatly in thickness within short distances. Partial exposures indicate that these deposits are less than 20 feet thick at many places on the highest part of the uplands, but in the preglacial valleys of small streams, and especially along a marginal zone that extends north-northwest from sec. 3, T. 7 N., R. 13 W., to sec. 16, T. 8 N., R. 13 W., they seem to be more than 100 feet thick. The present average thickness of these deposits in the area once overriden by the ice sheet is probably not far from 40 or 50 feet.

Lithologic character.—The deposits shown on the geologic map (pl. 1) as Illinoian till and stratified drift consist dominantly of pebbly till and subordinately of clayey till and small bodies of intimately associated water-laid gravel, sand, and, silt.

The pebbles and boulders in the till are composed largely of chert with some limestone and a very small amount of dolomite. But they also include exceedingly variable but generally small numbers of foreign igneous and metamorphic rocks that were transported great distances into the area by the ice. Aside from the chert, limestone, and dolomite, the fragments consist of such diverse rock types as basalt, diabase, gabbro, granite, rhyolite, pegmatite, vein quartz, schists, gneiss, and quartzite. According to local reports, a small boulder of native copper was found many years ago in the till in the northeast part of T. 7 N., R. 12 W., only a few miles east of the Hardin quadrangle. The pebbles and boulders range in shape from rounded to angular and distinctly facetted; only a few are sharply striated. In general, the smaller pebbles show more rounding, and the larger boulders are more distinctly facetted.

A few counts and numerous estimates by the writer indicate that among the rock fragments more than ¾ inch in diameter, the proportion of the definitely foreign to the possibly local chert and limestone pebbles ranges within surprisingly short distances between 1:5 and 1:1,000. Probably the average number of definitely foreign rocks among these larger fragments is not more than 2 in 100. However, these larger pebbles and boulders range from ¾ to 12 inches and, very rarely, several feet in diameter, and it is a striking fact that the larger boulders are commonly of foreign material.

Among the smaller pebbles quartz is much more abundant and, if it could be considered definitely foreign to the area, the proportion of foreign material would rise much higher than 2 percent. However, these small well-rounded quartz pebbles are so nearly identical in size, shape, and other peculiarities with those common in the Grover gravel that one is led to believe that many of them may have been deposited in the area as gravel and later transported only very short distances by the ice.

The dominant constituent of the till is clay or very finely ground rock flour. Where fresh, it is bluish gray, compact, and calcareous; where weathered, it is reddish brown, plastic, and noncalcareous. In most places the till is very sandy, but in a few exposures it seems to be entirely free from grit.

In many exposures the partially weathered—oxidized and leached—till grades upward into 2 to 4 feet of brown sticky clay or "gumbotil," which contains small scattered pebbles.[96]

The small bodies of stratified drift intimately associated with the Illinoian till were found chiefly in small preglacial valleys near the former margin of the ice-sheet. They consist both of distinctly cross-bedded and regularly bedded and of very indistinctly stratified deposits of well-sorted and poorly sorted gravel, sand, and silt (see pl. 11*B*). An excellent exposure of glacial till along the new highway in the SE¼ sec. 28, T. 8 N., R. 13 W., includes a lens of this gravelly sand that dips steeply eastward against the direction of ice movement (fig. 11*A*).

A second mode of occurrence of this stratified drift was seen at a few exposures on the uplands. In these the water-laid gravels occur intimately associated in the top of or gradationally above the glacial till. An exposure of this sort near the southwest corner of sec. 25, T. 8 N., R. 13 W., ½ mile south of Fieldon, shows till overlain by 10 feet of stratified silt, gravel, and sand, which in turn is overlain by 10 feet of loess. It is not certain that these deposits of stratified drift on the uplands were formed during the period of ice occupancy. They may have accumulated as the ice was disappearing or at any later time before deposition of the loess. These deposits are of interest because they show that at least locally the upper surface of the till plain has been cut and filled by currents of water. This fact suggests the possibility that some of the extreme flatness of the Illinoian till plain may be the result of degradation and aggradation by running water. (See pp. 118–119.)

Stratigraphic and physiographic relations.—The Illinoian till deposits and the till plain that they form are the most definitely correlated and dated Pleistocene features in the Hardin and Brussels quadrangles. Hence the stratigraphic position and relative age of other deposits were referred wherever possible to the Illinoian till and these stratigraphic relations are discussed under the headings of these other deposits.

The physiographic relations of the Illinoian till show clearly that, sometime after the development of the Calhoun peneplain and the deposition of the Grover gravel and probably long before the invasion of Illinoian ice, the region was trenched deeply by a river and many small tributaries, the position of which coincided very

[96] Leighton, M. M., and MacClintock, Paul, Weathered zones of the drift sheets of Illinois: Jour. Geology, vol. 38, pp. 32–33, 1930.

closely with that of Illinois River and its present tributaries. This preglacial topography was very similar to that of present time, not only in the position of the streams but also in the amount of relief. The chief difference seems to have been that the valleys then were deeper and narrower than they are today. (See pp. 110–113.)

Fossils.—Rather surprisingly, both invertebrate and plant fossils were found in the Illinoian till.

In a fresh creek bank exposure in the NW¼SE¼ sec. 28, T. 8 N., R. 13 W., an exceptionally well preserved shell of the snail, *Anguispira alternata*, was found well within—several feet below the upper surface of—the blue-gray pebbly till. (See Coll. 127, table on p. 174.) Probably the snail shell was picked up by the ice, transported but a short distance, and deposited with the till. The unusual feature of the occurrence is the fact that the fragile shell was not crushed by the ice.

At several localities, notably in the NE¼SW¼ sec. 21, the NE¼SW¼ sec. 28, and the NE¼ sec. 28, T. 8 N., R. 13 W., and in the NE¼NW¼ sec. 4, T. 7 N., R. 13 W., the Illinoian till contains numerous branches and small logs up to 8 inches in diameter of black or dark-brown partially carbonized wood. This wood was probably picked up by the ice as it advanced over forested areas.

POND DEPOSITS MARGINAL TO THE ILLINOIAN ICE

Along the eastern edge of the Hardin quadrangle and south of Otter Creek, the margin of the Illinoian till is marked by the silted-up basins of several glacial ponds or small lakes. At least five of the small valleys that flowed northward and eastward from Meadow Branch Ridge were dammed by the advancing Illinoian ice and formed separate ponds, each of which covered from 150 to 350 acres or more. Only one of these Illinoian ponds, that in the NW¼ sec. 14, T. 7 N., R. 13 W., lies entirely within the limits of the Hardin quadrangle; the other four lie chiefly in the quadrangle to the east.

Topographic expression.—All but one of these small lakes were filled up with clay, silt, sand, and gravel and, after disappearance of the ice and subsequent erosion, these filled valleys were left as flat elevated swales or meadows, which probably gave rise to the local name Meadow Branch.

The ancient lake in the W½ sec. 13, T. 7 N., R. 13 W., seems not to have been completely filled, or else it has been partially washed away through underground channels, because its center, just outside the Hardin quadrangle, is today a small pond, 40 or 50 feet below the level of the till and ancient lake surface. Similarly, the surface of the ancient lake in the NW¼ sec. 14, T. 7 N., R. 13 W., is marked by a deep but much smaller pond, the origin of which is unknown. It may be an unfilled depression or kettle in the old lake or a limestone sinkhole formed long after the Illinoian stage of glaciation. (See also p. 114.)

The flat loess-covered surfaces of the three northernmost of the old lakes stand at about the same elevation, approximately 650 or 670 feet above sea level. However the similarity in elevation is probably accidental for there seems to be very little likelihood that the three lakes were ever intercommunicating. The surfaces of the two southern lakes also stand at about equal elevations but much higher, at 760 or 770 feet. Although not now continuous with one another, these two may possibly at one time have been parts of a single larger lake. In the absence of adequate maps, detailed mapping of these old lakes that lie chiefly to the east of the Hardin quadrangle was not attempted by the writer.

Lithologic character.—The deposits in the old glacial ponds consist of clay, silt, sand, and gravel. A section measured in the north center sec. 14, T. 7 N., R. 13 W., will serve to indicate the diversity of these sediments.

Level of pond terrace, elevation 650± feet.	Feet
18. Covered	3
17. Loess; noncalcareous, light-brown (early Peorian?)	9
16. Loess, noncalcareous, purplish-brown. A humus-stained zone at top. (Late Sangamon?)	5½
15. Loesslike silt with small scattered chert pebbles. Noncalcareous, massive, purplish-brown	3
14. Fine-grained gravel, rounded chert pebbles in sandy matrix, few pebbles more than ⅜ inch in diameter	3
13. Sandy silt, noncalcareous, massive, tan	9
12. Sandy silt, noncalcareous, laminated	2
11. Covered	5±
10. Sandy silt, fine-grained, massive, noncalcareous, brown at top, tan below	15
9. Sand, medium-grained, well-laminated	3
8. Varved clay and silt, calcareous	½
7. Sand and clay, laminated, calcareous	1
6. Sand, medium-grained, massive	1½
5. Varved clay and silt, calcareous. Slumps badly. Near base contains a vertical log (pine?) 5 inches in diameter	15
4. Covered	10±
3. Varved clay and silt, calcareous	2
2. Gravel and till, calcareous (Illinoian)	10±
1. Hard pitted clay, noncalcareous (early Pleistocene)	5±

The varved clays and silts, though nowhere as much as half of the entire thickness, are the most conspicuous and characteristic of the pond deposits. Good exposures of these varved deposits were found in each of the five old ponds, but the 15 feet of beds marked Unit 5 in the foregoing section were examined most carefully pl. 11*C*). There are elsewhere the varved deposits consist of brownish-gray clay and pale tan, very fine grained silt in alternate thin layers. The clay layers underlie the silt layers along abrupt and sharply defined bedding planes, but the silt is more or less gradational into the next overlying layer of clay. In general, the layers of silt are somewhat thicker than those of clay.

Microscopic examination indicates that the varved clay consists almost entirely of particles of clay min-

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erals, but it also contains a few grains of quartz. The particles range from 1 to 25 and average about 8 microns in diameter. The silt layers consist largely of calcite and clay with subordinate amounts of quartz, green hornblende, and zircon. The material is poorly sorted; the angular grains range from 2 to 60, averaging about 15 microns in diameter.

The distinctly laminated clays and silts seem identical with the varved clays deposited in glacial lakes in other regions.[97] If so, each pair of layers is the deposit of a single year, the clay layers representing deposition in winters when the lakes were covered with ice and the silt layers representing open-water deposition in the summers.

Each varve or pair of layers is strikingly uniform in thickness but different varves vary greatly. Those examined by the writer range between extreme limits of 1 and 20 millimeters in thickness; they are more commonly from 4 to 9, and they probably average about 6 millimeters thick. In a sample collected 7 feet above the base of Unit 5 in the measured section, 49 varves have an average thickness of 7.6 millimeters each. (See pl. 12.) In a much smaller sample collected 1½ feet above the base of this unit 11 varves average 1.8 millimeters thick. Fairly careful estimates indicate that the 15 feet of beds in Unit 5 contain approximately 800 varves. If some of the noncalcareous silts, where undisturbed by weathering and leaching, and some of the beds that are not exposed are also varved deposits, the total number of varves in this section is at least 1,000 and may be several thousand.

The variations in thickness of successive varves are generally believed to represent variations in the rate of melting and hence in the climate of successive years. A detailed examination of the varves in this section might therefore afford valuable information on the variations in climate at about the time of the maximum advance of Illinoian ice.

The other types of pond deposits are less distinctive. Massive or indistinctly laminated sandy silt, sand, and gravel are the dominant constituents. These sediments may represent the material washed into the ponds at the times of minor adjustments and movements of the ice front.

Stratigraphic relations.—Remnants of till dams were recognized in the NE¼ sec. 14, in the east center sec. 14 and west center sec. 15 and in the NW¼ sec. 25, T. 7 N., R. 13 W., in front of three of the ancient ponds. The pond deposits abut sharply against the till in these dams, and they overlie a fairly rugged surface that was developed in different places upon Illinoian till and gravel, hard pitted clay (early Pleistocene), and Burlington limestone. The pond deposits are overlain by from 5 to 20 feet of loess, which, according to M. M. Leighton, is probably of late Sangamon and early Peorian age. (See p. 89.)

BRUSSELS FORMATION

A thick series of well-laminated silts, which locally contains much sand and gravel, is widespread throughout the Hardin and Brussels quadrangles. These deposits partially fill most of the small valleys tributary to Mississippi River and a few of the larger valleys tributary to Illinois River to an elevation approximately 100 feet above the level of these major streams. Near the village of Brussels, especially, these deposits make a widespread upland surface, and it is from the exceptional development of the constructional surface there and the excellent exposures of the sediments a few miles to the southeast that the names, Brussels terrace and Brussels formation, are proposed. Apparently the same terrace and deposits can be recognized across Mississippi River in Lincoln and St. Charles Counties and from there downstream to St. Louis, Mo.

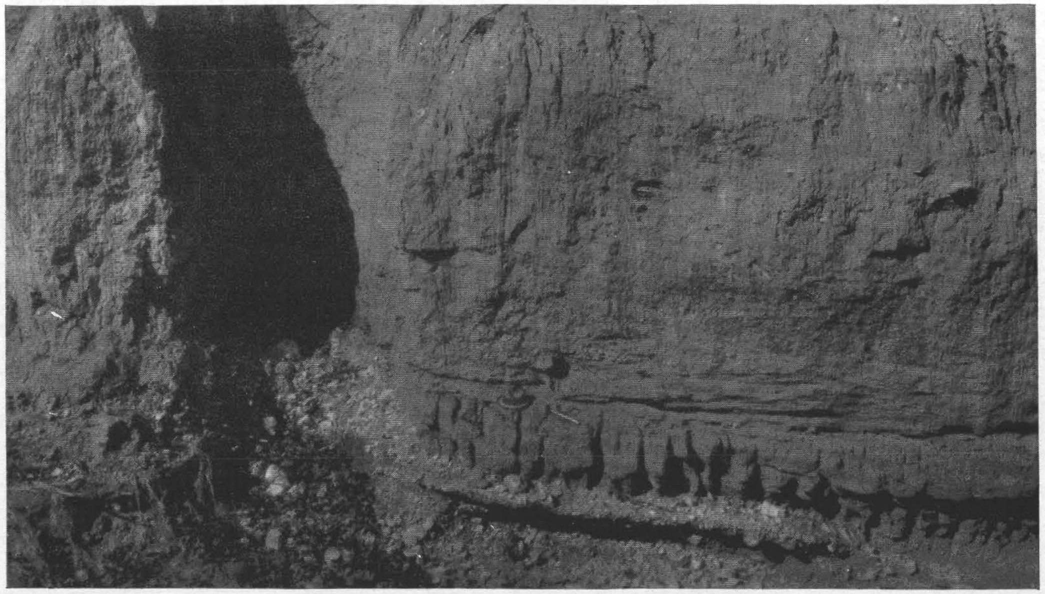
Topographic expression.—At most places within the area covered by this report the Brussels formation forms a well-defined terrace from 520 to 540 feet above sea level. (See pls. 17, 18.) This terrace, like nearly all other parts of the area, is mantled by 10 to 20 feet or more of loess. Most exposures are such that the Brussels formation cannot be definitely distinguished from the overlying loess at elevations greater than about 480 feet, but in a few places it extends somewhat higher.

Several exposures indicate, but do not afford conclusive evidence, that water-laid sediments in the Brussels formation were deposited to an elevation nearly that of the present terrace level. In the NE¼ sec. 28, T. 9 N., R. 13 W., regularly stratified sand in the formation grades upward into dune sands that rise higher than 540 feet above sea level. In the SW¼ sec. 12, T. 7 N., R. 13 W., stratified gravel in the Brussels formation extends up to an elevation of 540 feet on the flanks of a till-covered hill. In the NE¼ sec. 21, T. 13 S., R. 2 W., massive sand, possibly wind-blown, in or at the top of the formation rises to an elevation of 540 feet. However, none of these afford conclusive evidence. The only place where definitely water-laid deposits in the formation were found higher than 500 feet was in the exceptionally complete exposures in the miniature badlands, locally known as "General Brown's Cave-in," in the NW¼ sec. 5, T. 13 S., R. 2 W., where laminated deposits crop out from an elevation of 435 to 510 feet.

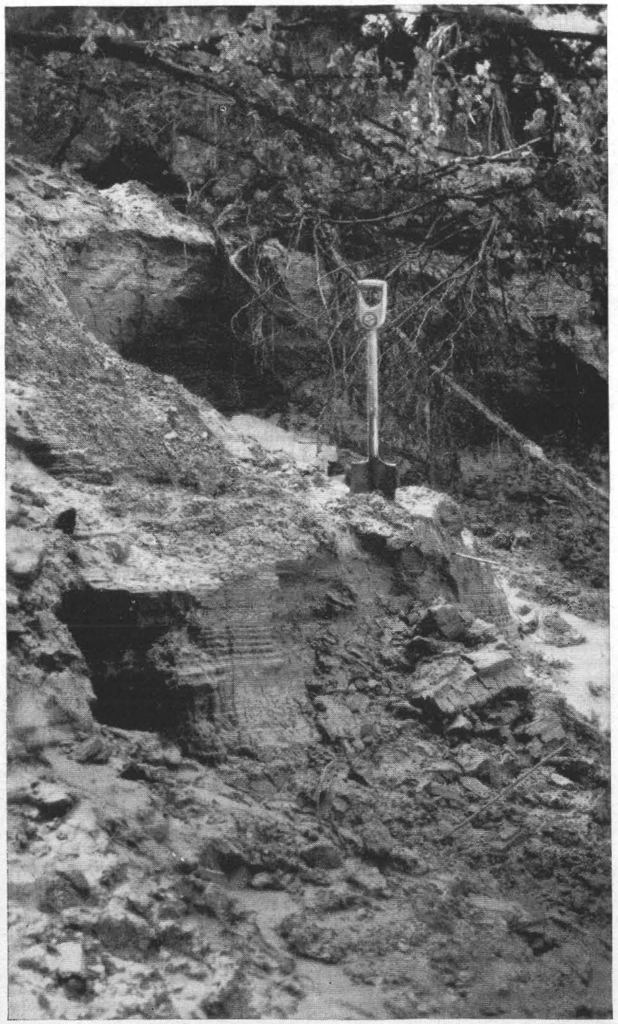
With such incomplete data on the precise elevation of the upper surface of the Brussels formation, it is obviously impossible to determine exactly how much or in what direction or directions the formation may slope. However, the loess-covered terrace developed upon the formation is of remarkably uniform elevation everywhere. No systematic differences of elevation in

[97] Antevs, Ernst, The recession of the last ice sheet in New England: Am. Geog. Soc. Research ser. 11, 1922; Retreat of the last ice sheet in eastern Canada: Canada Geol. Survey Mem. 146, 1925.

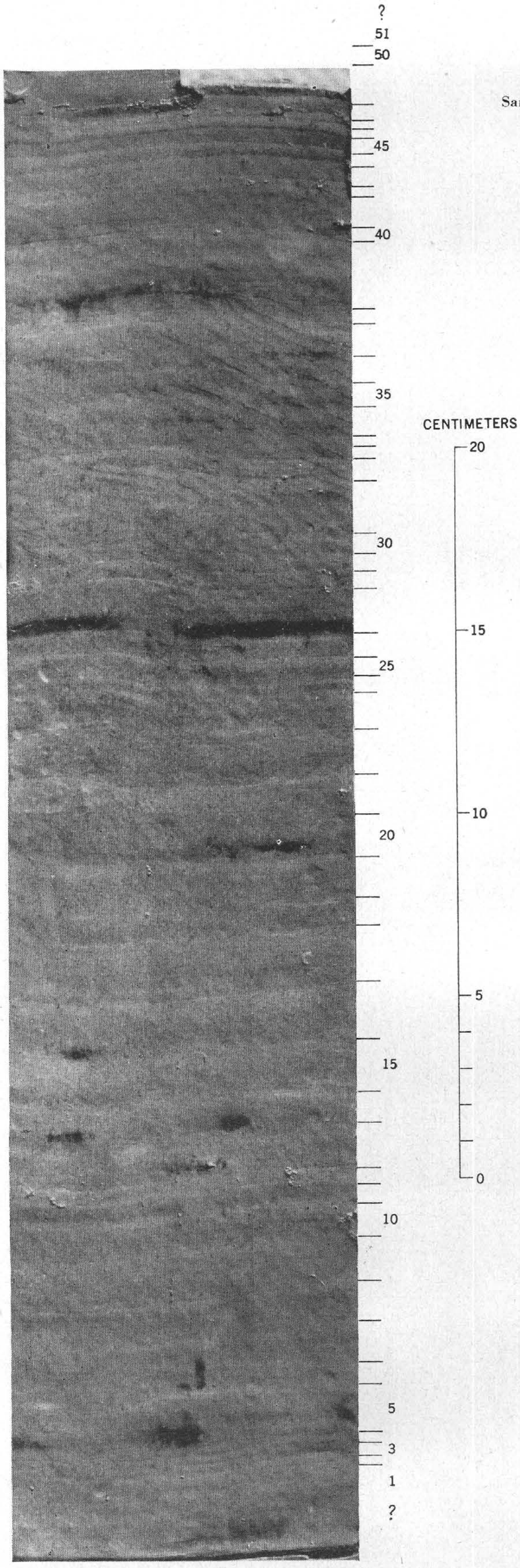
A. STRATIFIED DRIFT IN ILLINOIAN TILL INCLINED STEEPLY EASTWARD AGAINST DIRECTION OF ICE MOVEMENT.
NW¼SW¼ sec. 28, T. 8 N., R. 13 W.



B. STRATIFIED DRIFT ASSOCIATED WITH ILLINOIAN TILL.
SW¼NW¼ sec. 11, T. 8 N., R. 13 W.

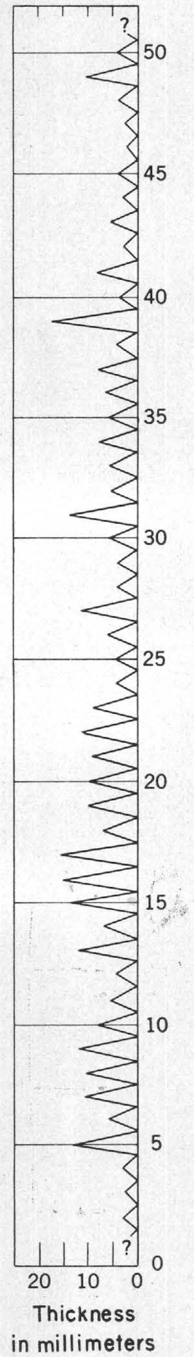


C. EXPOSURE OF VARVED CLAY AND SILT.
N. center sec. 14, T. 7 N., R. 13 W.



A. VARVES OR ANNUAL LAYERS OF CLAY AND SILT.

Sample collected in N. center sec. 14, T. 7 N., R. 13 W. Dark oblique lines in upper part of sample made by ferruginous diffusion bands.



B. VARIATIONS IN THICKNESS OF VARVES DEPOSITED IN GLACIAL POND DURING ILLINOIAN STAGE. ARBITRARY SCALE OF YEARS SAME AS THAT IN *A*.

any direction are recognizable; the irregularities upon it are all of the sort that might result solely from local differences in the thickness of the overlying loess. In view of this apparent flatness of the terrace, it seems probable that the Brussels formation also was essentially flat at the time of it deposition and that it has not been perceptibly disturbed by later movements.

In many places the formation has been cut by subsequent erosion. Locally it forms a degraded or truncated surface, called in this report the Metz Creek terrace (p. 120), that commonly stands about 485 feet above sea level. In a few places, where undercut by present-day streams, the Brussels formation makes nearly vertical bluffs from 30 to 50 feet high.

Thickness.—At several exposures, such as those in the SE¼NE¼ sec. 31, T. 10 S., R. 2 W., and the SE¼ NE¼ sec. 28, T. 13 S., R. 1 W., more than 50 feet of strata belonging to the Brussels formation is exposed. The maximum thickness observed at any one outcrop was 75 feet in the NW¼ sec. 5, T. 13 S., R. 2 W., but the true maximum thickness is doubtless much greater. Locally the formation extends as much as 100 feet above the level of Mississippi River and in the major valleys it probably was deposited below the present river levels.

Lithologic character.—The Brussels formation varies greatly in lithologic character from place to place. In general it has a fairly characteristic development in each of four regions within the Hardin and Brussels quadrangles although these different facies or aspects of development grade more or less completely into one another.

The most typical and the most widespread facies of the formation is that developed near Brussels in the valleys that slope eastward into Illinois and Mississippi Rivers. Here the lower third or fourth of the formation is a massive, calcaerous clay, and the upper part an alternating series of laminated and massive beds of silt, clay, and fine sand. The accompanying section, measured in the SE¼NE¼ sec. 28, T. 13 S., R. 1 W., contains much thicker beds of massive loesslike silt (beds 6, 8, and 10) than were seen elsewhere, but otherwise it illustrates fairly well this typical and widespread development of the formation (pl. 13*A*). Numerous wells near Brussels obtain their supplies of water from the middle or lower part of these beds.

Metz Creek terrace level (Elevation 490±).	Feet
13. Covered	4
12. Loess, sandy, massive, vertically jointed, buff-colored	9
11. Silt, indistinctly bedded in seven alternating sandy and clayey layers	9
10. Loesslike silt, sandy, massive, vertically jointed, very light buffy gray	4
9. Fine-grained sand and clayey silt in 11 alternating layers	5
8. Loesslike silt, coarse-grained, massive, vertically jointed, slightly calcareous, pale buffy gray	9
7. Laminated fine-grained sand, calcareous clay and silt in six alternating layers. Pale buff. Sand grains one-sixteenth to one-twelfth millimeter in diameter, subangular. Worm holes (?) filled with sand in basal layer of calcareous clay	4
6. Loesslike silt, clayey, massive, vertically jointed, slightly calcareous. Contains snail shells and small rootlets	3
5. Laminated calcareous clay	1
4. Massive silt, slightly calcareous	1½
3. Laminated fine-grained sand and silt, slightly calcareous	1
2. Clay, silt and some sand. Compact, massive, calcareous, and medium gray below; brown and only slightly calcareous in upper 3 feet	18
1. Covered	3
Creek level.	

This facies of the formation is also developed but in smaller masses, near Batchtown, along Turner Branch, Dixon Hollow, and Madison Creek. The laminated silts exposed along Cuivre River in sec. 14, T. 48 N., R. 2 E., St. Charles County, Mo.; along Piasa Creek in sec. 19, T. 6 N., R. 10 W., Madison Co., Ill.; and in the northern part of O'Fallon Park in the city of St. Louis, Mo., seem also to belong to this facies of the Brussels formation.

A second characteristic development of the formation is that found in southern Calhoun County in the valleys tributary to Mississippi River from Dogtown Hollow southward to Two Branch Hollow. This southwestern facies of the formation, as it may be called, resembles that near Brussels in the occurrence of massive calcareous clay below and of laminated silts above. It differs, however, in the common development of thick masses or lenses of medium-grained sand, which locally make up the entire thickness of the formation. This sand is notably well-sorted, rounded, and commonly iron-stained. Although generally massive, the sand in many places is indistinctly cross-bedded with the oblique laminations dipping steeply eastward. Persistent peculiarities of distribution in this southwestern region are the relative abundance of the sand on the north side as compared to the south side of the westward-flowing tributaries and the fact that most of the sand lenses are in coves some distance from the river and bounded on three sides by high bedrock walls. These details of local occurrence, together with the type of bedding and the excellent degree of sorting, strongly suggest that the sand was, at least in part, wind-blown rather than water-laid.

A third facies of the formation, developed in the valleys of Macoupin and Otter Creeks, is on the average much coarser grained than the others. It consists dominantly of sandy gravel, but in both valleys it grades within 1 or 2 miles downstream into finer-grained sand or laminated silts. The pebbles in the gravel are similar in composition to those in the Illinoian till but they are somewhat rounded and commonly from 1 to 2 inches in diameter with a few pebbles more than 6 inches across.

The westernmost exposures of the Brussels formation along Otter Creek are water-laid laminated silts essentially indistinguishable from those near Brussels. At its westernmost exposures along Macoupin Creek, the formation consists entirely of massive and regularly stratified beds of medium-grained, rounded, well-sorted sand, apparently identical with that in the southwestern facies of the formation (see p. 163). This sand seems to be in part water-laid and in part wind-blown, for the surface of the conspicuous terrace developed upon the Brussels formation (pl. 17) is surmounted by irregular hillocks that seem to be sod-covered sand dunes (p. 119).

The fourth facies of the formation is widely distributed in the silted-up valleys along Mississippi River from Mount Victory School north to McNabb Hollow. In this area, as elsewhere, the Brussels formation consists of laminated silts and forms a well-defined terrace. However, it is not so thick, and it contains a basal bed of local chert gravel from 1 to 10 feet thick that is imbedded in gray clay and overlain by a persistent bed, commonly about 5 feet thick, of dark-gray silt, so highly carbonaceous that it resembles peat.

This fourth facies of the formation may extend still farther northward, for the valleys north of McNabb Hollow also are heavily filled with silt and a few exposures of chert gravel and laminated silt were found in them. However, the covering of loess is so thick in this region that neither any diagnostic exposure nor the surface of the Brussels terrace could be recognized. These poorly exposed deposits may be equivalent to the Brussels formation or they may be much older, possibly a part of the Kansan stream deposits in the Batchtown channel. Because of this uncertainty they are included with "Undifferentiated stream deposits, etc." on the geologic map (pl. 1).

The gravelly, carbonaceous facies of the Brussels formation seems to be represented by the exposures in the Brussels quadrangle east of Illinois River near Hartford Church and at the quarry of the Missouri Portland Cement Co., at Bellefontaine, St. Louis County, Mo.

Microscopic examination of eight samples of the silt in the Brussels formation reveals that this material is very uniform in character and almost indistinguishable from the silt in the overlying loess. It consists chiefly of calcite, subordinately of quartz and orthoclase, and contains fairly numerous grains of green hornblende, zircon, chert, biotite, muscovite, plagioclase, and highly birefringent clay. In most of the samples the feldspar grains are somewhat kaolinized, and some carbonaceous or woody fragments may be recognized. These grains range from about 5 to 125 and average about 35 microns in diameter; most of them are sharply angular, but a small number show some rounding.

In general these silts in the Brussels formation seem to contain more carbonaceous or woody material, to exhibit more kaolinization and rounding, and to be slightly coarser grained and more poorly sorted than the silt in the loess. However, the samples vary so much from one to another that none of these average differences can be used to identify a specimen of unknown origin.

Two samples of the sand (p. 163) in the Brussels formation, collected from widely separated localities, were studied by H. B. Willman, of the Illinois State Geological Survey. The results of these examinations indicate that the two samples are very similar in grain size, sorting (see fig. 6), composition, and physical properties. (See also molding sand tests, p. 162.) Both are well-sorted, medium- to fine-grained sands, about 90 percent of which consists of quartz. (For a more detailed discussion of these samples, see pp. 92–95).

Fossils.—The beds of finer-grained silt and of clay in the Brussels formation are locally very fossiliferous. The collections made during the field work for this report were studied by F. C. Baker, who concluded that the fossils in this formation are most closely related to those that have been collected from Yarmouth and Sangamon deposits in other regions.

Dr. Baker's reports also show that the habitat of these fossils was exceedingly varied (pp. 174–175). Of seven lots reported upon at the time of this writing, all of which were collected from thin beds well within the Brussels formation, one contains only water-living species, two contain only land-living species, one contains both land and amphibious species, two contain both land and water species, and one contains all three forms—land, amphibious, and water. In short, the collections show an intimate mixture of land- and water-living forms.

At several localities the beds of massive loesslike silt contain many small vertical plant rootlets.

Stratigraphic relations and age.—Evidence within the Hardin and Brussels quadrangles shows that the Brussels formation is younger than parts of the Illinoian till and as old or older than the Sangamon(?) loess. The relation to the Illinoian till is shown clearly along Otter and, especially, Macoupin Creeks, where the formation fills valleys that were cut after at least a partial retreat of the ice.

The relation to the overlying loess is not so readily determinable. The contact is well exposed in only a few places and the evidence seems somewhat contradictory. In the SE¼NE¼ sec. 11, T. 7 N., R. 13 W., oxidized and greatly decomposed gravel in the top of the Brussels formation is overlain by brown (late Sangamon?) loess, which in turn underlies buff (early Peorian?) loess (pl. 13*C*). In an exposure near the corner of Florissant and Bircher Avenues, St. Louis, Mo., weathered gravel and silt in the top of the formation is overlain with sharp contact by reddish brown (late Sangamon?) loess which in turn is overlain by buff (early Peorian?) loess. At most other exposures, as in

SW¼ sec. 19, T. 10 S., R. 2 W., the NW¼ sec. 29, T. 11 S., R. 2 W., the NW¼ sec. 5, T. 13 S., R. 2 W., and the NE¼ sec. 28, T. 13 S., R. 1 W., the formation appears to grade into the overlying loess by an interbedding of laminated clay, silt, and sand with massive loesslike silt. In these and other exposures where the upper contact appears gradational, no similar evidence was found of deep weathering before deposition of the overlying loess. It is true that the coarser silt and sand layers appear somewhat less calcareous than the finer silt and clay layers, and this suggests, although it does not prove, that the coarser-grained materials may have been somewhat leached before the loess was deposited upon them. The only conclusion justified by the evidence is that locally the Brussels formation was deeply weathered before the loess was laid down but that in most places deposition of the loess was not preceded by an exceedingly long period of weathering.

Two lines of evidence indicate that the loess immediately overlying the Brussels formation is probably of late Sangamon age. On purely lithologic and stratigraphic grounds, M. M. Leighton[98] correlates the lower part of the thick loess mantle in the Hardin and Brussels quadrangles with the late Sangamon loess found widespread in other parts of western Illinois. (See p. 89.) F. C. Baker reports that many of the fossils collected in the area, especially lots 121, 125, and 179 (pp. 174–175) are of Sangamon age or older and that most of the loess appears to be Sangamon.

The stratigraphic relations thus indicate that within the Hardin and Brussels quadrangles the formation was laid down shortly after the maximum advance of Illinoian ice and sometime before and possibly during the deposition of late Sangamon loess. Local evidence outside these quadrangles seems at first thought somewhat contradictory. The Brussels formation may with reasonable assurance be traced by its physiographic expression and its lithologic character eastward and southward to but not beyond St. Louis, Mo. There it was definitely contemporaneous with a lobe of the Illinoian ice-sheet that filled the valley and crowded upon the western bank of what is now Mississippi River. (See fig. 4.)

In a small valley in the northern part of O'Fallon Park in the city of St. Louis, M. M. Leighton, Paul MacClintock, and the writer found excellent exposures that show this age relationship clearly. On the east side of the small valley, calcareous Illinoian till forms a hill or ridge that rises to an elevation of about 530 feet above sea level. On the west side the laminated sand and silts of the Brussels formation make a widespread flat terrace about 510 or 520 feet above sea level. Within the small valley the till may be seen to be intimately associated and definitely interfingered with laminated sand, silt, and gravel.

[98] Personal communication.

However, this evidence that the Brussels formation was contemporaneous with the maximum advance of Illinoian ice in St. Louis County, Mo., but younger than the maximum advance of Illinoian ice in Jersey County, Ill., is not necessarily contradictory. Even if the periods of maximum ice advance are assumed to be exactly contemporaneous in both areas, deposition of the Brussels formation might have begun during and continued for a short while after this maximum glaciation; or, as seems somewhat more probable from other evidence (p. 87), the Illinoian ice may have retreated somewhat in Jersey County, before it advanced to its maximum extent in St. Louis County. It is worth noting that although neither of these two alternatives, preclude the possibility that some of the later sediments may have been deposited during the early part of the Sangamon interglacial stage, yet both of them mean that most of the formation was laid down during the Illinoian stage of glaciation.

The stratigraphic relations of the formation to the scattered remnants of early Pleistocene clay were not satisfactorily determined. The hard-pitted clay (p. 78) is overlain by the Brussels formation, but its exact relationship to the gray calcareous clay in the lower part of the formation is unknown. No exposures were found that prove definitely that the hard-pitted clay is distinctly older than, rather than simply the leached equivalent of this calcareous clay.

Stratigraphic relations within the limits of the Brussels formation are also somewhat uncertain. In most exposures the strata seem conformable throughout, but in the SW¼SW¼ sec. 34, T. 11 S., R. 2 W., a lens of sand cuts sharply into laminated silts in the lower part of the formation. In the SE¼NE¼ sec. 28, T. 13 S., R. 1 W., the upper few feet of the lower calcareous clay member of the formation shows evidence of some leaching and oxidation (p. 83). Similarly, many sandy layers in the formation seem less calcareous than the underlying and overlying finer-grained sediments. This fact alone might have no significance but, considered along with the presence of both water- and land-living invertebrates and of beds of massive, loesslike silt, it indicates that during the deposition of the formation, periods of flooding alternated with brief periods of exposure to weathering.

Origin.—The Brussels formation and the conspicuous terrace that it makes are widespread and easily recognized features, and they constitute an important datum in the Pleistocene history of the Hardin and Brussels quadrangles and of adjacent regions as well. The present study is far from exhaustive, and many facts, such as its peculiarities of distribution and changes of lithologic character, cannot yet be explained satisfactorily. Nevertheless, as a guide to future investigations in the region, it appears desirable to state here the principal conclusions that have been reached.

A widespread silting-up of river and tributary valleys, such as that which produced the Brussels formation and terrace, might have been the result of any one of many possible causes. Consequently, many alternative hypotheses were considered before it was decided to test by a special examination the possible effects of a glacial dam at the point where the Illinoian ice sheet crossed the trench of Mississippi River at St. Louis, Mo. So fortunate and apparently so conclusive were the results of this special examination that it seems unnecessary to discuss various alternative hypotheses such as overloading of glacial stream, ponding above a sediment dam built by Missouri River, rise of sea level after deglaciation, or earth tilting caused by changes of ice load.

The Brussels formation and terrace are widespread along Mississippi River from the Hardin and Brussels quadrangles downstream to St. Louis, Mo. Yet reconnaissance examinations by M. M. Leighton, Paul MacClintock, and the writer to the mouth of Meramec River in Missouri and to Columbia in Illinois failed to discover any remnants of either the terrace or the deposits south of St. Louis. At the southern termination of the Brussels formation, in the northern part of the city of St. Louis, just where the Illinoian ice sheet crowded westward across the trench of Mississippi River, the deposits and the terrace abut sharply against a thick mass of Illinoian till (p. 85). It therefore seems safe to conclude that the Brussels formation was laid down at a time when the early Mississippi River was dammed by a till or ice dam at St. Louis.

However, this conclusion does not carry with it any implication as to whether the river was merely obstructed and thus gradually filled up by sedimentation in slackened water, or dammed abruptly so as to form a long narrow lake that extended many miles above St. Louis. No evidence bearing directly upon the relative probability of these two alternative interpretations was found near St. Louis, and at the present stage of investigations it is necessary to relie upon minor features of the formation observed in the Hardin and Brussels quadrangles.

Nearly all the facts indicate, but none of them prove conclusively, that the Brussels formation was built up gradually by aggradation of a flood plain rather than abruptly by deposition in a lake. The persistent bed of dark carbonaceous silt in the lower part of the formation (p. 84) suggests swampy conditions at the time of deposition, although it is of course possible that this carbonaceous material might have been carried into a deep lake and there deposited with the bottom muds. The small rootlets observed in certain layers of the formation (pp. 83–84) suggest intermittent land conditions although it is again possible that they may be the rootlets of ancient water plants or even the roots of large present-day trees grown far down into the formation. The intimate association of water, amphibious, and land invertebrates (p. 84) suggests strongly an alternation of water and land conditions at the time of deposition, but it is conceivable that the shells of land-living species may have been washed into deep water.

Purely physical criteria also seem to indicate a gradual building up of flood-plain materials. Locally, lenses of sand cut down into the laminated sediments (p. 85), thus showing that deposition was accompanied by at least some erosion. The presence of thick masses of well-sorted sand (p. 83) in protected coves out of reach of swift river currents seems to indicate an accumulation of dune sands above water level, hence a very slowly rising stream level. Partially leached and oxidized layers within the formation suggest that there was an alternation of aggradation and weathering. Most impressive to the writer is the striking similarity in general type of bedding and lithologic character of the sediments of the Brussels formation to those of the present flood plains. (See p. 98; pl. 14 *B*.) Furthermore, the Brussels sediments, though generally well-laminated, are by no means as uniformly and distinctly laminated as the truly lacustrine deposits in the ponds marginal to the Illinoian ice (pp. 81–82; pl. 11 *C*). The thick beds of massive vertically jointed silt, in which occur land fossils and small rootlets (p. 83), are nearly if not completely indistinguishable from the wind-blown loess on the uplands. It is of course conceivable that layers of silt, 4 to 9 feet thick, massive and without perceptible bedding, might under some conditions be deposited in water; but it is difficult to believe that these layers originated in a manner so fundamentally different from that of the upland loess. Finally, although any one of these different features might under certain circumstances be the result of lacustrine deposition, it seems that their association together in one formation is much more probably the result of gradual building up of a river flood plain.

It is also worth noting that the two apparently contradictory age relationships of the Brussels formation—its relation to the date of maximum ice advance and negligible amount of pre-Sangamon weathering—taken together suggest deposition over the entire time-range indicated.

One peculiarity in the areal distribution of the Brussels formation seems significant. The formation is readily recognizable in many valleys along the Mississippi River and near the mouth of Illinois River, but it was found in very few places along Illinois River; in fact, it is essentially restricted to the valleys of Macoupin and Otter Creeks, the two largest tributaries. It seems to the writer highly improbable that nearly all remnants of the formation should have been swept out of the small tributaries of Illinois River by subsequent erosion but have remained in large masses along Mississippi River. It seems much more probable that the formation was never deposited in great thicknesses along Illinois River. If this conclusion is justified, it follows that the greater quantity of silt deposits along Mississippi River must be explained as the result either of a greater supply of fine sediment and rock flour there or of more favorable conditions for deposition. It appears then that the relative scarcity of these deposits along Illinois River might be explained in either of two ways: by an exceedingly brief period of deposition or by a very small drainage area within the Illinois Basin, from which fine sediment and rock flour were being supplied.

As pointed out in a previous paragraph, it appears improbable that Brussels formation was deposited rapidly in a great lake; it seems more likely that it was built gradually by the successive floods of an obstructed and aggrading river. And if the period of deposition was not a very brief one, then the small quantities of Brussels formation mean that the valley of Illinois River must have drained only a small area, else it too would have been nearly filled with sediment.

The contemporaneity of the Brussels formation with Illinoian till at St. Louis, the lateral gradation from gravel to fine sediments within short distances along Macoupin and Otter Creeks, and the limits of Illinoian glaciation in and near northeastern Calhoun County (p. 78) suggest that the Illinoian ice sheet may have stood not far from its maximum extent during deposition of the formation and hence that the valley of what is now Illinois River had a very small drainage area at that time (fig. 4). If this interpretation is correct, the limited distribution of the Brussels formation along Illinois River supplements other evidence bearing on the age of the formation (p. 85) and indicates that it was deposited almost entirely during the Illinois stage of glaciation.

LOESS

The most widely exposed deposit in the Hardin and Brussels quadrangles is the Pleistocene loess. Only the Recent flood plains and the Deer Plain terrace are free from this material; the entire upland, except for relatively small rock exposures in the bluff faces and immediately along the beds of small streams, is mantled with loess. Furthermore, so widely distributed are these deposits that the small streams of the area are still cutting almost entirely in loess and their flood plains are therefore covered with sediment that is essentially indistinguishable from the original loess. A map of actual outcrops in the two quadrangles would be exceedingly difficult to read for it would show merely small isolated exposures of all the formations older than the loess. Consequently, it seemed advisable to indicate on the geologic map (pl. 1) only the thickest and most extensive deposits of loess. The loess that mantles the hill slopes and locally fills small valleys is arbitrarily omitted in order to represent diagrammatically the continuity of the other formations. (See pp. 5–6.)

Topographic expression.—The thick mantle of loess gives to the hill slopes of the area a characteristic shape not commonly seen in other regions. As pointed out by Fenneman,[99] small valleys cut in loess are normally bordered by convex side slopes, the steepness increasing toward the valleys. Even along larger streams that have developed flat flood plains, this convexity of the slopes commonly extends much lower than it does in regions not heavily mantled with loess.

Locally, where the loess has accumulated in greatest thicknesses, it seems to form nearly flat uplands or terraces, which, on the basis of topographic form alone, are indistinguishable from normal stream terraces. Along Mississippi River, from Hamburg southward for 7 miles to Star City, there is a relatively flat upland approximately 600 feet above sea level that, from numerous exposures and a few well records, seems to be built entirely of loess.

As stated elsewhere (p. 88) the loess is thickest on bluffs along the east sides of Mississippi and Illinois Rivers, and it thins abruptly eastward. Pronounced eastward slopes on many of the loess-covered surfaces along the two bluff lines immediately east of both rivers are further evidence of this eastward thinning.

The loess is also coarser-grained along the east sides of Mississippi and Illinois Rivers than in other parts of the area, and locally it consists in large part of sand. In such places, small hillocks or dunes of sand are to be found instead of the gentler and more regular eastward slopes characteristic of areas where the loess is finer grained.

However, the most striking topographic feature of the loess is its capacity, where it has been cut into by natural or artificial agencies, to stand for a long time in nearly vertical walls. Along many streams and especially in old road cuts, the loess is exposed in vertical banks that stand from 10 to 35 feet high. (See pl. 13 *B*.) Because of the loose friable texture of the material, many of these vertical faces are honey-combed with nests made by colonies of bank and rough-winged swallows. (See pl. 14 *A*.)

Thickness.—The loess varies greatly in thickness from place to place. In general, it is thickest on the bluffs immediately east of Mississippi and Illinois rivers, and from these bluffs its thickness decreases eastward, abruptly within the first half mile and then more and more slowly. But, apart from this eastward thinning, the thickness of the loess varies also with topographic position; it is commonly thicker in minor valleys and depressions than it is upon the highest parts of the uplands.

[99] Fenneman, N. M., Physiography of the St. Louis area: Illinois Geol. Survey Bull. 12, p. 16, 1909; Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, p. 10, 1911.

In most places the precise thickness of the loess is difficult to determine. As the material was obviously deposited upon an exceedingly irregular surface, it therefore does not suffice to measure merely the difference in elevation between the base of the loess in a bluff face and the top of a hill nearby. Judged this way, the loess would appear to be from 50 to 150 or even more feet thick throughout a large part of the area. However, these are maximum rather than true thicknesses, for both direct and indirect evidence indicate that the base of the loess rises with, and in many places more rapidly than, the slope of the hills. Vertical sections from the surface of the ground to the base of the loess and well borings, if numerous and uniformly distributed, would give the desired measurements. However, relatively few wells have been drilled in the area, and many of these were not recorded in such terms that the loess can be distinguished with certainty from the materials in the Brussels formation. Incomplete vertical exposures found here and there along roads and streams afford minimum measurements of the thickness of the loess, and these, supplemented by the maximum thicknesses just mentioned and by approximations based on interpolated slopes between observed bed rock outcrops give the best estimates that can be made at the present time.

These estimates indicate that the loess locally attains thicknesses of 60 to 80 feet in western Calhoun County and in parts of western Jersey County. They also indicate thicknesses of 20 to 50 feet on the divide in Calhoun County and in the bluffs of westernmost Jersey and Greene Counties and thicknesses of 5 to 20 feet in parts of eastern Calhoun County and over most of the uplands east of Illinois River. In a number of places on the flat uplands of the Illinois till plain the loess seems to be less than 5 feet thick, for numerous chert pebbles have been uncovered by plowing. Reconnaissance examinations indicate that in Lincoln County, Mo., the loess ranges from about 5 to 20 feet thick on the bluffs near Mississippi River, but that it is entirely absent a few miles to the west.

Lithologic character.—The loess in the Hardin and Brussels quadrangles consists dominantly of massive, fairly well sorted silt. Yet locally, where the deposit is thickest, the material is coarser-grained and more or less laminated and, where it is thinnest, finer-grained and clayey. For example, near Mississippi River in the SE¼ sec. 35, T. 9 S., R. 3 W., the SW¼ sec. 1, T. 10 S., R. 3 W., and the NW¼ sec. 32, T. 12 S., R. 2 W., the loess contains much sand and is distinctly stratified. Along the bluffs near Illinois River in the NE¼ sec. 28, T. 9 N., R. 13 W., and the NE¼ sec. 29, T. 8 N., R. 13 W., it consists largely of well-sorted sand that has accumulated in dunes. On the uplands near the eastern margin of the Hardin quadrangle, the loess is distinctly finer-grained and more plastic and clayey than it is farther west.

Throughout most of the area, however, the loess is made up of a relatively uniform silt. This characteristic form of the material is easily recognized; in most of its exposures it is massive, fairly open textured, and yet firm enough to stand in vertical bluffs. Because of these peculiarities and its presumed agricultural and horticultural value, distinctive names have been applied to the loess by the local residents. One of the commonest of these, "ground hog soil," refers to the numerous burrows dug by woodchucks in the loess.

Microscope examination of six samples of loess indicate that the silt consists almost entirely of fresh angular mineral grains from 8 to 75 and commonly about 25 microns in diameter. Calcite seems to be the commonest mineral, but quartz and orthoclase are abundant, and green hornblende, zircon, biotite, chert, plagioclase, and highly birefringent clay are present. Most of the feldspar grains show very little kaolinization. In both grain size and composition, this silt greatly resembles that in the Brussels formation (p. 84). The samples examined contain somewhat less kaolinized material and fewer rounded grains, and they are slightly finer-grained and better-sorted than the samples from the Brussels formation. However, these differences are not sufficiently marked to serve as criteria for distinguishing the two deposits. Mechanical analyses have been published [1] of samples of the loess from 4 miles west and 3 miles south of Brussels. The analyses indicate that these two samples consist chiefly of silt-sized material but they are less perfectly sorted than the samples examined by the writer appeared to be.

Although the loess is usually massive and without perceptible bedding, it is indistinctly laminated in many places. These indistinct layers are commonly a few inches thick and are marked by slight variations in the proportion of sand, clay, or calcium carbonate. During dry seasons this obscure stratification is easily overlooked but, following a period of rains, minor differences in grain size and permeability are made conspicuous by alternate wet and dry layers. This lamination or bedding commonly conforms to the local hill slopes. Another laminate structure totally unrelated to true bedding is developed at many exposures of the loess. It is a secondary fissility or minute joint system that is oriented essentially parallel to the face of the exposure. It may possibly be the result of incipient sliding or slumping of the material; whatever its cause, it is probably a factor in the preservation of the nearly vertical banks so common in exposures of the loess.

The loess is stained various shades of brown, buff, and yellow with iron oxides, and it normally contains a few ferruginous and calcareous concretions. In some places the stains occur as conspicuous brown and tan

[1] Fippin, E. O., and Drake, J. A., Soil survey of the O'Fallon area, Missouri-Illinois: U. S. Dept. Agric., Bur. Soils Field Operations, p. 823, samples 10831 and 10833, 1904.

diffusion bands. The ferruginous concretions are for the most part small and nodular; some are elongated into vertical "pipes," but others are nearly perfect spheres. The calcareous concretions are commonly somewhat ironstained. They are characteristic of the loess for they assume very irregular shapes, and locally they coalesce to form discontinuous nodular beds of impure limestone an inch or so thick.

Stratigraphic relations.—The general absence of bedding and the difficulty of distinguishing between original and reworked loess make the precise stratigraphic relations within these deposits rather obscure. It is clear that essentially all the loess is later than both the Illinoian till and the Brussels formation and earlier than the Deer Plain formation and the Recent flood-plain deposits. However, beyond his general conclusion that the loess is of middle or late Pleistocene age, the writer was at first unable to recognize any additional age relationships. He is therefore indebted to M. M. Leighton for calling his attention during field conferences to the fact that an application of the concept of weathered zones[2] reveals further stratigraphic relations within the loess itself.

Evidence of ancient weathering of the loess can be detected by the presence of oxidized, leached, and decomposed zones and of fossil soils stained dark by humus. With these criteria in mind, it was found that in many exposures the loess in the Hardin and Brussels quadrangles is divisible into a lower reddish-brown member, separated by a leached zone from an upper light-buff member. In some exposures, as in the SE¼NE¼ sec. 11, T. 7 N., R. 13 W. (pl. 13*C*), this interpretation is strengthened by the relationship of these two members to oxidized and decomposed zones and a fossil soil. At a few places, however, the brown and buff members are not separated by a leached zone and locally, as in the SW¼SE¼ sec. 28, T. 8 N., R. 13, W., they seem to be completely gradational into one another.

It is the opinion of M. M. Leighton, based on field observations of the lithologic character and stratigraphic relations of the loess in the Hardin and Brussels quadrangles, that the lower reddish-brown member and the upper light-buff member correspond respectively to the late Sangamon and early Peorian loesses seen by him in areas to the east and north.[3] Dr. Leighton also believes that the sandy loess in the valleys near Mississippi River in the SE¼ sec. 35, T. 9 S., R. 3 W., and NW¼ sec. 32, T. 12 S., R. 2 W., is of Wisconsin age. As stated elsewhere, the fossils collected from the diffent loesses in this region seem to confirm these correlations (pp. 85, 174).

[2] Leighton, M. M., and MacClintock, Paul, Weathered zones of the drift sheets of Illinois: Jour. Geology vol. 38, pp. 28–53, 1930.

[3] Leighton, M. M., The Pleistocene succession near Alton, Illinois, and the age of the mammalian fossil fauna: Jour. Geology, vol. 29, pp. 509–512, 1921; A notable type Pleistocene section: The Farm Creek exposure near Peoria, Illinois: Jour. Geol., vol. 34, pp. 167–174, 1926.

If correct, these correlations afford some additional information about the sequence of events in middle and late Pleistocene time. The lower reddish-brown loess (late Sangamon?) overlies and is thus younger than the Illinoian till and the Brussels formation. In many places it appears to grade imperceptibly into the pebbly weathered zones at the top of the till. Nevertheless, the presence of these weathered zones and the topographic position of the contact indicate that a period of weathering and erosion followed the retreat of Illinoian ice and preceded deposition of the lower loess. As stated elsewhere (pp. 84–85), no conclusive evidence of a long period of weathering between deposition of the Brussels formation and the lower loess was found. Only the upper or light bluff loess (early Peorian?) was seen upon the remnants of the Metz Creek terrace (see p. 120), and it thus seems probable that this terrace was formed sometime after the Sangamon but before the Peorian interglacial stage. The Deer Plain terrace is for the most part quite free from and thus younger than the loess; a thin discontinuous mantle of loesslike material that occurs in a few places may be either Wisconsin loess or materials eroded from the loess and redeposited by water or wind. (See p. 95.) Except for slope wash and redeposited material, the Recent flood plains of the region are entirely free from loess.

Fossils and origin.—Well-preserved shells of gastropods are relatively abundant in the loess of the Hardin and Brussels quadrangles. Collections of these fossils were studied by F. C. Baker who reports that they consist entirely of land-living forms. He also reports that Collections 125 and 179 are probably of Sangamon age, that Collection 132 is of either early Wisconsin or Peorian age, and that all the others are either Peorian or Sangamon. The determinations seem to confirm the correlations made on purely lithologic and stratigraphic grounds by M. M. Leighton.

It has long been known that loess is a wind-blown deposit. The presence of abundant land snails and the widespread distribution of the deposit over uplands, hillsides, and valleys would essentially establish this origin had it not been established previously in other regions. The greater thickness and coarseness of the loess along the east bluffs of Mississippi and Illinois Rivers and the rapid thinning and decrease of grain size eastward seem to show conclusively that the material was blown from the river lowlands by prevailing west winds. The angularity, freshness, and small size of the mineral grains indicate that the loess was derived, not from the usual clays and sands carried by streams but, from finely comminuted and unweathered fragments of diverse types of rocks. Very few natural agencies are known to produce large quantities of finely ground rock flour and of these few agencies, glaciers seem to be the most competent.

Combining the foregoing conclusions, it seems reasonably safe to infer that the ultimate source of the loess was rock flour that had been produced by glaciers; that this rock flour was carried southward from the old ice sheets by the major rivers and spread out over the flood plains in great mud flats; and that, during dry seasons, this rock flour was picked up by the wind from the flood plains and carried as dust onto the uplands and hillsides where it accumulated as great thicknesses of loess.

Essentially this same interpretation of the loess has been held by many geologists.[4] It satisfactorily accounts for many facts and peculiarities of the material. It does not, however, explain all features of the loess. For example, it is not clear to the writer how rapidly the material was deposited by the wind. Deposition from dust storms was evidently not so excessively rapid that it smothered the vegetation on which the large numbers of land snails were dependent, yet it must have been sufficiently rapid to prevent noticeable weathering of the newly deposited dust and leaching out of the calcite.

SCATTERED PEBBLES OF IGNEOUS AND METAMORPHIC ROCKS POSSIBLY OF WISCONSIN AGE

Igneous and metamorphic pebbles and boulders occur at a few places on the hillsides and intermediate uplands in the Hardin and Brussels quadrangles in positions where they clearly could not have been reworked from other Pleistocene deposits, such as the gravel in the Batchtown channel, the Illinoian till, or the Deer Plain formation. Nowhere were these pebbles seen in sufficient abundance to prove conclusively that they are natural deposits; they may possibly have been transported to their present positions during either historic or prehistoric times by man. However, certain peculiarities in their distribution suggest that they are natural deposits—they were recognized chiefly along Illinois River (secs. 14 to 34, T. 10 S., R. 2 W., sec. 26, T. 11 S., R. 2 W., sec. 35, T. 12 S., R. 2 W., sec. 1, T. 13 S., R. 2 W., Calhoun County, and secs. 9 and 10, T. 6 N., R. 13 W., Jersey County, and they occur most abundantly on the upper surface of the Metz Creek (485-foot) terrace. (See p. 120.) It is true that neither of these peculiarities of distribution is well defined. The areal distribution may be much greater than indicated, for in other parts of the region it is difficult to distinguish these pebbles from those obviously derived from other Pleistocene deposits. Similarly, the vertical distribution may not be restricted to the surface of the Metz Creek terrace. Erratic pebbles occur at lower elevations in many places, but they are indistinguishable from those in other Pleistocene deposits; and in sec. 9, T. 6 N., R. 13 W., foreign pebbles may be found at altitudes greater than 485 feet, but in this locality they are associated with Indian mounds and refuse heaps and other evidences of disturbance by man.

If these scattered pebbles were deposited by natural and not by artificial agencies, they are probably of late Pleistocene age. The Metz Creek terrace, on the surface of which they occur, is, from the physiographic relations, younger than the Brussels (Illinoian) and older than the Deer Plain (latest? Wisconsin) terraces. Furthermore, the pebbles lie on the upper surface of or in the upper few inches of the light buff (early Peorian?) loess which covers the Metz Creek terrace. Hence, from their physiographic and stratigraphic relations it seems that these scattered pebbles are probably of Wisconsin age. Their occurrence along Illinois River and their probable geologic age suggest that they may have been deposited during late Wisconsin time when Illinois River is thought to have carried great floods[5] of water discharged from Lake Chicago[6] and Lake Kankakee.[7] If this interpretation is incorrect, and if these pebbles were deposited in some other way, then no record of these late Wisconsin floods down Illinois River was recognized in the Hardin and Brussels quadrangles. (See pp. 96, 111, 115.)

DEER PLAIN FORMATION

A variable series of gravel, sand, and clay covers large areas in parts of the Hardin and Brussels quadrangles. These deposits occur as a wide terrace in the lowlands west of Illinois River and as small terrace remnants elsewhere along Illinois and Mississippi rivers. The name Deer Plain for both the formation and the terrace is proposed because of the exposures of the deposits and the development of the terrace at and near the village of Deer Plain in sec. 16, T. 13 S., R. 1 W. The same terrace and deposits are well-developed in the lowlands west of Mississippi River from Winfield to Old Monroe in Lincoln County, Mo.

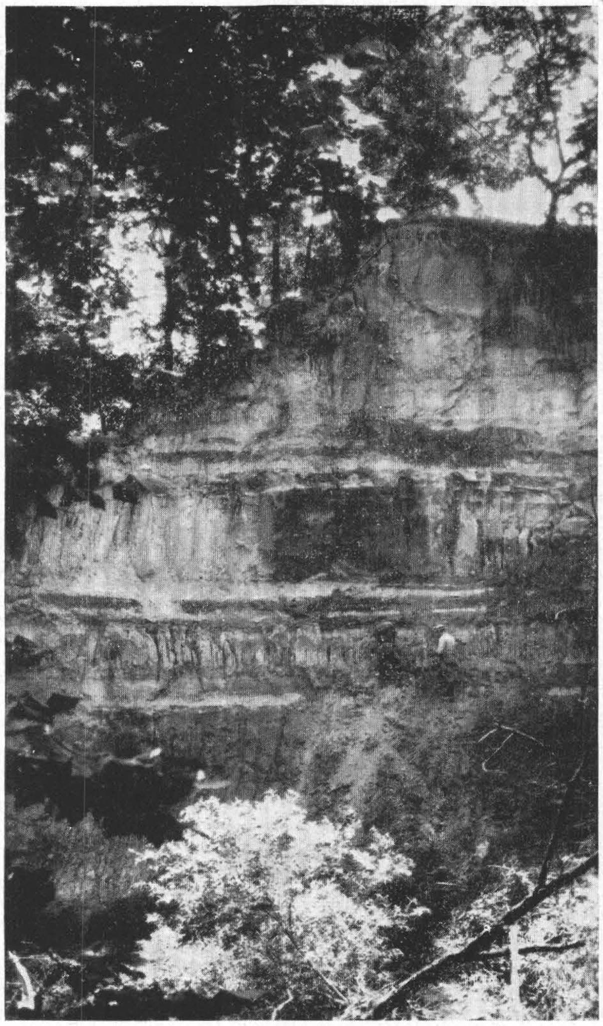
Topographic expression.—In parts of the Hardin and Brussels quadrangles the Deer Plain formation makes a prominent terrace. (See pl. 19 *A*, *B*.) The remnants of this terrace along Mississippi River commonly rise to an elevation 450 to 460 feet above sea level or about 40 feet above the normal level of the river. The largest remnants of the terrace lie along the west side of

[4] Carman, J. E., The Mississippi Valley between Savanna and Davenport: Illinois Geol. Survey Bull. 13, p. 73, 1909. Barrows, H. H., Geography of the middle Illinois Valley: Illinois Geol. Survey Bull. 15, p. 35, 1910. Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, pp. 46–47, 1911. Sauer, C. O., Geography of the upper Illinois Valley and history of development: Illinois Geol. Survey Bull. 27, pp. 65, 81, 1916.

[5] Barrows, H. H., Geography of the middle Illinois Valley: Illinois Geol. Survey Bull. 15, pp. 48, 53, 57, 1910. Cady, G. H., Lateral erosion in the upper Illinois Valley by the Chicago Outlet (abstract): Ill. Acad. Sci. Trans., vol. 9, p. 210, 1916.

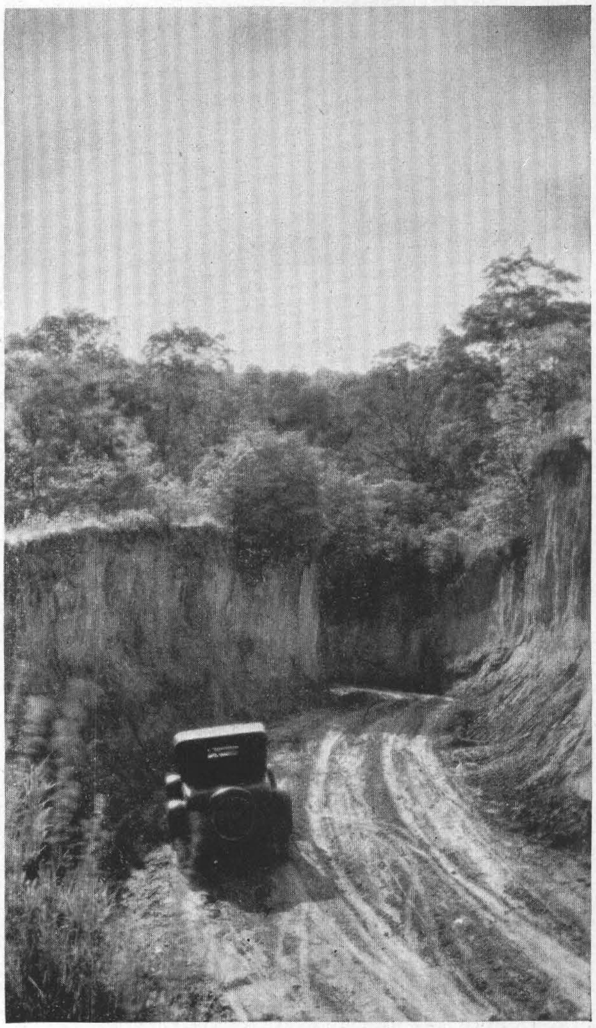
[6] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 418–428, 1899.

[7] Leverett, Frank, op. cit., pp. 328–338. Ekblaw, G. E., and Athy, L. F., The Kankakee torrent (abstract): Geol. Soc. America Bull., vol. 36, p. 155, 1925.



A. EXPOSURE OF BRUSSELS FORMATION SHOWING THICK BEDS OF LOESSLIKE SILT INTERBEDDED WITH LAMINATED CLAY.

SE¼NE¼ sec. 28, T. 13 S., R. 1 W.

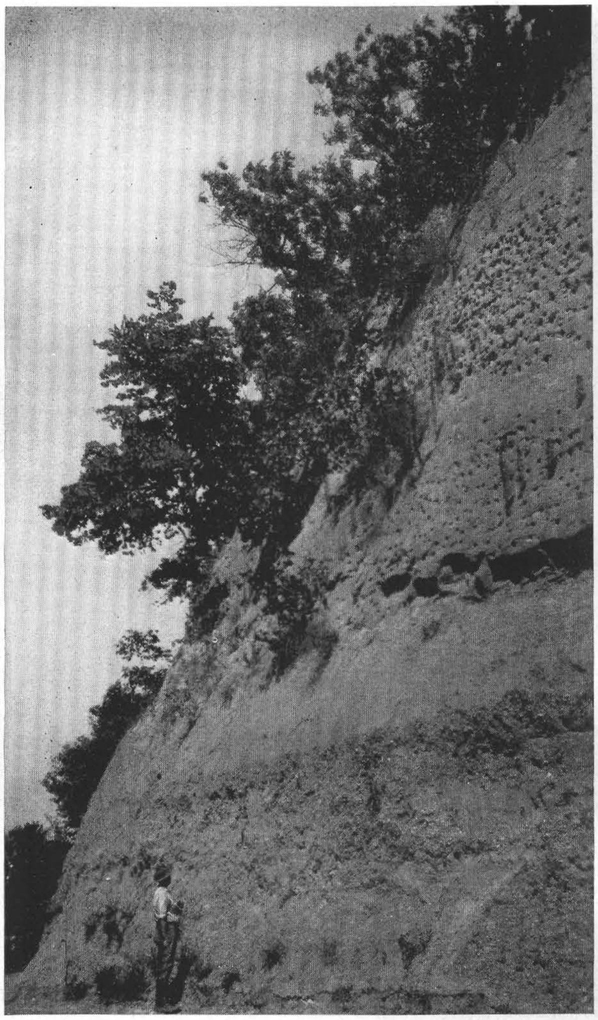


B. "DUG HILL." OLD ROAD BORDERED BY VERTICAL BANKS OF LOESS.

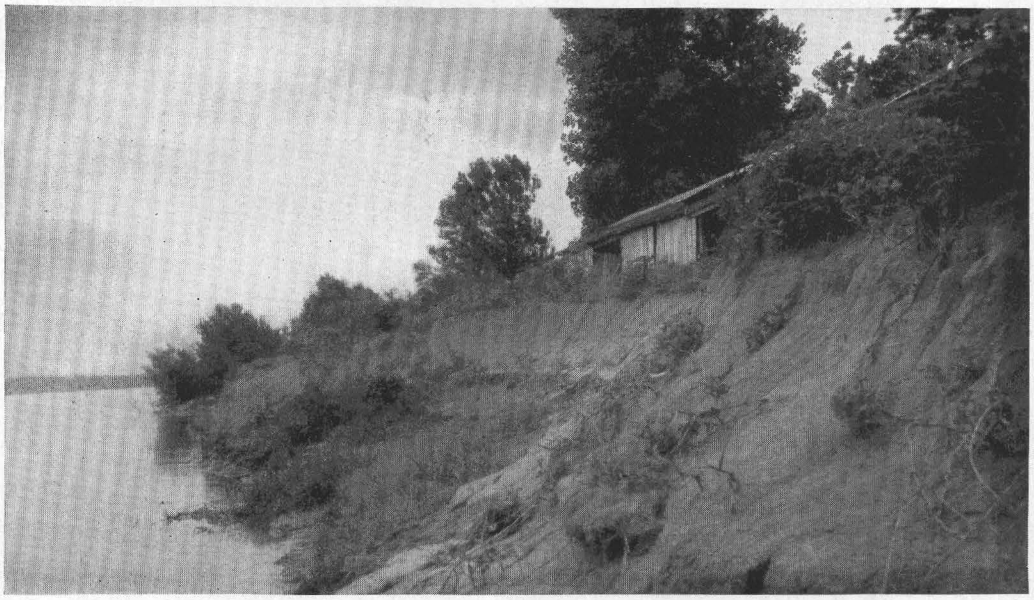
SE¼ sec. 16, T. 7 N., R. 13 W.

C. REDDISH-BROWN (LATE SANGAMON?) LOESS OVERLAIN BY LIGHT-BUFF (EARLY PEORIAN?) LOESS WITH A HUMUS-STAINED (OLD SOIL) ZONE AT CONTACT.

SE¼NE¼ sec. 11, T. 7 N., R. 13 W.



A. LOCAL STREAM GRAVELS OVERLAIN BY LOESS.
SW¼NE¼ sec. 35, T. 9 S., R. 3W.



B. RECENT ALLUVIUM DEPOSITED BY THE MISSISSIPPI RIVER.
SE¼ sec. 25, T. 11 S., R. 3 W.

Illinois River where they extend almost continuously from Deer Plain northward for about 15 miles. The southern part of this terrace is a conspicuous feature known locally as the "Sand Ridge," but it slopes gradually northward up the valley of Illinois River and can be recognized only with difficulty in the northern part of the Hardin quadrangle. At the southern extremity, in secs. 16, 21, and 22, T. 13 S., R. 1 W., near Deer Plain, the terrace stands at a general elevation of about 455 feet, and old sand bars upon it rise to a maximum elevation of about 470 feet, approximately 60 feet above the mean level of Mississippi River nearby. Northward from Deer Plain the surface of the terrace descends, rather steeply in the first 4 or 5 miles to an elevation of 445 feet, and then more gently in the next 10 miles to about 435 feet, approximately 25 feet above the present level of Illinois River. Scattered remnants of the Deer Plain terrace may be recognized here and there along both sides of Illinois River at elevations that decrease gradually northward. The smaller and more northern remnants are shown much more clearly on maps of the Engineer Corps, U. S. Army,[8] than upon the base maps used for this report. The northernmost remnant of the Deer Plain terrace that was recognized with reasonable assurance lies north of the Hardin quadrangle on the east side of Illinois River, opposite Kampsville, from secs. 7 to 32, T. 10 N., R. 13 W., and rises to an elevation of about 430 feet.

Thickness.—In many of its smaller remnants the Deer Plain formation is from 5 to 20 feet thick, but the true maximum thickness is unknown. Near Deer Plain, the formation is at least 50 feet thick, for there the terrace rises from 20 to 50 feet above the Recent flood plain at its base. At a few places small exposures of the St. Louis limestone mark the base of the terrace and hence show the complete thickness, but elsewhere the formation may extend below the flood plain to much greater depths. For example, the coarse gravel reported in borings in the Recent flood plains of Illinois and Mississippi rivers may possibly be part of the Deer Plain formation. (See pp. 101, 115.)

Lithologic character.—The outstanding lithologic feature of the Deer Plain formation is the systematic variation, both geographic and stratigraphic, in the grain size of the materials. Along Mississippi River and near the mouth of Illinois River the formation consists largely of gravel; up the valley of Illinois River it becomes finer-grained and passes within only a few miles through sand into silt and clay. There also appears to be pronounced vertical change, for at all exposures the material becomes progressively finer-grained upward.

[8] U. S. Corps Engineers (J. W. Woermann), Map of the Illinois and Des Plaines Rivers from Lockport, Illinois, to the mouth of the Illinois River, sheets 2, 3, 4, 5, and 6, U. S. War Dept., 1902–04.

The coarser-grained facies of the formation, which is developed along Mississippi River, consists chiefly of gravel and secondarily of poorly sorted sand. The pebbles commonly are from ¾ to 1 inch in diameter, but many of them range up to 4 to 6 inches and a few scattered boulders up to 1 to 4 feet in maximum diameter. Chert pebbles, many of which are stained brown, are the principal constituent, but smaller fragments of basalt, quartz, quartzite, conglomerate, granite, feldspar, limestone, sandstone, gneiss, and schist are not uncommon. The largest boulders are composed either of limestone—probably derived from nearby outcrops—or of fresh igneous rocks. The pebbles vary widely in shape; those of chert are angular to subrounded, but many of the foreign ones are well-rounded. In the upper few feet of the formation the granitic rocks and the fragments of feldspar are deeply decayed, and many of the chert pebbles are deeply etched by solution. The associated sand grains consist chiefly of rounded fragments of quartz, but many dark minerals also are present.

At most exposures a horizontal stratification marked by interlaminated beds of sand can be discerned in the upper part of the formation. On the open flood plains, as in sec. 30, T. 10 S., R. 2 W., Calhoun County, Ill., and near Winfield and Old Monroe, Lincoln County, Mo., these sandy layers are cross-bedded, the oblique laminations dipping southward down the valley of Mississippi River. However, in several remnants of the formation preserved in tributary valleys, the cross-bedded laminae dip up these tributaries away from Mississippi River. Still farther up the tributary valleys the formation becomes much finer grained and for that reason cannot be recognized with certainty. Many of these remnants have been included on the geologic map under the heading of "Undifferentiated stream deposits." Locally, in these valleys tributary to Mississippi River as in the NE.¼ SW.¼ sec. 35, T. 13 S., R. 2 W., the Deer Plain formation consists largely of laminated sand, silt, and clay.

The beds of interlaminated sand and gravel become somewhat finer grained upward and grade into a layer of fine alluvial soil from 1 to 2 feet thick at the top of the formation, immediately below the terrace surface. This relationship is very widespread and it seems to show clearly that the Deer Plain terrace is not a surface cut upon much older sediments but one contemporaneous with the final deposition of the Deer Plain formation.

Northward up the valley of Illinois River the Deer Plain formation becomes progressively finer-grained. At several exposures in secs. 27 and 33, T. 13 S. R. 1 W., it is composed largely of gravel, but in the southwest corner of sec. 22, T. 13 S., R. 1 W., it becomes much sandier, and from this point northward gravel occurs less abundantly and at successively lower elevations until it disappears below the flood plain north of the east center of sec. 16. Similarly the sand, which comes into the upper part of the formation in sec. 22, T. 13 S., R. 1 W., becomes finer-grained northward until in sec. 25, T. 12 S., R. 2 W., it in turn is replaced by silt, clay, and some fissile shale.

True shale—argillaceous rock with a shaly structure—is uncommon in beds as young as the Deer Plain formation.[9] However, not only are the megascopic characteristics of this material similar to those of true shale, but thin sections show that the microscopic characteristics also are nearly identical with those of older shales that have been examined by the writer. (See pp. 22, 38). The shale from the Deer Plain formation consists dominantly of flat micaceous flakes of colorless to pale brown, highly birefringent clay and subordinately of quartz with small quantities of organic matter, iron oxides, muscovite, and apatite. The individual particles range from less than 1 to more than 10 microns in maximum diameter. The flat clay particles lie roughly parallel to one another and are so abundant that thin sections cut normal to the bedding or the planes of shaly structure show a pronounced aggregate orientation and positive elongation.

Over wide areas the upper few feet of the Deer Plain formation seems to be made up of a uniform black clay. When damp, this clay has a peculiar rubbery consistency; when dry, it cracks deeply. It commonly contains smaller nodular concretions of calcium carbonate. Over much of its area of outcrop it supports only a sparse growth of small oaks and grasses. This black clay of the Deer Plain formation has been well described, and a mechanical analysis of it has been published.[10]

Yet even where only silt, shale, or clay is exposed, the lower beds of the Deer Plain formation seem to be made of sand and gravel. A well dug in the SE¼SE¼ sec. 25, T. 12 S., R. 2 W., started 8 feet below the surface of the Deer Plain terrace and penetrated the first thin layers of sand at a depth of 10 feet. These layers of sand were reported to become thicker and coarser-grained with increasing depth until at a depth of 40 feet coarse water-bearing gravel was struck.

At all its exposures the upper few feet of the Deer Plain formation is stained brown by iron oxides and leached of nearly all calcium carbonate. The depth to which leaching extends at any locality bears a close relation to the grain size and permeability of the material. In sec. 25, T. 12 S., R. 2 W., the silt and clay are noncalcareous to a depth of 1 or 2 feet below the terrace level. In sec. 21, T. 13 S., R. 1 W., the sand is leached to a depth of 4 or 5 feet. Along Mississippi River, within the upper 8 or 10 feet of the formation, the gravel contains no small pebbles of limestone, but in the upper few feet of the formation in nearly every exposure, there are a few very large boulders of limestone. Even below the zone of leaching in this gravel phase of the formation, limestone pebbles are not abundant. This fact, together with the preservation of stratification and crossbedding within the leached sand, indicates that limestone fragments were not abundant in the formation even at the time of deposition.

Mechanical analyses of three samples (pp. 163–165) collected from near Deer Plain show wide range in the size of materials that make up the formation. Sample 10 may be classified as a sandy gravel, sample 8 as a gravelly sand, and sample 9 as a sandy silt.[11] (See fig. 6.) Mechanical analyses of two other samples of the formation have been published,[12] which indicate compositions intermediate in grain size between those of samples 8 and 9. These five mechanical analyses by no means represent the extreme phases of the formation—much finer grained and much coarser grained samples might very readily have been selected.

Comparison of samples from Deer Plain and Brussels formations.—Inasmuch as analytic data on the composition of the Deer Plain and Brussels formations are available, it seems worth while to examine them for whatever light they may throw on the source and conditions of deposition and upon possible means by which the formations may be recognized and discriminated in other areas. Two of the Deer Plain samples (Nos. 8 and 9) were carefully examined by H. B. Willman, of the Illinois State Geological Survey, and his determinations of the composition of these samples afford data for an interesting comparison with the two samples from the Brussels formation (pp. 163–165).

The particle analyses indicate that quartz makes up about nine-tenths of the samples from the Brussels formation but only about two-thirds of the samples from the Deer Plain formation. Furthermore, fragments of igneous and metamorphic rocks and minerals from these types of rocks are much more abundant in the Deer Plain samples.

Detailed comparisons bring out other interesting relationships. The proportions of certain constituents vary with the average grain size of the different samples and seem to be nearly if not quite independent of the formation from which the sample came. For example, the proportion by weight of recognizable chert in each sample increases from about 1 percent in sample 9, through 3 percent in sample 1 and 4 percent in sample 16, to 15 percent in sample 8. This order of the samples (9, 1, 16, 8) is precisely the same as their order of aver-

[9] Lewis, J. V., Fissility of shale and its relations to petroleum: Geol. Soc. America Bull., vol. 35, p. 581, 1924.

[10] Fippin, E. O., and Drake, J. A., Soil survey of the O'Fallon area, Missouri and Illinois: U. S. Dept. Agr. Field Operations of the Bur. of Soils, pp. 833–835, sample 10846, 1904.

[11] Wentworth, C. K., A scale of grade and class terms for clastic sediments: Jour. Geology, vol. 30, p. 384, 390, 1922.

[12] Fippin, E. O., and Drake, J. A., Soil survey of the O'Fallon area, Missouri-Illinois: U. S. Dept. Agr.; Field Operations of the Bur. Soils, samples 10835 and 10841, pp. 838, 839, 1904.

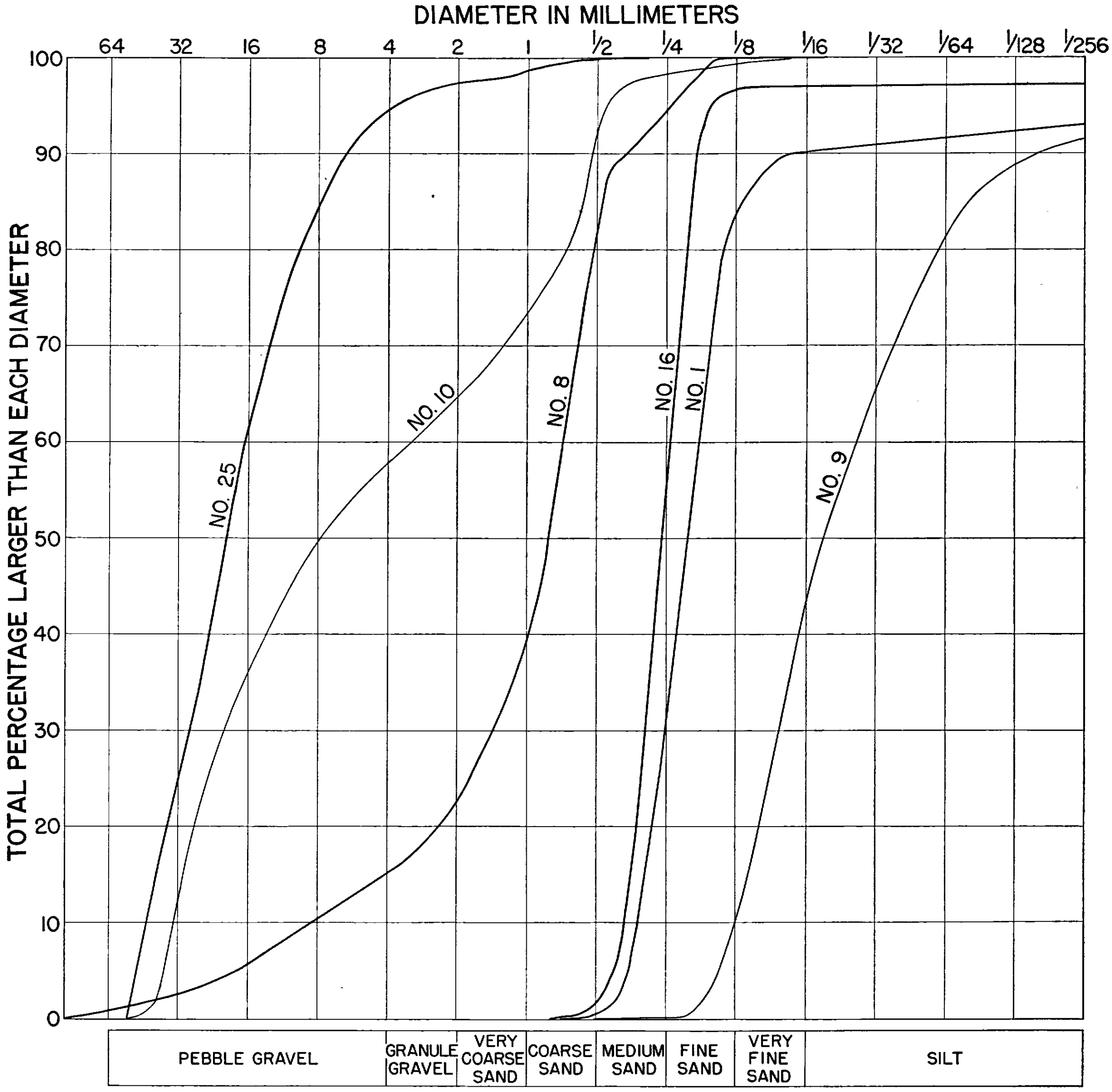


FIGURE 6.—Cumulative curves showing mechanical composition of three samples from the Deer Plain formation, two from the Brussels formation, and one from Recent stream gravels. Samples 8, 9, and 10 are from the Deer Plain; samples 1 and 16 are from the Brussels; and sample 25 is from Recent stream gravel.

age grain size. The estimated median diameters of the four samples are: No. 9, 0.05 mm.; No. 1, 0.20 mm.; No. 16, 0.26 mm.; No. 8, 0.81 mm. (See fig. 6.) Therefore the abundance of chert appears to vary directly with the coarseness of the samples. However, if this comparison is restricted to particles of essentially the same size in all samples—in this case, particles with diameters less than 0.589 and more than 0.147 mm., which occur in all four samples—the relation between abundance and grain size is much less noticeable. Between these two size limits, fragments of igneous rocks are much more abundant in the two Deer Plain samples, quartz is about equally abundant in all four samples, and chert is more abundant in the finest-grained sample (No. 9) and least abundant in the coarsest-grained sample (No. 8).

Within each of the four samples, the different constituents tend to occur most abundantly in different size fractions. In general, the heavier the different constituents, the smaller the size fraction in which they are concentrated. For example, if in sample 8 the relative percentages of the fragments of "light igneous" and "dark igneous" rock in each size fraction are multiplied by the percentages of the total sample in each fraction, it will be found that the "light igneous" rocks reach their greatest abundance between diameters of 1.65 and 3.33 millimeters and the "dark igneous" between diameters of 0.833 and 1.65. Similarly, in each sample, chert reaches its greatest abundance in larger size fractions than does quartz. In other words, within each sample, the fragments of heavy rocks tend to be small and those of light rocks large.

The relative abundance of the heavy minerals in these samples varies in somewhat the same way. Comparison of the Milner frequency numbers assigned by Mr. Willman to each heavy mineral species in the four samples discloses that the general order of similarity between the different samples is 9, 1, 16, and 8, and this order is precisely the same as the order of grain size. In other words, samples 8 and 9, although both from the Deer Plain formation, represent the extreme differences in heavy mineral assemblages. Upon closer comparison it may be noted that, although a few of the mineral species are more abundant in the two Deer Plain samples, most of the minerals seem more closely related to the average grain size of the samples. Epidote, kyanite, andalusite, rutile, and hypersthene are reported as progressively more abundant in the coarser-grained samples, and magnetite, ilmenite, zircon, muscovite, and biotite are reported as progressively more abundant in the finer-grained samples.

The five minerals that are characteristic of the coarser-grained samples have specific gravities that range from 3.2 to 4.2 and average about 3.6; the five minerals characteristic of the finer-grained samples range from 2.9 to 5.2 and average about 4.1. That is, the minerals most abundant in the finer-grained samples are, in general, heavier, and this difference holds in spite of the fact that they include muscovite and biotite, two minerals that are much lighter than any of those characteristic of the coarser-grained samples. Furthermore, the heavy fine-grained particles are in general relatively soft, and the lighter coarser-grained particles are relatively hard.

The concentration of heavy rock fragments in the finer-grained portions of each sample and the concentration of heavy mineral grains in the finer-grained samples, as found by Mr. Willman, is a matter of considerable interest. A general tendency toward this type of size distribution of the different grains might be predicted solely as a result of the processes of transportation and deposition. Nevertheless, it seemed desirable to check the results before drawing any conclusions. Accordingly, the heavy mineral crops from these samples were reexamined by the writer, and Mr. Willman's reports were completely confirmed by all essential matters.

Elsewhere the writer has published a qualitative analysis of the factors that control the size distribution of sand grains of different density.[13] In that article it was pointed out that, even among the sediments derived from exactly the same source rock, the various processes of sorting and abrasion materially affect the size distribution of different mineral grains. Small heavy grains fall rapidly and are deposited along with larger light grains that have the same settling velocity. Among particles transported equal distances, the heavier and softer ones suffer most from abrasion, so that the hard light minerals become concentrated in the larger sizes and the soft heavy minerals in the smaller sizes.

This brief discussion of the rather complex set of factors that control the distribution of heavy particles in gravels and sands is offered primarily with the object of pointing out the caution that is necessary in comparing the rock composition and heavy mineral assemblages of different formations. It would be highly desirable to know the assemblages of minerals and rocks characteristic of either the Deer Plain or the Brussels formation, not only because this information would indicate the types of source rocks, but also because it would aid in identifying and distinguishing these formations in isolated or distant areas. However, the foregoing discussion serves to emphasize the necessity of distinguishing sharply between those assemblages which are due primarily to differences in source rocks and those assemblages which owe their pecularities to modifications that are dependent upon the distance of transportation and the agents of transportation, of deposition, and perhaps of subsequent weathering.

With this qualification in mind, there are seen to be relatively few significant differences in the composition of the samples from the Deer Plain and the Brussels formations. Both formations may have been derived from essentially the same source rocks, for most of their present differences seem to be systematically related to differences in grain size. The differences in quartz and chert percentages cannot be relied upon to distinguish the two formations. Nor can the presence of a few fragments of igneous and metamorphic rock, which from these samples would appear diagnostic of the Deer Plain, be accepted in any area where glacial drift occurs.

The relative abundance of only five of the heavy minerals seems to be independent of the grain size of the samples. Of these five, garnet is essentially constant in all four samples. The four remaining minerals were recorded as more abundant in the Deer Plain than the Brussels formation: hornblendes as "flood" (Milner frequency number of 9 [14]) in the two Deer Plain samples and as very common to common (6 and 5) in the two Brussels samples; corundum as very scarce to rare (3 and 2) in the Deer Plain and absent in the Brussels; leucoxene as common to scarce (5 and 4) in the Deer Plain and very scarce to absent (3 and 0) in the Brussels; tourmaline (a very doubtful difference) as common to scarce (5 and 4) in the Deer Plain and scarce to rare (4 and 2) in the Brussels. These four minerals, which seem to be especially characteristic of the Deer

[13] Rubey, W. W., The size-distribution of heavy minerals within a water-laid sandstone: Jour. Sedimentary Petrology, vol. 3, pp. 3–29, 1933.

[14] Milner, H. B., An introduction to sedimentary petrography, p. 99, errata p. 9, 1922; Sedimentary petrography, p. 386, 1929.

Plain formation, are only moderately heavy, and their average hardness is greater than that of the other groups of minerals considered. Hence they are the types of minerals that would best withstand abrasion and it might possibly be inferred that they have been transported farther than the minerals in the Brussels formation.

These four Deer Plain minerals might have been derived from several types of either metamorphic or igneous rocks, nearly all of which types occur in glacial drift in the northern part of the Mississippi Valley. Similarly the pebbles of basalt, which are relatively common in many exposures of the Deer Plain formation, might have come originally from areas in Wisconsin or Minnesota, but until their distribution in the gravel has been carefully traced, it seems unwise to hazard opinions about their most probable source.

Physiographic and stratigraphic relations.—The stratigraphic and the physiographic evidence shows clearly that the Deer Plain formation is younger than the Brussels formation and the loess. Furthermore, physiographic relations demonstrate that the Deer Plain terrace is younger than the Metz Creek terrace and the scattered pebbles of igneous and metamorphic rocks that lie upon it. Yet evidence of several kinds seem to show conclusively that the Deer Plain formation is much too old to be included within the latest or Recent stage of earth history.

Physiographic relations alone are sufficiently clear to show the relative age of the Brussels and Deer Plain formations, but the stratigraphic relations between the two formations may also be seen in a few places, as in the SW¼NW¼ sec. 5, T. 14 S., R. 1 W.

The evidence that the Deer Plain formation is also younger than the loess is not so direct, but it appears to be none the less conclusive. On the uplands and hill slopes and on the Brussels and Metz Creek terraces, the loess is nearly everywhere more than 20 feet thick. Even the upper light buff member (early Peorian?) is more than 10 feet thick at all exposures where it was recognized. On the Deer Plain terrace, however, wide areas are covered by a black sticky mud totally unlike the brown silts of the loess. It is true that, in isolated patches here and there and in narrow strips at the foot of the bluffs and along some of the small streams, the soil on the Deer Plain terrace is a brown loesslike silt. Yet nearly all this loesslike silt is found in just those situations where the great quantities of loess that each year are washed from the uplands and terraces would be deposited by the minor streams as they spread out over the Deer Plain terrace. (See pl. 1.) Even if all of this doubtful material should be considered as true wind-blown loess, the difference in thickness and continuity of the loess on the Deer Plain and the older terraces remains in striking contrast. To the writer the conclusion seems inescapable that the Deer Plain terrace was developed after all but a very small part of the loess had been deposited.

On the other hand, the Deer Plain formation is almost certainly not of Recent age. It stands far above the highest floods that have been recorded within historic times. Furthermore the size and composition of the materials that make up the gravel phase of the formation are very different from those of the materials being carried by the present Mississippi and Illinois rivers. (See pp. 98–101.) Finally, the depth below the upper surface of the terrace to which calcareous material has been leached from the gravel and the sand phases of the formation seems much too great to be attributed solely to post-Pleistocene weathering.

Age and origin.—No fossils were found in beds of undoubted Deer Plain age. Hard silts exposed in the bank of Illinois River in the NW¼NW¼ sec. 19, T. 12 S., R. 1 W., contain numerous bleached shells of invertebrates (Coll. 44, pp. 174–175). These silts are shown on the geologic map, pl. 1, as Recent alluvium but they may possibly be part of an uneroded remnant of the Deer Plain formation. Samples taken from shallow depths in borings on the east side of Illinois River at the site of the proposed bridge at Hardin were found to contain a number of shells. (Coll. 200, pp. 174–175.) It seems probable that the river sediments represented by these cuttings are of Recent age, but it is entirely possible that they may be part of an uneroded remnant of the Deer Plain formation.

Despite the absence of fossils, it seems from the stratigraphic and physiographic relations that the Deer Plain formation is certainly post-Illinoian and post-Sangamon, probably post-Peorian, and almost certainly pre-Recent. That is to say, the formation can with reasonable assurance be assigned to the Wisconsin stage of the Pleistocene. Further considerations, dependent upon an interpretation of the conditions of deposition and outlined in the following paragraphs, suggest that the formation may have accumulated very late in the Wisconsin stage.

Several peculiar features of the Deer Plain formation seem to call for control of deposition by a large stream that flowed in the valley of the present Mississipi River. The coarseness of the Deer Plain gravel along Mississippi River demands as a transporting agent a stream more powerful than the present Mississippi River (see pp. 71–72, 99–101), and the progressive decrease in grain size of the material northward up the valley of Illinois River suggests relatively slack-water conditions there. This conclusion is in a measure strengthened by the northward slope of the Deer Plain terrace up the valley of Illinois River. Terraces that slope upstream may of course be formed by subsequent tilting. But there is no evidence of a similar northward slope of the terrace along Mississippi River, and the form of the northward slope—relatively steep to the south and progressively flatter to the north—is precisely that which might be expected had a turbulent Mississippi River dropped some of its load across the mouth and built a more or less deltalike deposit northward up the flooded valley of Illinois River. The observed relationships can be most readily explained by assuming that the Deer Plain formation was deposited from abnormally high flood stages of an ancient Mississippi River with virtual ponding and backwater for many miles up the lower part of Illinois River.

It must be pointed out, however, that the exposures of St. Louis limestone along the inner margin of the Deer Plain terrace in sec. 36, T. 12 S., R. 2 W., sec. 1, T. 13 S., R. 2 W., and secs. 6 and 7, T. 13 S., R. 1 W., show that the uplands composed of the Brussels formation were at those places defended terraces [15] and that at some time Illinois River actively corroded its right bank at approximately the level of the Deer Plain terrace. It is conceivable that the deposition of the Deer Plain formation and the lateral cutting by Illinois River may have been independent events and that their coincidence of level might be entirely accidental. Nevertheless, it appears much more probable that the two events were essentially contemporaneous and, if this interpretation is correct, Illinois River could not have been a merely passive, sluggish stream at the time of deposition of the Deer Plain formation. These somewhat contradictory conclusions might be reconciled by the hypothesis that detritus from Mississippi River deflected the current of Illinois River and concentrated it against the west bank.

The Deer Plain formation is essentially the latest record of Pleistocene events in the lower Illinois Valley. No exceptionally great flood of waters could have come down Illinois River after the deposition of the Deer Plain formation without washing it away and burying all its remnants. Hence, if there were great floods [16] down Illinois River during late Wisconsin time from Lake Chicago [17] and Lake Kankakee,[18] these floods must have antedated the deposition of the Deer Plain formation. That is, the Deer Plain formation would then be somewhat younger than these late Wisconsin lakes. This conclusion obviously depends upon the probability that the waters of Lakes Chicago and Kankakee were discharged rapidly enough to cause great floods throughout the entire length of Illinois River. If, instead, these lake waters were discharged more slowly, an interpretation which may be entirely consistent with present knowledge,[19] then the Deer Plain formation may have been deposited long before the draining of the late Wisconsin lakes.

However, the possibility or the probability, whichever it may be, that the draining of these lakes caused great floods down Illinois River and the fact that the coarse materials of the Deer Plain formation were brought into the Hardin and Brussels quadrangles by an early Mississippi River raise the question of the most probable source of a large, post-Chicago outlet flood down Mississippi River. Several possible sources of a very late Wisconsin flood from the Upper Mississippi Valley might be considered. M. M. Leighton and Paul MacClintock suggested to the writer that the abrupt drops of lake level recorded in the old beaches of Lake Agassiz [20] may have caused great torrents down the Mississippi River. W. C. Alden pointed out to the writer that melting back of the western ice front from the drainage basin of Missouri River to that of Saskatchewan River [21] may have abruptly diverted great volumes of water southeastward through Lake Agassiz and down Mississippi River. The coarse detritus carried by any such large flood might all have been picked up along the river course far south of Lake Agassiz.

RECENT AND PLEISTOCENE

UNDIFFERENTIATED STREAM DEPOSITS, SLOPE WASH, AND TALUS

A wide variety of Recent and Pleistocene alluvial deposits, which could not be classified readily under more specific headings, are here included in a rather miscellaneous grouping called Undifferentiated stream deposits, slope wash, and talus. All but a very small part of the materials shown on the geologic map under this grouping occur in narrow alluvial floors and broad gently sloping alluvial cones (see pl. 19*C*) along and at the mouths of the streams tributary to Illinois and Mississippi rivers. In some of the smaller valleys, such as Gresham Hollow and the North and South Prongs of Irish Hollow, older alluvial deposits occur in low terraces that could not be correlated satisfactorily with either the Brussels or the Deer Plain formation, and these undifferentiated terrace deposits are included under the present heading. Narrow zones of talus—steep aprons formed by loose blocks of chert and limestone along the foot of the bluffs and gentle slopes made by accumulations of silt or redeposited loess flanking many of the hills—make up an additional part of the materials included here.

The diverse origin of the deposits grouped together under this heading accounts in large part for their great diversity in lithologic character. Fine silts washed

[15] Davis, W. M., Geographical essays, pp. 547–549, 1909.

[16] Barrows, H. H., Geography of the middle Illinois Valley: Illinois Geol. Survey Bull. 15, pp. 48, 53, 57, 1910. Cady, G. H., Lateral erosion in the upper Illinois Valley by the Chicago Outlet (abstract): Ill. Acad. Sci. Trans., vol. 9, p. 210, 1916.

[17] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 418–428, 1899.

[18] Idem., pp. 328–338. Ekblaw, G. E., and Athy, L. F., The Kankakee torrent (abstract): Geol. Soc. America Bull., vol. 36, p. 155, 1925.

[19] Sauer, C. O., Geography of the upper Illinois Valley and history of development: Illinois Geol. Survey Bull. 27, p. 114, 1916. Alden, W. C., personal communication.

[20] Upham, Warren, The glacial lake Agassiz: U. S. Geol. Survey Mon. 25, pp. 223–225, 1896.

[21] Upham, Warren, op. cit., pp. 64–65.

down from the loess on the uplands is the most abundant constituent, but chert gravel and sand along the minor streams, chert blocks and limestone boulders in the talus, and layers of clay in the alluvium also are common. Pebbles of quartz and quartzite from the Grover gravel occur here and there in the Recent stream gravels and slope wash. A sample of the chert gravel (p. 165) that is being carried from the limestone uplands by the small stream in the North Prong of Michael Hollow was chosen as representative and sampled by T. B. Root and assistant. Tests by the State Highway Department show that this sample is a fairly well sorted gravel and consists largely of pebbles between 1/3 and 1½ inches in diameter. (See fig. 6.)

A mechanical analysis of the loesslike silt deposited on the flood plain of one of the smaller streams near Brussels has been published.[22]

The miscellaneous character of the deposits included under the present heading gives rise to a wide variety of stratigraphic and age relationships. Most of the materials are of Recent age, because they are clearly younger than the loess and the Deer Plain formation. However, some probably should be correlated with the Deer Plain formation (p. 91); others are certainly older than the loess (pl. 14*A*) and should be correlated with the Brussels or even older formations (p. 84).

Numerous attempts were made to discover some system of classification of the alluvial deposits that would avoid this inclusion of Pleistocene sediments with those of Recent age, but each of the attempted classifications proved impracticable. Up many of the minor valleys the Deer Plain terrace merges with and becomes indistinguishable from this Recent flood plain. Again, silt that has been washed from the loess-covered uplands and deposited upon the valley floors is essentially indistinguishable from the original loess. Hence it is impossible to differentiate sharply between alluvium and loess and between postloess and preloess alluvium. Furthermore, chert and clay derived from the weathering of limestone grades insensibly from residual materials in place to slightly transported talus, slope wash, and stream alluvium, and in many exposures it is difficult to estimate the relative proportions of each.

Very few fossils were found in these Recent and Pleistocene alluvial deposits. In the NW¼NW¼NW¼ sec. 32, T. 11 S., R. 2 W., numerous pelecypod and gastropod shells (Coll. 39, pp. 174–175) occur associated with artifacts in Recent stream gravel and silt. In the center of the SW¼SE¼SE¼ sec. 9, T. 6 N., R. 13 W., north of Hartford Church, shells (Coll. 129, pp. 174–175) were found associated with chipped flints and potsherds in hard alluvial silt that fills an old channel cut long after the deposition of the Brussels formation. In both localities the bivalve shells may possibly have been introduced by human agencies. According to local reports, remains of proboscidean teeth were found years ago in alluvium in Salt Spring Hollow, but these reports could not be confirmed.

[22] Fippin, E. O., and Drake, J. A., Soil survey of the O'Fallon area, Missouri-Illinois: U. S. Dept. Agr., Field operations of the Bureau of Soils, p. 831, sample 10769, 1904.

CALCAREOUS TUFA

Small deposits of calcareous tufa were found at a number of localities in the Hardin quadrangle. The individual deposits range in size from small masses a few feet in diameter in springs to large cones several hundred feet across on hillsides. Six of the deposits of tufa are sufficiently large to be shown on the geologic map. Of these, three in the SW¼NE¼ sec 21, T. 11 S., R. 2 W., in the NE¼NW¼ sec. 3, T. 7 N., R. 13 W., and in the east center NE¼ sec. 8, T. 7 N., R. 13 W. are obviously spring deposits, for they are being built up at the present time by active springs. The other three in the NE¼SW¼ sec. 26, T. 9 S., R. 3 W., in the NE¼NE¼ sec. 16, T. 11 S., R. 2 W., and in the NW¼SE¼ sec. 28, T. 8 N., R. 13 W., are no longer associated with springs, but their composition, form, and topographic position clearly show that they were formed in essentially the same manner. All the deposits of calcareous tufa that were recognized occur at outcrops of the Chouteau or the Hannibal formation. Springs are very common in the Hardin and Brussels quadrangles along the contact of these two formations, but only a very small proportion of these springs are depositing calcareous tufa.

The material making up the tufa cones is a fairly hard but exceedingly porous, brown, impure limestone. Distinct impressions of leaves and plant stems are common, and mammillary masses that exhibit both concentric and radial structure are abundant. Thin sections show that the material consists dominantly of coarsely crystalline calcite, much of which has a radial structure, and of finer-grained carbonates. Both the coarse and the fine-grained carbonates occur in layers that alternate with thinner and concentrically curved layers made by clay minerals and scattered grains of angular quartz sand.

Chemical analysis of a sample (p. 157) collected from the tufa cone in the NW¼SE¼ sec. 28, T. 8 N., R. 13 W., indicates that about 88 percent of the rock consists of slightly magnesian calcite, 8 percent of clay minerals, 4 percent of quartz, and 0.1 percent of iron sulfide. (See pp. 16–17). The sample apparently contains very little organic matter. In many respects the chemical composition of the tufa is surprisingly similar to that of the samples of Chouteau and Cedar Valley limestones. (See pp. 40 and 32.)

Plant remains are common in the tufa. Not only are there many impressions of leaves and stems, but at least a part of the concentric and radial structure is apparently due to the former presence of algae. Thin sections and polished faces of samples from the NW¼SE¼ sec. 28, T. 8 N., R. 13 W., that showed this mammillary structure were submitted to David White for examination. His report is given below:

As with the recent deposits, the plant structures are often obliterated even close to the surface of actual growth of the travertine. The larger specimen, which is gray with irregular configuration, is irregularly penetrated with the casts of stems, twigs, leaves, and mosses. Solution and recrystallization have apparently obliterated microscopical plant structures from much of the specimen. In portions, however, the tubes left by filamentous microscopical algae, probably belonging to the blue-green group, are clearly discernible. In some cases indications of the detailed cell structure are present. It is probable, therefore, that blue-green algae are responsible for the deposition of most of the lime in the deposit, though simpler and smaller bacterial forms presumably played an important role as well. The general physical, including the mineral characters and zoning of the specimen, are in agreement with those found in deposits known to be laid down largely through the instrumentality of filamentous blue-green algae in fresh water at the present day. Large numbers of filamentous algae tubes are visible in portions of two thin sections.

The brown specimen with the radiating fibrous mineral structure has a stalactitic aspect. The other two thin sections reveal characters common in the deposits made by algae. Some of the concentric zoning is characteristic of the work of the blue-greens and is traversed by the tubes of the algae exactly as they are seen in the deposits now forming, in which the living algae are examined *in situ*.

So far, therefore, as the travertines are illustrated by the four thin sections, they represent typical alga travertines, in the deposition of which the filamentous blue-greens appear to have played the major role.

The only animal remains found in the tufa were some gastropod shells collected in the NE¼NE¼ sec. 16. T. 11 S., R. 2 W. (Coll. 78, pp. 174–175.)

Most of the calcareous tufa is clearly of Recent age, but some of the larger cones are in places overlain by loess or loess-like silt. If this overlying material is true loess and not merely silt that has been washed from the original loess and redeposited by streams, then these larger tufa cones are in part of Pleistocene age.

RECENT

RIVER ALLUVIUM

The flood plains of Mississippi and Illinois rivers are the surface expression of the Recent alluvial deposits of these streams. These alluvial deposits occur in great volume, for the depth of fill seems to average between 50 and 75 feet, and the flood plains range from about 1½ to 5 miles in width.

Thickness.—In the Little Silver well, 2½ miles north of St. Peters, Mo., and in the flood plain of Mississippi River, bedrock was encountered at a depth of only 25 feet. However, in two wells near Orchard Farm, Mo.—in secs. 16 and 26, T. 48 N., R. 5 E.—in the Mississippi flood plain, opposite the mouth of Illinois River, the alluvium was found to be 122 and 125 feet thick; that is, the bedrock floor stands at elevations of about 313 and 309 feet, respectively, above sea level, or approximately 100 feet below the low water level of the river.

Detailed records are not available of the few other borings that have been made along Mississippi River within and near the Hardin and Brussels quadrangles. However, the thickness of alluvial fill may be compared with the thicknesses that have been recorded along Mississippi River farther north and south. Borings are rarely so located that they strike the bedrock at its maximum depth below the river, and furthermore, Mississippi River at several places has abandoned its old alluvium-filled course and taken a new channel across bedrock. Consequently, a graph of bedrock elevations along the river shows great irregularities, and most of the plotted points are unquestionably much higher than the lowest elevations of the bedrock floor somewhere nearby. In other words the few lowest elevations of the rock floor are much more significant than all the others. On this basis, the depth to bedrock of approximately 100 feet below low-water level near Orchard Farm may be compared with depths farther down the river of 96 feet at East Saint Louis and 50 feet between Fountain Bluff and Thebes, Ill., and with depths farther up the river of 137 feet at Fort Madison, Iowa, 142 feet near Muscatine, Iowa, 166 feet at Fulton, Ill., and 200 feet at St. Paul, Minn.[23]

The depth of filling in the trough of Illinois River seems to be of about the same order of magnitude. In a series of 5 borings at the site of the proposed railroad bridge from sec. 13, T. 6 N., R. 13 W., to sec. 1, T. 13 S., R 1 W., bedrock was encountered at depths of 57 to 87 feet or at elevations of 352 to 320 feet above sea level. In a series of 15 borings at the site of the proposed bridge over Illinois River at Hardin, Ill., 9 of the holes were drilled through 92 to 101 feet of alluvium without encountering bedrock; in other words, the rock floor there lies at elevations lower than 316 feet above sea level. These depths of from 87 to more than 101 feet of fill are to be compared with the depths of approximately 100 feet below low-water level in the two wells near Orchard Farm, at the mouth of Illinois River, and with the depths of about 98 feet at Putnam and in the old channel between Princeton and Hennepin.[24]

It is noteworthy that the available records indicate that the alluvial fill in the valley of Mississippi River thickens progressively upstream, whereas that in the valley of Illinois River seems to maintain the same thickness from near the Great Bend at Hennepin to the mouth of the river.

Lithologic character.—The composition of the Recent alluvial deposits of Mississippi and Illinois rivers must

[23] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 475–476, 1899.

[24] Leverett, Frank, op. cit., pp. 501, 634; Outline of Pleistocene history of Mississippi Valley: Jour. Geology, vol. 29, p. 618, 1921.

be judged by indirect as well as direct evidence. Foremost among the different types of observations are the actual exposures of alluvium along Mississippi River in cut banks and on sand bars and mud flats. In these exposures fine-grained silt or mud predominates. This silt is commonly massive, brownish gray, somewhat gritty, and slightly calcareous. In size, texture, and massiveness, and in its capacity to stand in nearly vertical banks (pl. 14 *B*), it greatly resembles the materials that make up the loess and the Brussels formation. It differs markedly from loess, however, in that it contains more clay-sized and carbonaceous material, and it is therefore more plastic and darker-colored. It differs from the materials in the Brussels formation chiefly in its darker color.

Subordinate amounts of sand occur here and there interbedded in the silt and upon bars in the river. This sand is for the most part medium-grained, fairly well sorted, subangular and composed chiefly of quartz. Locally, however, it grades into the finer-grained silt in some places and into coarse-grained sand in others. On many of the sand bars that are exposed at low stages of Mississippi River the sand is heaped in low wide waves or ripples that extend at right angles to the elongation of the bar and the course of the river. These ripples are from 6 to 18 inches deep, but their crests are 10 to 40 feet apart, and of the two slopes the downstream ones are much the steeper. The coarsest sand is concentrated on the crests of these ripples, and the intervening troughs are made of mud or silt. Superimposed upon these large ripples are many smaller irregularly branching current marks.

Illinois River is not now actively corrading its banks nor is its channel choked with sand bars and mud flats. Hence, exposures of alluvium are much less common along this stream. The few exposures seen were made up entirely of fine clayey silt.

Less direct evidence of the lithologic character of the alluvial materials is afforded by the soils on the flood plains. These soils indicate by their composition that along both rivers the fine-grained silts are much more extensive areally than the sands. The soils also indicate that black clay, indistinguishable from that found on portions of the Deer Plain terrace (p. 92) is widespread in the undrained marsh lands along Illinois River. This black clay in the Brussels quadrangles has been described and a mechanical analysis of it (No. 10974) published under the name, "Yazoo clay," in the soil survey of the O'Fallon area.[25]

Aside from the actual exposures of the alluvium and the character of the soils developed upon it, two other types of observations afford some information about the Recent river sediments. One of these consists of samples of the deposits in or on the bed of the streams. Such samples certainly indicate in a general way the nature of the sediments, but it is not certain that they represent adequately the true average composition of the materials being transported by a stream. Bottom samples from a river are likely in two important ways to be unrepresentative of the materials that are being carried. First, the coarser pebbles carried during times of flood may become buried at normal and low stages of a river beneath a veneer of finer-grained sediments. Hence, unless the sampling were done at times of flood, the coarsest materials may not be represented. Secondly, it is conceivable that pebbles much too large to be transported by a given stream might be dumped into it by steep tributaries or by caving banks. Therefore bottom samples collected at the mouths of tributary streams or near Pleistocene gravel terraces might give a totally erroneous impression about the size of materials that the present river is competent to transport. These two possible sources of error give rise to opposite effects, the first yielding samples much finer and the second samples much coarser than the true average. They may approximately compensate one another, but it is nevertheless essential that the very definite limitations of the evidence afforded by bottom samples be kept in mind.

No samples from the beds of the rivers were collected in the course of the field work for this report. However, during a trip from Hamburg to Alton on the Bureau of Lighthouses steamer *Wake-robin*, brief notes were taken on the nature of the bottom sediments as reported by the sounding men. These observations seem to show that sand is more abundant in the bed of Mississippi River than it is in the deposits of the flood plains. They also suggest that, in general, the coarsest-grained materials occur in intermediate depths of water; that is, the finer silts are found chiefly on the shallowest mud flats and in the deepest "pools." This distribution of the coarsest sediments accords with the known fact[26] that the fastest currents and hence the coarsests sediments in rivers are to be found at the shallows or "crossings" between the deeps or pools.

These meager observations on the bottom sediments of Mississippi River in the Hardin and Brussels quadrangles can be supplemented by the much more precise data collected by Lugn. Eighteen of Lugn's bottom samples were taken from Mississippi River between Hamburg and the eastern margin of the Brussels quadrangle and three from the mouth of Illinois River at a point about 1 mile east of the Brussels quadrangle.[27] The detailed data and the plotted histograms of the mechanical analyses of these samples show great diversity in grain size. Of the 18 samples from Mis-

[25] Fippin, E. O., and Drake, J. A., U. S. Dept. Agr. Field operations of the Bureau of Soils, pp. 833–835, 1904.

[26] Gilbert, G. K., The transportation of débris by running water: U. S. Geol. Survey Prof. Paper 86, pp. 220–222, 1914.

[27] Lugn, A. L., Sedimentation in the Mississippi River: Augustana Library Pubs., no. 11, pp. 55–59, pls. 5, 14, 15, 1927.

sissippi River, 9 may be called moderately well sorted coarse sands, 5 moderately well sorted medium sands, and 4 poorly sorted sandy silts. Of the three samples from Illinois River, 2 may be called silty clays and 1 a well sorted medium sand.[28]

It is impossible to summarize in a few words the details that are contained in a group of mechanical analyses, but the general nature of the data can perhaps be indicated. Of the 18 Mississippi samples, none contain any particles more than 16 millimeters in diameter, and less than half contain any particles more than 4 millimeters in diameter. (See also p. 71.) Similarly, 4 of these 18 samples have some grains less than 1/32 millimeter, and 15 samples have some grains less than 1/8 millimeter in diameter. Twelve of the 18 samples range between extreme limits of 8 and 1/32 millimeters.

In a mixture of different-sized particles, half of the material (by weight) is coarser and half finer than some intermediate size, which may be called the median diameter. This median diameter, which is probably the most significant single measurement in any given mechanical analysis, can be estimated closely by plotting the ordinary mechnical analyses in cumulative curves.[29] In this group of 18 samples from Mississippi River, the median diameters, estimated by this method, range from approximately 0.68 to 0.015 with a median value of 0.40 millimeter. Again, those diameters that limit the quarters (by weight) of material next coarser and next finer than the median diameter may be called the upper-quartile and lower-quartile diameters. In other words, these two quartile diameters are the extreme size limits of the middle half of the sample. In this group of 18 samples, the upper quartile diameters range from approximately 1.25 to 0.032 with a median value of 0.64 millimeter; and the lower quartile diameters range from approximately 0.43 to 0.007 with a median value of 0.28 millimeter. The estimates on these 18 samples may be summarized as follows:

Diameters of samples, in millimeters

	Largest particle less than	Upper quartile particle	Middle or median particle	Lower quartile particle	Smallest particle more than
Coarsest sample	16.0	1.25	0.68	0.42	0.125
Median	4.0	.64	.40	.28	.0625
Finest sample	.25	.032	.015	.007	?

Considered as a group, the one most nearly typical diameter is 0.4 millimeter. Bottom samples[30] collected in 1881 in a prolonged series of dredgings from the Mississippi at Hannibal, Mo., contain no particles with diameters greater than 3/4 inch (19 millimeters), and the average median, upper quartile, and lower quartile diameters are all between 1/10 and 1/100 inch (2.5 and 0.25 millimeters).

The three samples from the Illinois River are consistently finer-grained than those from the Mississippi. The one sample of sand is finer-grained than 9 of the 14 sands from the Mississippi, and the 2 silty clays are much finer than any of the 4 sandy silts from the Mississippi.

The fourth source of information about the alluvial material is the evidence afforded by drill records and well cuttings. No data of this type are available for the alluvial material of Mississippi River within the Hardin and Brussels quadrangles, but, according to local reports, coarse gravel and even large boulders were found at depths of 75 to 100 feet in the excavations for bridge piers at Louisiana, Mo., and Alton, Ill. Information about the alluvial material of Mississippi River several hundred miles downstream is given in the records of 76 borings along the Mississippi River between Cairo, Ill., and Lake Providence, La.[30a] Sixty-six of these borings disclosed, at depths commonly between 50 and 100 feet, relatively thin beds of gravel that contain some pebbles with diameters of 1 inch or more. The median diameter of the largest individual pebbles or cobbles found in each of the 66 borings is about 1 7/8 inches; but the associated materials—the coarse sand and fine gravel that make up the bulk of the exceptionally coarse grained beds in which these largest individual pebbles occur—have a median diameter of only one-fifth inch. The proportion of these buried gravels in the lower Mississippi that may be attributed to the deposits of steep tributaries, to talus from marginal bluffs, and to buried remnants of Pleistocene gravels is not known.

Fortunately, the borings along Illinois River afford fairly definite information about the size and character of the materials encountered at different depths. The test holes dug at the site of the proposed railroad bridge just east of the Brussels quadrangle penetrated first an upper layer of mud less than 10 feet thick, then from 34 to 52 feet of fine-grained and medium-grained sand, and, just above the bedrock, from 17 to 31 feet of coarse-grained sand and fine gravel. Samples examined by the writer indicate that this material consists of rounded peebles less than three-fourths inch in diameter of quartz, chert, and igneous rocks. The test hole nearest the bluff on the north side of the river encountered larger angular fragments of limestone and chert at much shallower depths, but these fragments are evidently talus from the bluff. The 15 borings put down at the site of the proposed highway bridge at Hardin first went through a fairly definite layer of clay and sand from 5 to 23 feet thick, but all the lower alluvium was found to

[28] Wentworth, C. K., A scale of grade and class terms for clastic sediments: Jour. Geology, vol. 30, p. 390, 1922.

[29] Wentworth, C. K., Methods of mechanical analysis of sediments: Univ. Iowa Studies, vol. 11, no. 11, pp. 49–51, 1926.

[30] See Vogel, H. D., Sediment investigations on the Mississippi River and its tributaries prior to 1930, U. S. War Dept., Engineer Corps, U. S. Waterways Exper. Sta. Paper H, pp. 83–84, 1930.

[30a] Report of the Mississippi River Commission, 47th Cong., 1st sess., S. Doc. 10, 1881.

be a rather heterogenous mixture of fine gravel, coarse and fine sand, and clay. Samples of the gravel seen by the writer contained no pebbles more than one-half inch in diameter.

The outstanding characteristic of the alluvium of both rivers, judged by exposures, soils, and bottom samples, is the dominance of fine-grained materials and the virtual absence of any grains that can properly be called pebbles. In this respect the Recent alluvium contrasts sharply with the Deer Plain formation as exposed along Mississippi River. The scattered drill records and well samples yield the only evidence that gravel occurs in the alluvium in anything more than negligible amounts. This conflicting testimony from the different types of evidence certainly might be explained by the burial, during subsiding stages of the river, of the gravels carried during floods. In support of this interpretation, it is known that many small tributary streams are building into both rivers small deltas composed in part of coarse chert gravel and that at a number of places Mississippi River borders remnants of Deer Plain gravel. Without some such interpretation, the absence of these gravels in the present alluvium and on the sand bars is not readily explained. (See, however, p. 71.) Furthermore, Mississippi River at St. Louis, Mo.,[31] and Missouri River at several places in Nebraska [32] are reported to scour out their alluvial fills to depths of 60 to 100 feet during times of flood, and it is conceivable that Mississippi and Illinois Rivers occasionally scour to these depths in the Hardin and Brussels quadrangles.

Nevertheless, certain considerations make it seem improbable that all the buried gravels can be interpreted in this way. Three successive surveys of the lower Illinois River, made since 1900 by the Engineer Corps, United States Army, strongly indicate, if they do not prove, that the present channel of this river is remarkably stable.

Detailed comparisons of the portions of these large-scale maps and of those lines of soundings that fall within the Hardin and Brussels quadrangles disclosed no indication whatever of horizontal or vertical changes during a period of more than 20 years. This evidence of great stability accords with the statements of river pilots that Illinois River does not shift its channel perceptibly and also with the writer's observation that this stream is not at the present time actively corrading its banks. (See also pp. 123, 125, 129.) It appears extremely improbable that the present river is capable of handling the great thicknesses of sand and fine gravel that overlie its bedrock floor. The inference therefore seems justified that the processes of scour and fill, which are believed to be effective agents on other streams nearby, have been of only negligble importance on Illinois River during historic times.

On Mississippi River, conditions are different. There the channel shifts somewhat at each flood; new bars are constantly forming, and old ones are cut away. Scour and fill are therefore active processes, and the only questions are the depth to which they extend and the maximum size of the materials that are being moved. On these questions there are unfortunately very few direct data. However, indirect evidence suggests that even at times of extreme floods the part of the river that borders the Hardin and Brussels quadrangles is unable to transport cobbles and boulders. As stated elsewhere in this report (p. 71), the highest mean channel velocities that have been recorded on Mississippi River above St. Louis, Mo., are approximately the same as the bottom velocities at which pebbles about 3½ inches begin to move. Hence it appears highly probable that any cobbles and boulders more than 4 or 5 inches in diameter, such as have been reported at Louisiana, Mo., and Alton, Ill. (p. 100), must have been brought to their resting places by streams more powerful than the present Mississippi River—that is to say, by a much more vigorous Pleistocene river or by steep lateral tributaries.

Both considerations—the stability of the channel of Illinois River and the maximum flood velocities of Mississippi River—point to the conclusion that some at least of the deeper and coarser material within the alluvial fill must have been deposited there when the rivers were more powerful than they are today. It is indeed possible that, after the deposition of the Deer Plain formation and before historic times, these rivers have undergone fluctuations of discharge great enough to account for all of the more deeply buried coarser material, but it seems more probable that much of this buried alluvium may properly belong with the Deer Plain and even older formations (p. 115).

The conclusion that the very coarsest materials, regardless of their exact age, probably are not being transported by the present-day rivers leads to an interesting corollary: the largest cobbles and boulders dumped into both rivers from steep tributaries and undercut banks of Deer Plain gravel very probably are being reduced to manageable dimensions by a process of wet-blasting or abrasion from the finer-grained sand that is swept over and past them at all times of the year.[33]

PHYSIOGRAPHY

The description and interpretation of the land forms of an area may be cast into either of two very different

[31] Fenneman, N. M., Physiography of the St. Louis area: Illinois Geol. Survey Bull. 12, p. 30, 1909. See, however, Shaw, E. W., Newly discovered beds of extinct lakes in southern and western Illinois and adjacent States: Illinois Geol. Survey Bull. 20, p. 153, 1915.

[32] Todd, J. E., The moraines of southeastern South Dakota: U. S. Geol. Survey Bull. 158, pp. 150–153, 1899.

[33] Barrell, Joseph, Marine and terrestrial conglomerates: Geol. Soc. America, vol. 36, pp. 330–331, 335–336, 338, 1925.

molds. The method of treatment may be primarily empirical or primarily interpretative. In the empirical method the different features are described systematically according to their geographic or some other type of distribution, and an effort is made to reduce to a minimum all interpretations of their origin and significance. Under the interpretative method the conclusions regarding the origin and significance of the different features become the guiding principle in their discussion, and the descriptions merely supplement and support the conclusions. Both methods have their desirable and their undesirable qualities. The descriptive method is much the safer, but its procedure is tedious, and its listing of uncoordinated facts becomes monotonous. The interpretative method is much more easily read because it emphasizes significant facts and focuses attention upon critical observations. However, it likewise has serious defects; the facts believed at one time to be of greatest significance may in the light of additional information seem of only secondary importance. Also, by its emphasis upon interpretations, it leaves no proper place for unexplained features, and these features, having no place, are too readily neglected.

The present treatment of the land forms in the Hardin and Brussels quadrangles follows neither of these two methods strictly. The interpretative method is adopted to the extent that a chronologic order of classification and discussion is attempted. But under the successive chronologic headings the discussion is primarily descriptive. This combined type of treatment is adopted because it affords the basis of interpretation requisite for a coherent presentation of the descriptions and because it accords with the historical order of events followed in the sections on Stratigraphy and Geological History.

As stated elsewhere, much that might more logically have been restricted to this section on Physiography has in the interest of continuity been included in the section on Stratigraphy.

THE CALHOUN PENEPLAIN (MIDDLE OR LATE TERTIARY)

The long interval of time between the withdrawal of the Pennsylvanian seas and the advance of the first Pleistocene glaciers left very little stratigraphic record in the central Mississippi valley region. Almost the only evidence of the geologic events during that long interval of time are the land forms that were produced then. This evidence from the land forms consists primarily of an upland level, which is here interpreted as an old erosion surface and which, from its partial preservation in Calhoun County, Ill., is called the Calhoun peneplain.

THE SKYLINE SURFACE

It may be true, as some geologists believe, that the concept of partial peneplains and of multiple erosion cycles has been carried to extreme limits in certain regions. However, it seems equally true that an overly skeptical attitude founded on this belief may lead to an unjustifiable denial of the existence of any peneplanation whatever in regions where the hypothesis is supported by many facts. The remnants of the upland surface in and near the Hardin and Brussels quadrangles seem rather clearly to be the remnants of an old peneplain. The old land surface is very flat, it bevels across rock structures, and it is very widespread. If, furthermore, local coverings of deeply weathered residuum and of stream gravels are additional criteria of peneplanation, then this identification seems to be confirmed.

The upland surface in this region, particularly in Calhoun County, Ill., and St. Louis County, Mo., appears remarkably flat. It is true that it slopes gently and that its elevation is not the same over wide areas, but the departures from true horizontality are not apparent to the unaided eye.

This flat upland surface also bevels across rock structures. In northern and central Calhoun County it lies at different places upon the Sedalia, the Burlington, or the Keokuk formation, and its flatness is not noticeably affected by differences in the hardness or resistance to erosion of the underlying rock. In western Jersey County and southwestern Greene County, the precise relations are somewhat obscured by a covering of glacial till, but the flat upland surface of the bedrock clearly cuts across the Chouteau, Sedalia, Burlington, Keokuk, and Warsaw formations. Minor folds, like the Meppen syncline in the southern part of T. 12 S., R. 2 W., involve these formations, but they are not reflected in the flat upland surface. (See pl. 10 *A*; fig. 3 *D*.) From southern Calhoun County southward across St. Charles County and into western St. Louis County, the flat upland cuts across successively older beds from the Pennsylvanian McLeansboro formation to the Mississippian Burlington limestone (pl. 10 *A*), and farther to the southwest it appears to cut down onto still older formations. A structure section drawn westward along the synclinal axis from Brussels, Ill., to Troy, Mo., would show that the upland surface also bevels this same sequence of beds in an east-west direction.[34]

The upland surface is very extensive. From his own observations the writer believes that it can be traced with reasonable certainty for at least 60 miles north and south and 25 miles east and west through and beyond the Hardin and Brussels quadrangles. How much farther it may extend is not known. It is probably the same surface as the upland peneplain along Mississippi

[34] Potter, W. B., Geology of Lincoln County: Missouri Geol. Survey prelim. Rept. iron and coal fields, 1872, pt. 2, pl. 8, 1873. U. S. Geol. Survey, topographic map of O'Fallon quadrangle, Missouri-Illinois.

River near St. Louis, Mo.,[35] and in Carroll County, Ill.[36] and that along the upper Illinois River.[37] (See also pp. 66, 109–110.)

The occurrence of old stream gravels on the upland surface has been discussed much more fully in the stratigraphic description of the Grover gravel. The remnants of this old gravel that have been found lie chiefly within a relatively narrow north-south zone roughly parallel to the course of Mississippi River (p. 62). The thick accumulations of residual chert and clay (p. 74) that underlie the upland surface in the Hardin and Brussels quadrangles might possibly be cited as additional support of the interpretation that this upland surface is an old peneplain, for these residual materials are evidence that the surface has been subjected to prolonged weathering.

If the upland is an old peneplained surface it represents the product of long-continued erosion. Lands that once stood higher were cut down by streams until nearly the whole region was reduced to a broad flat plain. The only hills seen by the writer that seem to rise above this old upland surface are the so-called "Lincoln Hills" or Lincoln Ridge [38] in northeastern Lincoln County, Mo. These hills stand only 100 to 200 feet above the general upland level but, so flat is the upland elsewhere, they are conspicuous landmarks for many miles. They may possibly be monadnocks or residual hills that were left unreduced by the streams that cut the peneplain.

RELATION TO PRE-PENNSYLVANIAN UNCONFORMITY

The volume of rock removed in the production of the Calhoun peneplain would be difficult to estimate. Throughout most of the region the Burlington to McLeansboro formations underlie the surface of truncation, but in parts of Calhoun County, Ill., and Lincoln County, Mo., the surface almost certainly extended onto Ordovician rocks. If all of these formations had been truncated after the Pennsylvanian deposition, it would be a relatively simple matter to estimate from the known thickness of the different formations the volume of rock removed during the development of the peneplain. However, many of these formations had been truncated much earlier by post-Mississippian, pre-Pennsylvanian erosion. In fact, so nearly does the level of the Calhoun peneplain coincide over wide areas with the average level of the unconformity between the Mississippian and the Pennsylvanian rocks that in some places the peneplain might be considered an exhumed or resurrected pre-Pennsylvanian land surface.

However, the correspondence between the two surfaces holds only in a general and not in a detailed way. All available evidence indicates that the pre-Pennsylvanian surface was one of considerable local relief (pp. 55–56) whereas the peneplain is strikingly flat. In some places, as in central Calhoun and much of Lincoln Counties, the peneplain cuts down below the deepest valleys and sinkholes on the old pre-Pennsylvanian surface. In other places, as in southern Calhoun County, it lies well above the Mississippian and entirely within Pennsylvanian rocks. But in most of the area, as in northern Calhoun, western St. Louis, and parts of Lincoln Counties, the peneplain was stripped to a level intermediate between the highest hills and the lowest valleys and sinkholes in the pre-Pennsylvanian surface. Hence, remnants of Pennsylvanian rocks are left scattered here and there on and immediately below the peneplain surface. (See pls. 10 *A*, *B*, 20; fig. 3 *D*.) Apparently the erosion that produced the Calhoun peneplain consisted in large part of the removal of the Pennsylvanian sediments. In some places the streams cut away only a part of these sediments; elsewhere they removed all the Pennsylvanian and some of the older rocks.

This general correspondence between the two surfaces suggests that the regional base level of the streams that developed the peneplain may have been controlled at least in part by the difference in hardness of the Pennsylvanian and the older rocks. The streams may have cut readily through the Pennsylvanian sediments till they encountered the more resistant older rocks, and thus at many places the local base level would be held up near the unconformity. Had there been no deformation after withdrawal of the Pennsylvanian seas, the completed peneplain would probably have come to coincide almost exactly over the entire area with the level of the deepest valleys in the pre-Pennsylvanian surface. But this simple stripping off to the level of the unconformity was prevented by warping sometime after Pennsylvanian deposition and before the completion of the peneplain (fig. 3 *B*). On the uplifts the streams bevelled deeper than this level, but in the sunken areas they were unable to cut down as far as the base of the Pennsylvanian.

AGE OF THE PENEPLAIN

The geologic date at which the old surface was finally cut most nearly to a plain must be estimated by indirect methods. The peneplain cuts across and so is clearly later than the Pennsylvanian McLeansboro formation. It is also distinctly pre-Pleistocene, for Nebraskan till is found not far away in valleys cut well below it (pp. 65, 76, 110). The intermediate postmature upland surface, cut after the Calhoun peneplain was uplifted, is

[35] Fenneman, N. M., Physiography of the St. Louis area: Illinois Geol. Survey Bull. 12, p. 52, 1909; Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, pp. 43–44, 1911.

[36] Carman, J. E., The Mississippi Valley between Savanna and Davenport: Illinois Geol. Survey Bull. 13, p. 28, 1909.

[37] Sauer, C. O., Geography of the upper Illinois Valley: Illinois Geol. Survey Bull. 27, pp. 55–56, 1916.

[38] Shepard, E. M., Underground waters of Missouri: U. S. Geol. Survey Water-Supply Paper 195, pp. 8, 10–11, 1907.

likewise pre-Pleistocene, and it seems necessary, in order to allow adequate time for the development of this surface, to conclude that the peneplain must be as old or even older than the earliest Pliocene (p. 109). Furthermore, the apparent relationship between the Mississippi embayment and the drainage pattern on the peneplain, if correctly interpreted (pp. 108–109), would mean that the peneplain could not have been completed until long after the Cretaceous period when the embayment came into existence. Finally, the Grover gravel, which lies upon the peneplain, has yielded very few fossils, but the few that have been reported indicate a Tertiary age, and deposits similar to those of the Grover gravel overlie Eocene rocks at the head of the Mississippi embayment (pp. 65–66); that is, the various lines of indirect evidence all converge to indicate that the Calhoun peneplain attained its flat surface sometime within the Tertiary period, probably earlier than the Pliocene epoch and later than the Eocene.

ORIGIN OF THE TROUGHS OF MISSISSIPPI AND ILLINOIS RIVERS

EVIDENCE OF DRAINAGE PATTERNS

The courses followed by streams are the result of the rock structure of a region and the geologic processes that have operated there—the term "rock structure" is here used in the broad sense of gross arrangement of materials under which W. M. Davis includes original distribution and stratification and subsequent dislocations and fracturing. If the bedrock materials are essentially homogeneous, if the local geologic processes have operated with relative uniformity, and if all later diastrophic changes have taken place gradually, the major streams may hold courses that were established soon after the first uplift of a region. However, with greater irregularities of rock material, greater alterations of the local processes, or more abrupt or intense diastrophic disturbances, modifications of the original drainage become increasingly probable. As examples of the geologic processes, glaciation and marine planation may greatly modify previous surfaces and develop new land forms which come to influence the courses of later streams. Similiarly a peneplain, inasmuch as it develops at the expense of previous surfaces, means the destruction of nearly all traces of earlier land forms.

If peneplanation necessarily means absolutely complete lateral planation so that streams could meander freely over the entire area, then of course all evidence of earlier stream courses would be effaced. Peneplanation, however, does not necessarily imply this final stage of widespread lateral planation. In fact, the attainment of such a degree of ultimate planation over wide areas seems highly improbable in nature. An area of very gentle relief—a peneplain but not a pediment (see p. 70)—might be formed much more readily by simple downcutting in many valleys and the continued reduction of hill slopes in interstream areas. Accordingly, many streams on old erosion surfaces of very gentle relief may have held the same courses or parts of the same courses throughout the long period of downcutting. Consequently, even though all the preexistent surfaces should have been destroyed, the courses of those streams that flowed upon the peneplain, if they can be identified, will still give some clue to the general topographic relationships before the peneplain was cut.

However, the determination of the former drainage pattern upon a peneplain may be very difficult. The early streams, after peneplanation and rejuvenation of the region, may have been able to maintain only parts of their original courses because of subsequent deformation or burial. In that event the resultant drainage pattern will contain elements of both the old and the new which are difficult to identify and disentangle correctly. It is therefore necessary, in order to interpret the earlier history of a stream, to know first the subsequent modifications it has undergone so that the newer elements may be separated from the old. And it is obvious that, for this purpose, the chronologic order of treatment and discussion followed throughout this report must be temporarily reversed.

In many regions, diversion of streams is a common accompaniment of continental glaciation, and many of the smaller streams in Illinois and Missouri have been thrown out of their channels by successive advances of the ice. Near the Hardin and Brussels quadrangles, however, the Mississippi and Illinois rivers follow courses that seem clearly to have been established before the region was glaciated (pp. 65, 76, 110). In fact, throughout the region much of the present courses of these two rivers and parts of Missouri River[39] seem to have been inherited from the streams which trenched into and dissected the peneplain; and, in turn, some or parts of these dissecting streams probably inherited their courses from streams that flowed upon and fashioned the peneplain. The problem thus becomes one of identification of those parts of the stream courses that have been inherited from the peneplain.

POSTPENEPLAIN DIVERSION OF STREAMS

Before the first advance of the ice, the Calhoun peneplain had been uplifted and deformed. It is not certain whether the Grover gravel was deposited chiefly before, during, or immediately after this deformation, but a comparison between the pebbles and boulders deposited in this formation and those carried by present-day streams leads to the conclusion (pp. 70–73) that the coarsest of these gravels probably were transported by streams that were being rejuvenated by the

[39] Todd, J. E., Formation of the Quaternary deposits: Missouri Geol. Survey, vol. 10, pp. 204–212, 1896 Hinds, Henry, and Greene, F. C., U. S. Geol. Survey Geol. Atlas, Leavenworth-Smithville folio (no 206), p. 10, 1917. Leverett, Frank, Outline of Pleistocene history of Mississippi Valley: Jour. Geology, vol. 29, p. 617, 1921.

uplift. Nevertheless, the peneplain and the gravel that lies upon it were undoubtedly deformed and it seems certain that at least part of this deformation was distinctly later than the deposition of the gravel. In western St. Louis County the gravel is cross-bedded with oblique laminae that dip steeply southward (p. 63), yet this gravel and the wide plain on which it rests now slope about 7 feet to the mile northward across St. Charles County into southern Calhoun County. There, at the Cap au Grès flexure, the old peneplained surface rises abruptly about 175 feet onto the Lincoln anticline, from which it again slopes gently northward or northeastward. (See pl. 10*A*.)

In the region near the Hardin and Brussels quadrangles, the deformation of the peneplain was a renewed movement of preexisting structural units (pp. 145–146). As a result, in practically every area in Calhoun, Jersey, and Greene Counties, Ill., and Lincoln, St. Charles, and St. Louis Counties, Mo., where both topographic and structural data are available,[40] the slope of the upland peneplain and the dip of the underlying rocks are in the same direction, but the angle of the slope of the peneplain is much less than the angle of dip of the rocks. The mere directions of dip and slope, therefore, do not serve to distinguish stream courses that may have been established on the original uplift from those that have been disturbed and modified by subsequent deformation of the peneplain.

Nevertheless, a purely empirical classification of present river courses, based upon the angle between the directions of stream flow and the directions of bedrock dips and upland slopes, tends to simplify the complex relationships and avoids the sometimes premature or ambiguous conclusions forced by rigid adherence to the well-known genetic classification. And for these reasons the empirical classification is useful in the present discussion. Streams that flow essentially straight down the bedrock dip—which in this particular area are also those that flow down the direction of upland slope—may be said to have "dip" valleys. Local examples are the Missouri River from Labadie to St. Charles, Mo., and the Meramec River from Moselle to the big bend at Valley Park, Mo. (See fig. 7.) The special but important case of dip valleys in which streams flow down the axes of pitching synclines may be called "synclinal pitch" valleys. Local examples are parts of Cuivre River in Lincoln County, Mo., and the Mississippi from the mouth of Illinois River to Alton, Ill. (See figs. 7, 8 *B*.) Dip valleys and synclinal pitch valleys follow the lines of readiest surface and ground water discharge, but they have no certain and unique genetic significance. They may have been established immediately after the first uplift of the region or the later warping of the peneplain and have maintained their courses through a long period of down cutting, or they may have developed these courses much later by progressive headward erosion back up the dip.

Streams that flow in the opposite direction, up the dip and up the pitch, may be said to have "counter dip" valleys and "counter pitch" valleys. The lower part of Otter Creek, which flows up the axis of the Otter Creek syncline (see pl. 2), the Illinois River above Meredosia and, apparently, the Mississippi River from East St. Louis to Valmeyer, Ill., which flow up the regional dip, are local examples (fig. 7). Counter dip valleys may have been established by relatively rapid tilting in a direction opposite to that of the principal movements of the region or, more probably, by progressive piracy of old dip valleys, as the result of headward erosion of later streams.

Streams that flow essentially parallel to the strike of the underlying rocks may be said to have "strike" valleys. Local examples are the Mississippi River from Hannibal, Mo., to Belleview, Ill., from Alton to East St. Louis, Ill., and from Valmeyer, Ill., to Ste. Genevieve, Mo., the Missouri River from the mouth of Osage River to Labadie, Mo., and the Meramec from the big bend at Valley Park to its mouth. (See figs. 7, 8 F.) These rivers follow courses that coincide with the belts of outcrops of less-resistant rocks; hence these courses probably developed sometime after dissection of the original uplift had begun, but whether immediately after the original uplift or the later warping or long subsequent to both movements is a more difficult question.

Streams that flow neither parallel nor at right angles to the dip of the rocks and the slope of the upland surface may be said to have "structurally oblique" valleys. The Illinois River from Meredosia to its mouth and the Mississippi River from Belleview to Dogtown Landing—and probably to the mouth of Illinois River—are examples. The rivers may possibly have established these oblique courses by more or less accidental headward erosion, but it seems much more probable that they acquired them while flowing upon very flat surfaces and maintained them during gradual uplift and tilting or during downcutting from some series of unconformable sediments.

It is an interesting and perhaps significant fact that the present rivers show the least relation to the underlying structure and the upland slopes in the general vicinity of the Lincoln anticline. It is true that both of the rivers cross the Cap au Grès flexure approximately at right angles but, viewed regionally, they certainly are not adjusted to the rock structure. Had Mississippi River continued southeastward in a strike

[40] Marbut, C. F., Physical features of Missouri: Missouri Geol. Survey, vol. 10, pl. 1, 1896. Illinois Geol. Survey, Geologic map of Illinois, 1917. Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Mo., to Nauvoo, Ill.: Illinois Geol. Survey Bull. 45, pl. 1, 1924. Missouri Bur. Geology and Mines, Geological map of Missouri, 1926. U. S. Geol. Survey, topographic maps of the O'Fallon, St. Louis, St. Charles, Brussels, Hardin, Pearl, Nebo, and Roodhouse quadrangles.

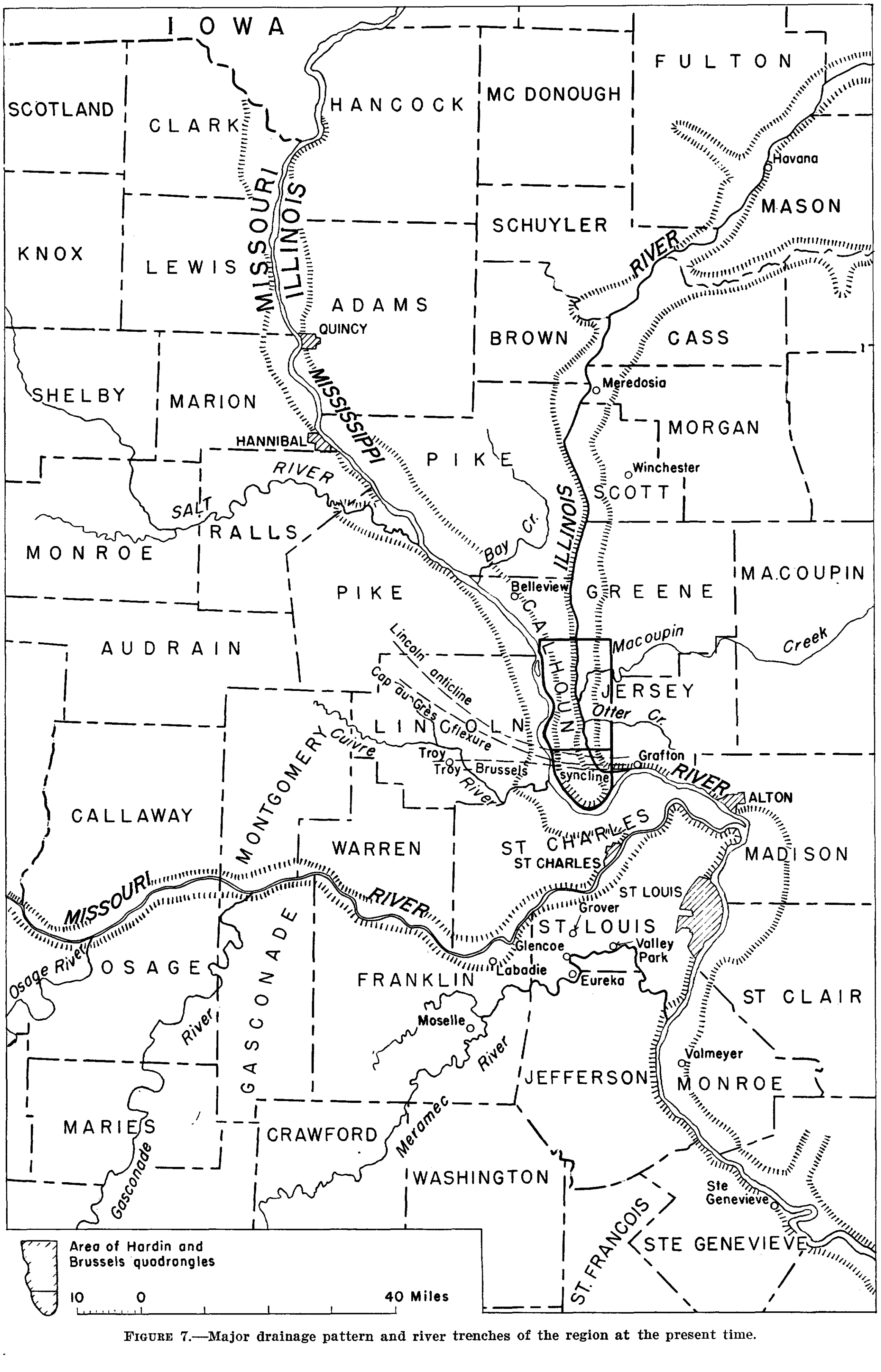


FIGURE 7.—Major drainage pattern and river trenches of the region at the present time.

valley from Belleview nearly to Alton it would have found not only a more easily excavated but a much shorter path. (See fig. 7.) Instead, its valley turns southward near Belleview, cuts obliquely across older rocks to the Cap au Grès flexure, then swings through a wide semicircle in younger formations before joining the synclinal pitch valley at the mouth of the Illinois River. Similarly, Illinois River flows southward, obliquely across the strike of the rocks and parallel to the Mississippi until near its mouth it turns abruptly eastward down the pitch valley.

So obvious a lack of adjustment between the stream courses and the underlying structure strongly suggests partial inheritance from earlier streams, and the indirect, devious courses seem to imply modifications of these earlier streams.

This inference based upon the drainage pattern is strengthened by other and more direct evidence bearing on the positions of the streams that flowed on the Calhoun peneplain—that is, by the geographic distribution of the Grover gravel. The remnants of this formation lie in a relatively narrow north-south belt that coincides roughly with the present course of Mississippi River (p. 62). In a general way, this linear belt occupies the area in which Mississippi and Illinois rivers now follow oblique and indirect courses, and it extends southward approximately in line with these structurally oblique valleys of Mississippi and Illinois rivers and with the lower strike valley of Meramec River. This linear distribution, together with the evidence of the cross bedding, makes it appear highly probable that the principal stream or streams that deposited the Grover formation once flowed nearly straight south (see pp. 63, 68) through the area of the Hardin and Brussels quadrangles, across western St. Louis County and into the valley of Mississippi River near Valmeyer, Ill. (See fig. 8*A*.)

If these inferences from the drainage pattern of the region and from the distribution of the Grover gravel are correct, it then becomes necessary to consider the changes whereby the ancestral rivers might have been diverted from their former direct southward course into their present roundabout channel past Alton, Ill., and St. Louis, Mo. (See fig. 7.) Several possible explanations might be offered. The region along which the warping of the Calhoun peneplain was most abrupt—the Cap au Grès flexure and the nearby Troy-Brussels syncline—lies nearly at right angles to the supposed courses of these ancestral rivers. If this warping took place more rapidly than the rivers could adjust their gradients, they might have been diverted sharply eastward down the Troy-Brussels synclinal axis into a southwestward flowing tributary—the counter dip valley from Alton to Valmeyer—which was not equally disturbed. (See fig. 8*A*.) As another possibility, if the warping were more gradual, the northeastward tilting of the region south of the Cap au Grès flexure, supplemented perhaps by heavy sedimentation at the mouth of an ancestral Missouri or Osage River, which would have been rejuvenated by this tilting, might have so handicapped the two rivers that a lower subordinate tributary, not equally handicapped, was enabled to work back by headward erosion from Alton along this synclinal axis and behead the two rivers. And, once diverted into this roundabout course by either tilting or piracy, the ancestral stream might readily have held its course during the subsequent dissection of the peneplain and the development of the present topography.

The foregoing interpretation may be summarized in terms of the genetic classification by statements that the lower Illinois River nearly to its mouth and Mississippi River from Belleview to Dogtown Landing and from Alton to Valmeyer, Ill., are thought to be antecedent [41] to the postpeneplain uplift; the Mississippi River from Dogtown Landing nearly to the mouth of Illinois River is thought to be superimposed [41] from the Calhoun peneplain and the Grover gravel; and the Mississippi River from the mouth of Illinois River to Alton, Ill., is thought to be consequent [41] upon the trough formed by the postpeneplain deformation.

DRAINAGE PATTERN ON THE PENEPLAIN

If this interpretation affords a reasonable explanation of the diversion of the ancestral Mississippi River eastward around the St. Louis County "peninsula," it then becomes possible to reconstruct with some degree of confidence the general pattern of major streams that flowed upon the Calhoun peneplain. Two large streams—the ancestral Mississippi and Illinois Rivers—seem to have flowed south through structurally oblique valleys across the Lincoln anticline and the Troy-Brussels syncline. Which of the two streams was then the larger is not known. The valley of Illinois River may then, as at a later period (p. 115), have carried the drainage of the present Rock River and upper Mississippi Valley, and this, together with the greater distance along which the Illinois River flows in an oblique valley, seems to indicate the greater size of the ancestral Illinois.

On the other hand, two considerations suggest that the ancestral Mississippi may then have been the larger stream. First, the remnants of the Grover gravel are essentially restricted to the uplands bordering the Mississippi, thus indicating that the Illinois transported less, or at any rate finer-grained, detritus. Secondly, it has been tentatively suggested [42] that Salt River in

[41] Davis, W. M., The rivers of northern New Jersey with notes on the classification of rivers in general: Geographical Essays, pp. 485–487, 1909.

[42] Todd, J. E., Formation of the Quaternary deposits: Missouri Geol. Survey, vol. 10, p. 212, 1896.

Misouri and Kansas River [43] in Kansas may once have been parts of a single drainage line and that this line may have been but one of a group [44] of parallel eastward-flowing streams, which before they were integrated by the spreading ice sheets into the Missouri River system, drained from the Tertiary High Plains of Kansas and Nebraska eastward into the Mississippi (fig. 8*A*). With such a large drainage area the ancestral Mississippi may well have been a larger river than the ancestral Illinois. The parallel alinement of these two trunk streams as they flow southward through the area of the Hardin quadrangle might possibly, under this interpretation of the ancient drainage, be explained as the result of natural levees built between converging streams much as Mississippi and Missouri Rivers are now forced to flow parallel to one another for many miles before they join.

The two streams from the north were probably joined by a stream, ancestral to the lower Missouri or the Osage River, that flowed east along a general strike valley on the northern flank of the Ozark area. Below the juncture of the three streams the drainage apparently continued southward or southeastward toward the head of the Mississippi embayment along a strike valley on the eastern flank of the Ozarks. (See fig. 8*A*.)

According to this interpretation, most of the major drainage on the Calhoun peneplain was not inherited from the original uplift. The ancestral Mississippi and related rivers flowed, not straight out into the Illinois coal basin as the original streams may have done, nor westward toward the interior Cretaceous sea, but southward onto and then high along the eastern flank of the Ozarks. Streams that were ancestral to the Meramec and other rivers that like it radiate outward from the present Ozark Highland and, possibly, a stream ancestral to Cuivre River may still have followed courses upon the peneplain that were taken immediately after the original post-Pennsylvanian uplift. However, most of the drainage had been modified perhaps several times into a very different pattern long before the peneplain was completed.

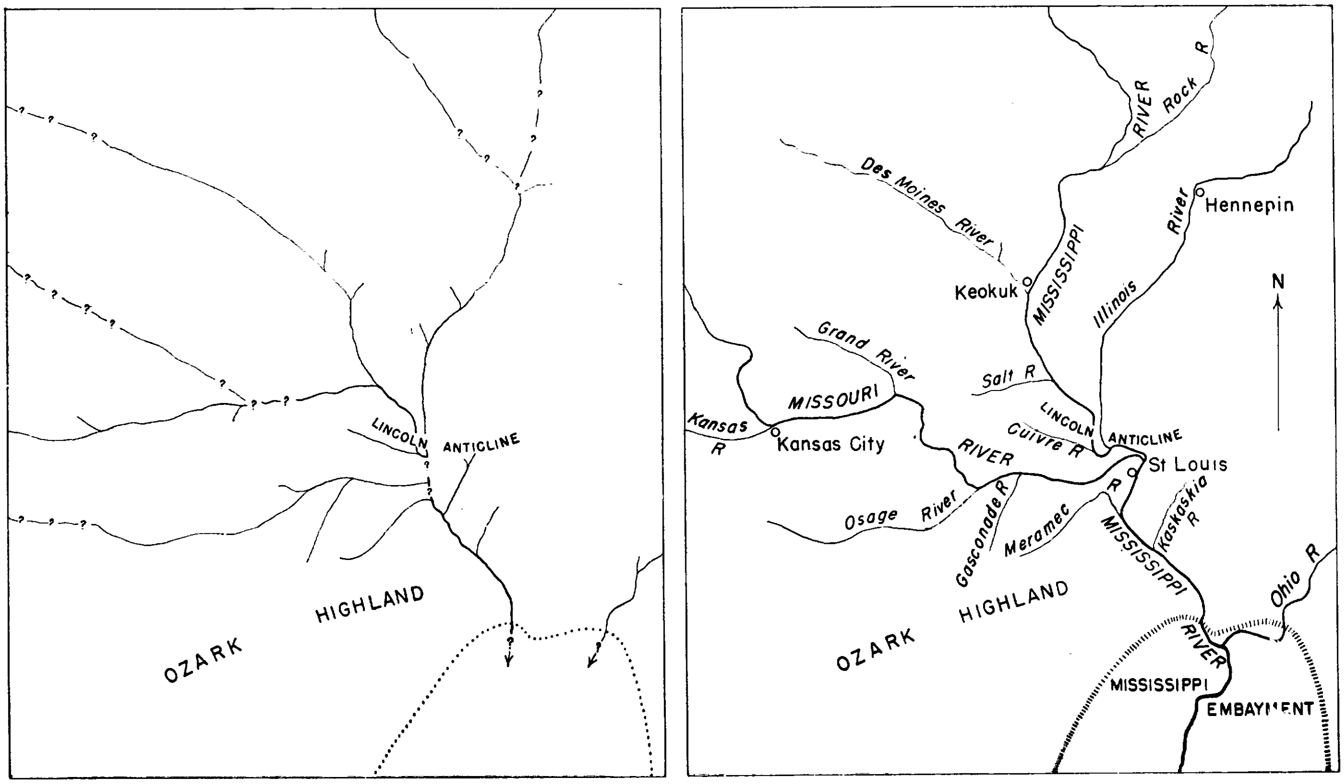


FIGURE 8.—Schematic diagrams: *A*, Hypothetical drainage pattern on the Tertiary peneplain; *B*, Major drainage pattern at present time.

The story of this profound modification of the earlier consequent drainage into the later drainage on the peneplain is now badly obscured, if not hopelessly lost, through the destruction of evidence. It is, however, possible to deduce from the accepted laws of stream development a probable sequence of events that would account for the known facts. The initial streams on the post-Pennsylvanian uplift must have cut into the underlying, tilted rocks and eventually have developed tributaries along strike valleys. Nothing whatever is known about modifications of this first drainage system

[43] Hinds, Henry, and Greene, F. C., U. S. Geol. Survey Geol. Atlas Leavenworth-Smithville folio (no. 206), p. 10, 1917. Greene, F. C., Preliminary sketch of the history of the lower Missouri: Bull. Geol. Soc. America, vol. 32, pp. 83–86, 1920.

[44] Upham, Warren, Age of the Missouri River: Amer. Geologist, vol. 34, pp. 84–85, 1904. Todd, J. E., The Pleistocene history of the Missouri River: Science, new ser., vol. 39, pp. 265–269, 1914.

during Permian, Triassic and Jurassic times; but in the Cretaceous period warping, intrusion, and probably faulting brought into existence the Mississippi embayment.[45] The structural disturbances at this time might readily have given an advantage to those tributary streams that happened to flow most directly into the head of the embayment and, with this advantage, a new drainage system could have extended itself far northward by successive captures of the preexistent strike valleys. (See fig. 8 *A*.)

By this interpretation, the early Mesozoic drainage system, whatever it may have been, is now all but hopelessly lost; only the merest fragments of it now remain. However, the Calhoun peneplain must, by the same interpretation, be distinctly younger than Cretaceous, for the streams which finally cut it low did not establish themselves until after the Mississippi embayment had been blocked out.

DISSECTION OF THE PENEPLAIN

Immediately after the deformation and uplift of the Calhoun peneplain, the streams started entrenching themselves and dissecting the land surface. This dissection proceeded in two distinct cycles of downcutting, the first of which has left in the present land forms only such dim records as the sloping upland spurs, but the second cycle still dominates the landscape and geography as the major trenching of the region, and it has left evidence of a complex series of events.

INTERMEDIATE UPLAND SURFACE (PLIOCENE?)

The upland spurs or interfluves that extend from the Calhoun County divide west toward Mississippi River and east toward Illinois River and from the uplands in Jersey and Greene Counties west toward Illinois River slope gently but unmistakably from the divide toward the two rivers. The angle of these slopes is difficult to measure accurately because of the thick mantle of loess and glacial till on the uplands, but it seems to average from 25 to 50 feet to the mile along the present length of the spurs (pls. 10 *B*, *C*, 20), being steepest in the southern part of the Hardin quadrangle where the uplands are highest. If these slopes are extended from both sides out over the flood plain of Illinois River, they meet very irregularly at elevations from 125 to 250 feet below the surface of the Calhoun peneplain but fairly uniformly at an elevation of about 125 to 150 feet above the present river level. In other words, the intermediate surface occurs at a relatively constant interval above the level of the present streams, but its position seems to be quite unrelated to that of the peneplain. True, this extrapolation of the interfluve slopes yields only uncertain results, but it serves to indicate that the intermediate upland slopes were cut sometime after the deformation, tilting, and uplift of the Calhoun peneplain.

The intermediate upland surface was clearly formed later than the deposition of the Grover gravel for remnants of this gravel are now found on the crests of the highest divides. (See pls. 10 *B*, *C*, 20.) The long gentle slopes of this intermediate upland surface indicate that dissection of the uplifted Calhoun peneplain had progressed far beyond the stage of simple trenching. The existing data do not permit a precise restoration of the intermediate surface, but they seem to show clearly that the development of the valleys had progressed somewhat beyond the stage of maturity and possibly well into old age. Stated another way, the cutting of the river trenches had apparently proceeded at least as far and probably much farther in a cycle of erosion before the first advance of Pleistocene ice than it has since then. The time required for the development of this postmature surface must have been very great; just how great is not known, but inasmuch as Nebraskan till is found in valleys cut far below the upland (pp. 65, 76, 110), it seems reasonable to conclude that the intermediate upland surface and the subsequent trenching required a large part it not all the Pliocene epoch for their development. This intermediate surface therefore affords some information bearing on the age of the still older Grover gravel and Calhoun peneplain.

The presence of the intermediate postmature surface both north and south of the Cap au Grès flexure considerably strengthens the conclusion (pp. 64–65) that the Calhoun peneplain was deformed along this flexure after the deposition of the Grover gravel. If there were no evidence of the intermediate upland surface south of the flexure, it would be necessary to weigh carefully the evidence for and against the possibility that the gravel-covered upland of southern Calhoun County was equivalent to, even though not at the same elevation as, the intermediate surface north of the flexure. But even had this been the case, there would still remain the northeastward slopes of the upland surface throughout the entire region to prove that there had been some subsequent tilting of the gravel-covered peneplain. The presence of these interfluve slopes south of the flexure thus affords independent confirmation of the correlation of the Calhoun peneplain and Grover gravel to the north and to the south of the flexure.

Two upland levels have been reported in the Ozark region by Hershey[46] and Marbut[47] and in southern

[45] Stephenson, L. W., and Crider, A. F., Geology and ground waters of northeastern Arkansas: U. S. Geol. Survey Water-Supply Paper 399, pp. 34–35, 124, 1916. Stephenson, L. W., Major features in the geology of the Atlantic and Gulf Coastal Plain: Wash. Acad. Sci. Jour., vol. 16, pp. 466–467, pl. 1, 1926; Major marine transgressions and regressions and structural features of the Gulf Coastal Plain: Amer. Jour. Sci., 5th ser., vol. 16, pp. 281–298, 1928; Structural features of the Atlantic and Gulf Coastal Plain: Geol. Soc. Amer. Bull., vol. 39, pp. 887–900, 1928.

[46] Hershey, O. H., Peneplains of the Ozark Highland: Amer. Geologist, vol. 27, pp. 29–39, 1901.

[47] Marbut, C. F., The geology of Morgan County: Missouri Bur. Geology and Mines, 2d ser., vol. 7, pp. 8–10, 1908.

Illinois by Shaw and Savage,[48] and Trowbridge[49] has summarized the evidence for two upland plains in the Driftless Area of the northern Mississippi valley. Marbut found that the difference in elevation between the two upland surfaces in the Ozark region decreases northward until on the north-central rim of the highlands the two are difficult to distinguish. In the eastern part of St. Louis County, Mo., the Grover gravel caps low hills that rise about 50 feet above the general upland surface.[50] (See p. 62.) It is possible or even probable that the Calhoun peneplain is equivalent to the upper and the intermediate postmature surface is equivalent to the lower of the two upland plains reported by these observers.

LATEST PREGLACIAL DISSECTION AND TRENCHING

A second rejuvenation of the rivers, apparently without much tilting or warping, followed the development of the intermediate upland surface. This rejuvenation resulted in deep trenching and dissection of the old upland surfaces, and it established the major and minor drainage patterns in essentially their present form.

The available evidence indicates strongly that this trenching extended to essentially its present depth before the first Pleistocene glaciers invaded the region. Bell and Leighton[51] report two definitely pre-Illinoian tills far below the upland in a tributary of Illinois River, near Winchester, 25 miles north of the Hardin quadrangle, and Leverett and Leighton[52] found similar relations in the trough of Mississippi River near Quincy, 50 miles northwest of the Hardin quadrangle (see p. 76). Hence, it seems clear that portions of the trenches now occupied by Mississippi River and other streams of the region were excavated at least to the depth of the present flood plain before the Nebraskan stage. It does not of course follow that all parts of these trenches are necessarily of pre-Nebraskan age throughout. Trowbridge[53] concluded that the Driftless Area of the northern Mississippi Valley was not uplifted and dissected until the first interglacial stage but in this conclusion he has not been followed by Leverett[54] and Thwaites.[55] Leverett believes that the valleys in the Driftless Area were eroded before the first glacial stage.

It is of interest to summarize here the succession of events between the development of the Calhoun peneplain and the first advance of Pleistocene ice as deduced from evidence in and near the Hardin and Brussels quadrangles:

1. Development of the Calhoun peneplain (middle? Tertiary).
2. Deposition of the Grover gravel (late Miocene?).
3. Deformation, tilting, and uplift.
4. Deepening of valleys and development of intermediate post-mature upland surface (Pliocene?).
5. Vertical uplift, trenching, and dissection.
6. First stage of glaciation (Nebraskan).

This succession may not be as absolute as the tabular form of presentation implies; a certain amount of overlapping is not only possible but very probable. Nevertheless, the general order of events seems to be unmistakable, and this in itself indicates that the Calhoun peneplain and the Grover gravel cannot be of the very latest Tertiary age (pp. 103–104, 109).

VALLEY WIDENING—RECESSION OF THE BLUFFS

The preglacial valleys were not only as deep as or deeper than the present one, but they were also much narrower. This fact is attested by the abundant evidence that the river valleys have been greatly widened by recession of the bluffs. It is true that the most obvious widening has occurred within Recent and late Pleistocene times, but it seems probable that the widening began much earlier, perhaps before the first ice advance, and has continued without important interruption to the present time.

The evidence of this bluff recession may readily be seen in the strikingly parallel alinement of the river bluffs and in the pronounced topographic unconformities between the upland surface, the bluffs, and the river flood plains. True, the topographic unconformity probably has been accentuated somewhat by aggradation of the flood plains. Nevertheless, the alinement of the bluffs is independent of structural control; the intervalley spurs have been trimmed back to a nearly straight line without regard to structural irregularities such as the Hardin syncline and the anticlinal axis at Cap au Grès.

Minor details of land form support the conclusion that the valleys have been widened. Back of many of the bluffs, the hills slope away from the river (fig. 9), thereby demonstrating that the parts of these hills that formerly extended riverward have somehow been removed. Many tributary valleys, such as that of Madison Creek, Bond Hollow, the one at Martin's Landing, Hardin Hollow, and Lead Hollow, maintain their rela-

[48] Shaw, E. W., and Savage, T. E., U. S. Geol. Survey Geol. Atlas, Murphysboro-Herrin folio (no. 185), p. 1, 1912.

[49] Trowbridge, A. C., The erosional history of the Driftless Area: Univ. Iowa Studies, vol. 9, no. 3, pp. 84–95, 1921. Howell, J. V., The iron ore deposits near Waukon, Iowa: Iowa Geol. Survey, vol. 25, pp. 54–62, 1916.

[50] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, pp. 9, 31, 1911.

[51] Bell, A. H., and Leighton, M. M., Nebraskan, Kansan, and Illinoian tills near Winchester, Ill.: Geol. Soc. America Bull., vol. 40, pp. 481–489, 1929.

[52] Leighton, M. M., personal communication.

[53] Trowbridge, A. C., The erosional history of the Driftless Area: Univ. Iowa Studies, vol. 9, pp. 123–127, 1920.

[54] Leverett, Frank, Outline of Pleistocene history of Mississippi Valley: Jour. Geology, vol. 29, p. 621, 1921.

[55] Thwaites, F. T., Pre-Wisconsin terraces of the Driftless Area of Wisconsin: Geol. Soc. America Bull., vol. 39, pp. 640–641, 1928.

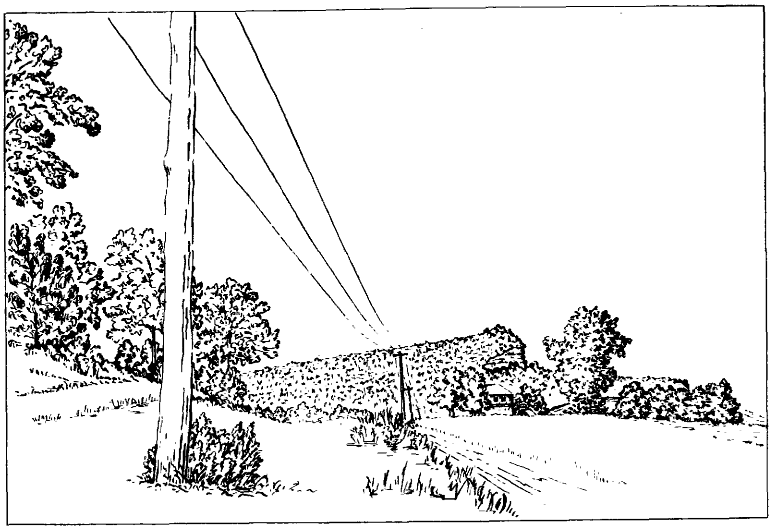


FIGURE 9.—A hill that slopes landward from bluff along Illinois River. Evidence of lateral erosion by river. Three miles north of Hardin.

tively narrow and steep-sided cross-section to their mouths at the river flood plains; they do not widen perceptibly downstream. In traveling down these valleys, one is surprised at coming so abruptly onto the flat aluvial plain; the more-open lower reaches that would normally be expected are not there. The tributary valleys also exhibit a pattern that displays the dismemberment they have undergone. Many groups of the small valleys, like those of Two Branch Hollow, the two streams near Martin's Landing, Turner Branch and Dixon Hollow, McNabb Hollow, Gresham and Irish Hollows, De Gerlia and French Hollows, Lincoln Valley, and the streams near Grafton, lie in courses which converge toward points now on the margin of or well out into the present river flood plains. Supplementary evidence, such as the exposures of fresh rock in the bluffs and the asymmetry of the Calhoun County upland, the occurrence of late Pleistocene alluvial cones, and a few cases of piracy, lend additional support to the conclusion that the river bluffs have retreated landward.

CAUSE OF THE BLUFF RECESSION

An essentially straight line of sharp topographic unconformity that is independent of rock structure might be produced by wave erosion, by faulting, by longitudinal scour, or by lateral planation. Wave erosion and faulting are clearly inadequate to explain the lines of bluffs that border Mississippi and Illinois Rivers. Barrows [56] and Cady [57] concluded that longitudinal scour by floods through the Chicago outlet (pp. 90, 96, 115) straightened the valley walls of the upper Illinois River. However, it seems extremely improbable to the writer that this process was an important factor in the bluff recession along the lower Illinois River. Longitudinal scour, in order to be effective, would require huge torrents as wide as the present trough and very deep. With so much water and such rapid erosion, tributary valleys should have been filled with detritus to the highest flood level; but no such deposits are found. Furthermore, any such torrential scour must have preceded the deposition of the Illinoian Brussels formation, else the widespread deposits of that formation near Brussels would have been entirely swept away. Hence, longitudinal scour, if ever effective, could not have been caused by the Chicago outlet in late Wisconsin time. Finally, if longitudinal scour is required to explain the parallel walls of the Illinois trough, it must logically be called upon to explain also the similar but even wider walls of the Mississippi trough.

On the other hand, lateral planation by streams no larger than the present rivers seems entirely competent to have produced the straightening of the valley walls. As a stream cuts deeper toward its base level, it is compelled to expend progressively more and more of its energy in lateral cutting. Jutting headlands are repeatedly undercut and the walls are gradually trimmed back, just as Mississippi River is even now trimming its walls along southern Calhoun County. This process, if continued, would eventually give nearly straight valley walls.

EXTENT OF VALLEY WIDENING

The amount of bluff recession can be estimated very roughly by several different methods. Minimum estimates might be made by restoring the complete form of those hills that slope landward behind the bluffs. However, estimates that are believed to be more significant can be made by other methods.

Restorations of the groups of valley courses that converge upon points within the present flood plains suggest that at one time the Calhoun County upland

[56] Barrows, H. H., Geography of the middle Illinois Valley: Illinois Geol. Survey Bull. 15, pp. 48, 53, 54, 57, 1910.

[57] Cady, G. H., Lateral erosion in the upper Illinois Valley by the Chicago Outlet (abstract): Illinois Acad. Sci. Trans., vol. 9, p. 210, 1916.

extended at least half a mile farther westward into the Mississippi flood plain and 1 mile farther eastward into the Illinois flood plain. This criterion does not afford any dependable measurement of the former westward extent of the uplands of Jersey and Greene Counties.

Another and quite independent method of estimation may be based upon the length of uninterrupted bluff lines. It seems fair to assume that evenly trimmed spurs or interfluves, like those north of McNabb Hollow, south of Dixon Hollow, between West Point and Dogtown Hollows, southeast of Two Branch Hollow, between Monterey and Union schools, south of Lincoln Hollow, and south of Macoupin Creek, once extended at least one-half as far riverward as the present length of the uninterrupted bluff line. (See fig. 10.) If this

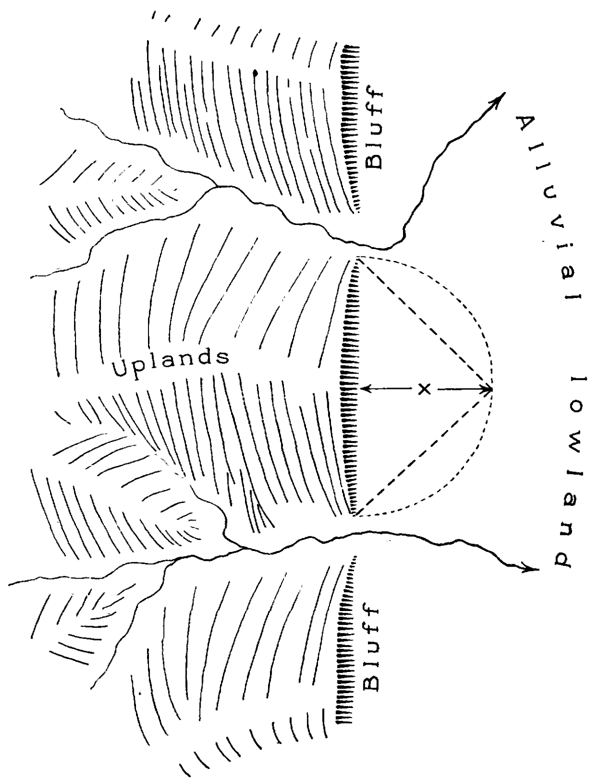


FIGURE 10.—Method of estimating a probable minimum distance of bluff recession. X=one-half of the present length of uninterrupted bluff line.

assumption is warranted, it then appears that the Calhoun County upland, and especially the eastern side of this upland, has suffered more loss by recession of the bluffs than have the uplands of Jersey and Greene Counties. Mississippi River seems to have cut eastward in many places and Illinois River westward in many places at least three-quarters to 1¼ miles, whereas the valley of Illinois River shows evidence of widening eastward in only a few places, a conclusion accordant with that based on the groups of converging valleys.

The asymmetric profile of the Calhoun County upland also suggests that the eastern side of this upland has lost more by bluff retreat than the western side. In the Hardin quadrange the divide between Mississippi and Illinois Rivers is consistently closer to the margin of the Illinois flood plain, despite the fact that this flood plain is somewhat lower than that of Mississippi River. In the Brussels quadrange, south of the Cap au Grès flexure, the asymmetry of the profile is reversed; there the divide lies much closer to Mississippi River. Inasmuch as this asymmetry south of the Cap au Grès flexure is the one that might be expected from the dip of the rocks, it affords no sound basis for estimation. But the asymmetry in the Hardin quadrangle is precisely the opposite of that which the dip of the rocks would indicate. Hence, it seems fair to assume that the upland in the Hardin quadrangle once extended eastward into the Illinois Valley at least as far at it now extends westward toward the Mississippi Valley. Judged by this criterion the Calhoun County upland once extended at least ½ to 1½ miles farther eastward than it does today.

Still another method of estimation gives simply a maximum measures of the amount of bluff recession. The slopes of the intermediate upland surface, if extended from both sides out over the flood plain of Illinois River, meet near the eastern bluff line. Estimated by this method, therefore, the western wall of the Illinois Valley seems to have retreated from 2 to 3 miles whereas the eastern wall has retreated only ½ to 1 mile.

The several lines of evidence considered all indicate that the valleys of Mississippi and Illinois Rivers have widened at the expense of the uplands. The western wall of Illinois Valley appears to have receded most and the eastern wall least, and the eastern wall of Mississippi Valley an intermediate amount. Estimates indicate that the western wall of Illinois Valley has receded at least ½ to 1¼ miles and possibly as much as 2 to 3 miles—that is, that Illinois River seems to have encroached upon its western bank far more than upon its eastern bank.

DATE OF VALLEY WIDENING

Obviously, this bluff recession postdates the development of the intermediate upland surface and at least the initial stages of the trenching, that followed. Most of it probably took place within Pleistocene time but where Mississippi River now impinges sharply against the bluffs, as at the Cap au Grès, it is still continuing. The western wall of Illinois Valley shows evidence of very extensive and relatively recent undercutting, but even here this lateral planation antedates the end of the Pleistocene epoch, as is shown by the presence of the Deer Plain terrace at the foot of the bluffs. (See geologic map, pl. 1.) Almost all the present bluff lines in the Hardin and Brussels quadrangles seem to have been cut since the deposition of the Illinoian till, the Brussels formation, and the Sangamon (?) loess. But from Hamburg to Batchtown there is a double line of bluffs, the outer one of which is younger and the inner one older than the Brussels formation. The older of these two bluff lines is now greatly dissected, but the remaining headlands fall into smooth curves that suggest a bolder bluff line sometime in the past. The older bluffs may possibly have been cut during the Kansan stage of glaciation or they may have been formed much earlier.

TRIBUTARY VALLEYS

While the ancestral Mississippi and Illinois Rivers were cutting first the intermediate upland surface, then the deep trenches, and finally widening their valleys, a complex system of tributary valleys was developing. The larger tributaries of the region, such as Cuivre River, Salt River, Macoupin Creek, Otter Creek, and Bay Creek, may have inherited part or all of their courses from streams that flowed on the Calhoun peneplain, but most of the smaller streams probably developed their own courses by headward erosion.

That headward erosion was an important factor in the development of the tributary valleys is evidenced by the tendency of these valleys to follow preexistent lines of weakness. Dogtown Hollow and Greenbay Hollow are strike valleys along the Cap au Grès flexure. The two valleys that enter Mississippi River in sec. 17 and in sec. 27, T. 13 S., R. 2 W., seem to be exhumed or resurrected pre-Pennsylvanian valleys, because they follow lines where contact between the Mississippian limestone and the Pennsylvanian formations is lowest.

A number of valley courses seem to be controlled by the joint systems in the limestone bedrock. In the NE¼ sec. 2, T. 10 S., R 3 W., the stream in Gresham Hollow follows the prevailing joint system in the Silurian limestones. In the NE¼NW¼ sec. 22, T. 9 N., R. 13 W., a valley tributary to Tar Hollow is obviously controlled by joints in the Burlington limestone. Similarly, parts of Haushalter Hollow in the NW¼SE¼ sec. 14 and parts of the valley in the NW¼ sec. 24, T. 8 N., R. 13 W., follow closely the dominant joint system in the Burlington limestone.

The obvious relation between these valley courses and the joint systems suggests that the northeast-southwest alinement of minor drainage that is so striking in parts of Jersey, Greene, and Macoupin Counties, Ill.,[58] may be in part the result of headward erosion of the preglacial streams along joint lines. However, the parallelism of this alinement with the direction of Illinoian ice movement makes it appear more probable that glacial erosion of parts of preexistent valleys was the dominant factor. (See p. 118.)

[58] Illinois Geol. Survey, geologic map of Illinois, 1917; topographic map of Roodhouse, Illinois, triangle.

TOPOGRAPHIC EXPRESSION OF DIFFERENT ROCK LAYERS—STRATUM BENCHES

The Calhoun peneplain was dissected by the branchwork of tributary streams and carved, probably before the first advance of Pleistocene ice, into a rugged mature land surface. In this dissection many different Paleozoic formations were uncovered and, as the rocks of these different formations vary widely in their resistance to erosion, they strongly influenced the resulting land forms.

The stratigraphic section in the Hardin and Brussels quadrangles consists essentially of an alternating series of five resistant units of limestone separated by four soft units of shale. The resistant units are the Ordovician limestones, dolomites, and sandstone, the Silurian, and Devonian limestones and dolomites, the lower Mississipian limestones, the middle Mississippian limestones, and the Pennsylvanian limestones. These units are separated by the relatively nonresistant Maquoketa, Hannibal, Warsaw, and Carbondale formations. Where the rocks dip perceptibly, the shale units have been excavated into strike valleys and the limestone units into longitudinal ridges and cuestas; where the rocks are flat lying, the shale units have formed slopes and lowlands beneath the plateau caps and stratum benches made by the limestone units. "Structural terrace" and "rock terrace," two terms that have been applied to the features here called "stratum benches," seem unsatisfactory because they are used with very different meanings by some geologists. And within each unit, the different formations and the different beds are characterized by differing degrees of resistance to erosion. These individual differences of topographic expression have been discussed somewhat more fully in the stratigraphic description of the Paleozoic formations. The characteristic topographic expressions of the different formations were found very useful in the geologic mapping of the two quadrangles, because it permitted recognition and tracing of the units even where the rocks are covered by a mantle of loess.

SINKHOLES

Locally, the uplands and stratum benches developed on the Kimmswick, Brassfield, Burlington, and St. Louis limestones are pitted with depressions known as sinkholes. These depressions are normally circular or elliptical in plan, and they range from about 25 to 2,000 feet in diameter and from less than 10 to more than 60 feet deep. A few of them have steep sides with exposures of porous limestone in their deepest parts, and these may still be in the process of enlargement; but most of the sinkholes are now gentle grassy swales, and some, the drainage of which has completely stopped, have formed ponds.

The most conspicuous groups of these sinkhole depressions are on the St. Louis limestone in and around sec. 3, T. 13 S., R. 2 W., and sec. 33, T. 12 S., R. 2 W., and on the Kimmswick limestone in and near secs. 8 and 20, T. 12 S., R. 2 W. (See pl. 15 *B*.) The group of sinkholes in the NW¼ sec. 20 and the SW¼ sec. 17, T. 12 S., R. 2 W., may be the intakes of a subterranean drainage system that emerges from the Kimmswick limestone at the "Cave Spring" along Madison Creek. A large spring at the base of the bluff of Plattin limestone in the SE¼ sec. 7, T. 12 S., R. 2 W., may drain the group of sinkholes in section 8.

A cave spring in McNabb Hollow, similar to the one along Madison Creek, discharges a stream of water from a small cavern in the Brassfield limestone. No sinkholes were noted along the outcrops of the Brassfield limestone nearby, but elsewhere they are developed in this formation. These two springs from caverns in the Kimmswick and Brassfield limestones suggest that other springs of the region may also be outlets of sinkhole drainage. However, most of the springs in the Hardin and Brussels quadrangles seem unrelated to such sinkhole drainage, for the Chouteau limestone, the principal source of the hillside springs, is nowhere pitted with these depressions.

One of the ponds marginal to the Illinoian ice certainly, and another one possibly, is connected with an underground drainage system (p. 81). The till dams at both of these ancient ponds seem to show that the underground drainage cannot be the cause of the ponds, and it seems much more probable that the underground drainage at these two places was caused by the standing water in the glacial ponds.

It is probably significant that the sinkholes are developed only upon formations made up of fairly pure calcite and that they occur in positions where the limestone beds are relatively flat lying. The sinkhole or karst topography on the St. Louis limestone coincides approximately in its distribution with the broad flat trough of the Troy-Brussels syncline. This relation holds in spite of an apparent identity of composition of the rocks along the axis of the syncline and on its flanks. It may possibly indicate something of the conditions of ground water circulation at the time the sinkhole cavities were formed.

Although the sinkholes are developed above relatively flat-lying ledges of fairly pure limestone, yet as surface features nearly every one of them is sunk its entire depth in loess and not in limestone. Inasmuch as loess is for the most part insoluble in water, this common relationship suggests that the sinkholes have been formed by the falling and washing down of loess into solution cavities and crevices in the underlying limestone.

According to the generally accepted interpretation, the cavities below sinkholes were formed by the solution of limestone in descending ground waters during a time when the region stood above the ground-water level. By this interpretation the cavities were dissolved sometime after the uplift of the surfaces on which they are now found. This orthodox interpretation of the origin of limestone caverns has recently been questioned by W. M. Davis,[59] who believes that much of the solution may take place below the water table. If this alternative hypothesis is correct, the cavities below sinkholes in the Burlington limestone on the narrow upland in Tps. 11 and 12 S., R. 2 W., may have been formed before the Calhoun peneplain was uplifted, and the cavities below the sinkholes in the Kimmswick, Brassfield, and St. Louis limestones in other parts of the area may have been formed sometime later but before the lower surfaces were uplifted.

The correct interpretation is not known. The residuum-filled sinkholes at the Mississippian-Pennsylvanian contact (pp. 55–56) are distinctly pre-Pennsylvania in age, but they may possibly have been formed before the post-Mississippian uplift. The abundance of sinkholes along the trough of the Troy-Brussels syncline might possibly be interpreted as evidence in favor of Davis' hypothesis that much of the limestone was dissolved below ground-water level.

PLEISTOCENE MODIFICATIONS OF THE LAND SURFACE

With the exception of the Grover gravel, the entire record of post-Pennsylvanian, pre-Pleistocene events in the Hardin and Brussels quadranges is one of erosion. However, with the beginning of Pleistocene time conditions changed again, and most of the important Pleistocent events are recorded by deposition instead of by

[59] Davis, W. M., Origin of limestone caverns: Geol. Soc. America Bull., vol. 41, pp. 475–628, 1930.

EXPLANATION OF PLATE 15

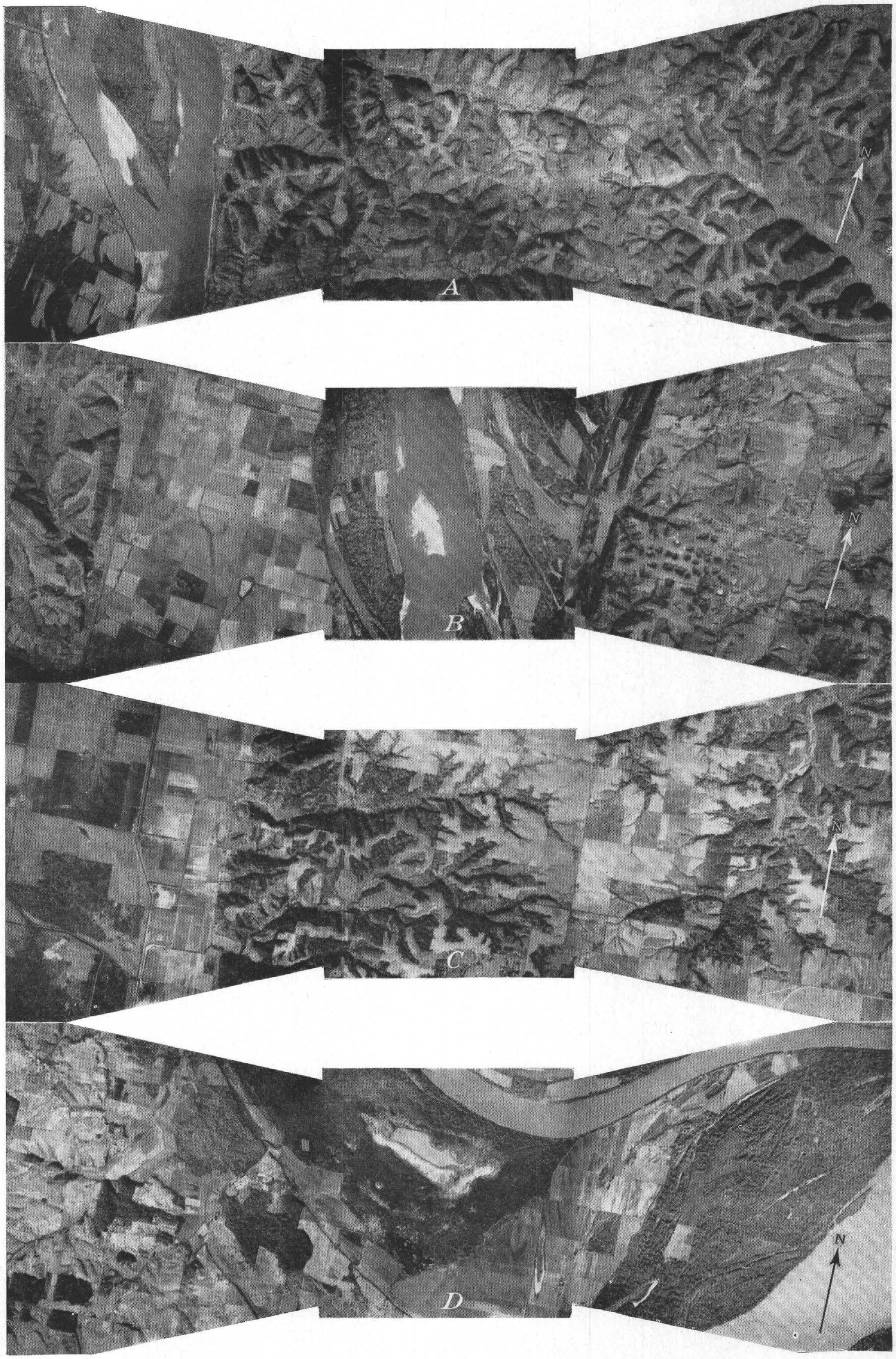
Airplane photographs taken March 1926 by the Air Service, U. S. Army for use by the U. S. Geological Survey. Scale, approximately 1:62,500.

A. Part of Mississippi River and unglaciated uplands. At left, a part of Mississippi River and its flood plain and of Mozier Island and Thomas Chute. Light-colored areas are sand bars along island and shoals behind wing dams. In center and at right, unglaciated uplands and slopes of Calhoun County. Pancake Hollow and North Prong of Irish Hollow in center and Crater Creek at right.

B. Mississippi River and sinkholes near Batchtown. At extreme left, uplands of Lincoln County, Mo. At left and in center, flood plain and channel of Mississippi River, showing part of Sandy Island, head of Sarah Ann Island, Sand Bay, and a series of flood-plain swales. At right, uplands of Calhoun County, Ill., showing sinkholes in Kimmswick limestone, a part of Batchtown channel, and the town of Batchtown.

C. Partially dissected till plain near Fieldon. At left, flat flood plain of Illinois River (secs. 19, 20, 29, and 30, T. 8 N., R. 13 W.). In center and at right, dissected remnants of Illinoian till plain northwest and northeast of Fieldon.

D. Illinois and Mississippi flood plains and Deer Plain and Brussels terraces. At extreme upper left corner, town of Brussels on Brussels terrace. In lower center, town of Deer Plain on Deer Plain terrace. In center, flat flood plain of Illinois River, showing Flat Lake and a part of Gilbert Lake. At right, bars and swales on Mississippi River flood plain.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cutting. Nevertheless, outside the limits of actual glaciation and of stream deposition and even within the area subjected to temporary aggradation, dissection continued throughout the Pleistocene.

Both the Kansan and the Illinoian ice sheets advanced into but not across the area of the Hardin and Brussels quadranges and, as a result, the preexistent land forms were greatly modified. The major streams of the region were forced out of their courses by the ice and became choked with glacial debris, the intricate pattern of smaller valleys was almost completely masked out by thick deposits of till, and, during interglacial stages, the uplands were heavily mantled with loess.

At the time of the Kansan glaciation and possibly in earlier periods as well (p. 107 and fig. 84) the region now drained by the present Rock River and the Upper Mississippi River seems to have discharged its waters through the valley of Illinois River,[60] and at that time the valley of the present Mississippi immediately above the mouth of Illinois River was drained by a much shorter stream. However, the Illinoian ice sheet apparently forced this northern drainage westward into the valley of the early Pleistocene or preglacial Iowa River [61] and, with only minor modifications, this course seems to have been maintained ever since.

The maturely dissected preglacial land surface was completely changed and levelled up to a new plain by filling of the valleys with iceborne debris. After the glaciers melted away these till plains began to be dissected by streams and the resulting youthful topography now stands in sharp contrast to the mature topography of the unglaciated parts of the region.

Even outside the limits of actual glaciation the modifications were great. The quantity of water and the volume of detritus being discharged into the streams were tremendously increased and the rivers were compelled to build up and cut down their bed levels alternately in adjustment to the changing conditions. No doubt the climatic environment also fluctuated sharply [62] and the unglaciated uplands were subjected to alternate periods of increased precipitation and heavy dustfalls.

DATE OF DEEPEST SCOURING AND POSSIBLE CAUSES OF AGGRADATION

Stratigraphic evidence seems to show that the major streams had cut their valleys essentially to present depths below the upland before the beginning of the Pleistocene epoch. However, this evidence tells almost nothing about the date at which the deepest parts of the bedrock floors of these streams were cut. These deepest parts of the rock floor are discovered only by drilling and the age of the immediately overlying deposits is rarely if ever determinable. If the present rivers occasionally scour to their bedrock floors, the deepest cutting may be entirely of Recent age. If, however, the lower part of the alluvial fill is of Pleistocene age, the valleys may have been cut deepest during times of great stream flow in the Pleistocene or at an even earlier time when the streams first trenched to lower levels. The conclusion was reached in another part of this report (pp. 70–72, 101) that within the Hardin and Brussels quadrangles the present Mississippi and Illinois Rivers very probably are not scouring their deepest alluvium and therefore that the deepest parts of the bedrock floor must have been cut by earlier streams. This conclusion accords with that of many other writers,[63] but it does not indicate the exact date of deepest cutting.

The very low gradient of the bedrock floor of the lower Illinois River (pp. 98, 129, 136) has a bearing on the date of deepest cutting there. Several writers [64] have suggested that this cutting may have been accomplished by the waters discharged from Lake Chicago. An examination of the profile of the river [65] makes this explanation appear rather improbable. The remarkably flat gradient of the present river and the depths of approximately 100 feet to bedrock are essentially restricted to that part of the river between the mouth and the Great Bend at Hennepin (p. 98). About 15 miles east of the Great Bend the gradient steepens abruptly and bedrock comes to the surface. It is therefore difficult to understand how floods competent to scour out the lower valley could have flowed through the upper valley without also flattening the gradient there.

The very low elevation of bedrock at Princeton,[66] about 10 miles north of the Great Bend and in the old valley of the pre-Illinoian Mississippi and Rock Rivers,[67] seems to indicate that, at least near the Great Bend, the rock floor was cut to its greatest depths long before the Chicago Outlet. This suggests that the very

[60] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 467, 484, 1899; Outline of Pleistocene history of Mississippi Valley: Jour. Geology, vol. 29, pp. 615–626, 1921.

[61] Leverett, Frank, op. cit., p. 617.

[62] Bryan, Kirk, Glacial climate in non-glaciated regions: Amer. Jour. Sci., 5th ser., vol. 16, pp. 162–164, 1928.

[63] Leverett, Frank, the Illinois glacial lobe: U. S. Geol. Survey Mon. 38, p. 476, 1899; Outline of Pleistocene history of Mississippi Valley: Jour. Geology, vol. 29, pp. 618–620, 1921. Carman, J. E., The Mississippi Valley between Savanna and Davenport: Illinois Geol. Survey Bull. 13, p. 28, 1909. Shaw, E. W., Newly discovered beds of extinct lakes in southern and western Illinois and adjacent States: Illinois Geol. Survey Bull. 20, pp. 153, 156, 1915. Sauer, C. O., Geography of the upper Illinois Valley and history of development: Illinois Geol. Survey Bull. 27, p. 89, 1916. Trowbridge, A. C., op. cit., The erosional history of the Driftless Area: Univ. Iowa Studies, vol. 9, pp. 119–120, 1920.

[64] Cooley, L. E., The Lakes and Gulf waterway, pp. 2–3, 61, 1891. Barrows, H. H., Geography of the middle Illinois Valley: Illinois Geol. Survey Bull. 15, pp. 4, 47–48, 53, 57, 1910. Leverett, Frank, Outline of Pleistocene history of Mississippi Valley: Jour. Geology, vol. 29, p. 626, 1921.

[65] Leighton, M. O., Pollution of Illinois and Mississippi Rivers by Chicago sewage: U. S. Geol. Survey Water-Supply Paper 194, pl. 2, 1907. Sauer, C. O., Geography of the upper Illinois Valley and history of development: Illinois Geol. Survey III, Bull. 27, p. 18, fig. 3, 1916.

[66] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, pp. 500–501, 1899.

[67] Leverett, Frank, op. cit., pp. 466–467, 484; Outline of Pleistocene history of Mississippi Valley: Jour. Geology, vol. 29, fig. 2, p. 625, 1921. Alden, W. C., The Quaternary geology of southeastern Wisconsin: U. S. Geol. Survey Prof. Paper 106, pp. 113–115, pl. 2, 1918.

low gradient on the rock floor from Princeton to the mouth of the river may also have been cut by the combined waters of the ancient Mississippi and Rock Rivers sometime before the Illinoian and possibly before the earliest stage of glaciation.

The factors that may have led to later aggradation upon the old rock floors of both Mississippi and Illinois Rivers are many. Several writers have attributed the filling to glacial debris, but Trowbridge [68] concludes that the initial trenching of the streams was followed by a period of subsidence and possible tilting. Leverett,[69] however, points out that the gradual extension of the Mississippi delta gulfward and the heavy load of sediment carried by Missouri River might account for the difference in altitude of the rock floors and the present rivers.

The aggradation might also be explained in any one of several other ways. Davis [70] cites factors that cause a stream, while developing normally from youth to maturity, to aggrade its valley, and this process may explain much of the aggradation in the Mississippi and Illinois Valleys. Still another possible explanation is that of world-wide changes of sea level due to glaciation—the lowering of sea level that is believed to accompany widespread continental ice sheets and the resulting rise when the ice has melted.[71]

Of these various possible interpretations, those of more local nature, such as uplift and warping or the load of detritus carried by Missouri River, seem less adequate to account for the general aggradation than those, like glacial débris, the advance of the delta, or changes of sea level, that are more regional in their effects. Whatever factors may have contributed, the apparent thickening of the alluvial fill up the valley of Mississippi River (pp. 98, 136) seems to show that this stream has built up a steeper slope by aggradation, and this suggests that at least part of the aggradation was caused by some change, such as a decrease of volume or an increase of load, which lowered the transporting power of the river.

But it is fruitless to search for some one simple explanation of the aggradation of the valleys. There is clear evidence, both stratigraphic and physiographic, of at least four cycles of alternate cutting and filling in Pleistocene and Recent time, and it is quite unlikely that the aggradation in each of these periods was due to precisely the same cause.

THE KANSAN TILL PLAIN

To those who have not grown too accustomed to them by everyday familiarity, perhaps the most striking topographic features in the central Mississippi Valley region are the widespread prairies or flat till plains. These plains make up the landscape of the greater part of Illinois and northern Missouri. Along all stream courses and particularly near the larger rivers these till plains have been intricately dissected, and only narrow remnants are left along the divides to show their former extent. But back from the streams, the very gently undulating flat surfaces are monotonously widespread.

The Kansan till plain, which lies west of Mississippi River, is older and more thoroughly dissected than the Illinoian till plain east of Illinois River, but the remnants of it are no less plainlike. Viewed from the general level of the remnants, the more recently cut valleys become inconspicuous, and the eye unconsciously restores the original plain. Even in an area of considerable dissection, such as that along Bryant Creek in northern Lincoln County, Mo., the remnants of the Kansan till plain are readily recognized by their topographic form alone. However, the fact that this considerably dissected flat surface is actually that of an ancient till plain is abundantly shown by the exposures of deeply weathered till.

Todd [72] reported that throughout most of its extent the Kansan ice sheet was bordered by relatively high land. A significant exception to this rule was noted by him in St. Charles County, Mo., where a lobe of the glacier extended southeastward down the gentle slope to an indeterminate margin. Todd's mapping shows a narrow unglaciated strip in eastern Lincoln and Pike Counties, Mo., north of this southeastern lobe.[73]

Reconnaissance examinations by M. M. Leighton and the writer in southeastern Lincoln and western St. Charles Counties and by the writer in eastern Lincoln and southeastern Pike Counties seem to show that south of the Cap au Grès flexure the Kansan till plain extends over the entire upland, but that north of there, or more exactly north of Apex, a narrow strip of upland along the Mississippi River bluffs has not been glaciated. This region coincides roughly with the unglaciated area reported by Todd, but the approximate limits shown on fig. 4 outline an area much smaller than that indicated by him.

The reconnaissance examinations also seem to show that the margin of the Kansan ice sheet was exceedingly lobate. In the rough topography of eastern Lincoln

[68] Trowbridge, A. C., op. cit., pp. 119–120.

[69] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, p. 476, 1899; Outline of Pleistocene history of Mississippi Valley: Jour. Geology, vol. 29, pp. 618–620, 1921.

[70] Davis, W. M., Rock floors in arid and humid climates: Jour. Geology, vol. 38, pp. 138–141, 1930.

[71] Barrell, Joseph, Factors in movements of the strand line and their results in the Pleistocene and post-Pleistocene: Amer. Jour. Sci. vol. 40, pp. 1–22, 1915. Antevs, Ernst, Quaternary marine terraces in nonglaciated regions and changes of level of sea and land: Amer. Jour. Sci. 5th ser., vol. 17, pp. 35–49, 1929. Daly, R. A., Swinging sea level of the Ice Age: Geol. Soc. America Bull., vol. 40, pp. 721–734, 1929. Cooke, C. W., Correlation of coastal terraces: Jour. Geology, vol. 38, pp. 577–589, 1930.

[72] Todd, J. E., Formation of the Quaternary deposits: Missouri Geol. Survey, vol. 10, pp. 125–126, 1896.

[73] Todd, J. E., op. cit., pl. 12.

and Pike Counties the till plain has a very irregular margin with long and relatively narrow tongues extending down several of the larger valleys. No suggestion of terminal moraines was noted. (See p. 119.) Furthermore, in at least three localities the ice sheet near its margin seems to have lapped completely around low isolated hills, thus leaving nunataks (fig. 4). However, investigations much more detailed than those the writer was able to make would be necessary to establish this fact.

The southeastern limits of the St. Charles County lobe are unknown. In figures 4 and 5 they have been extended, on the basis of examinations by Leverett, Leighton, and the writer, somewhat beyond the limits shown by Todd. This extension raises a question about the date of the diversion of Missouri and possibly of Mississippi Rivers in northeastern Franklin County, Mo. Leverett [74] has suggested that, during the Nebraskan (?) glaciation, Mississippi River, and with it the Missouri, were diverted westward into the Meramec and Big River basins, near Labadie, Mo., across the col, pointed out by Todd,[75] at Gray's Summit. (See fig. 4.) However, if the Kansan ice sheet extended only a short distance farther southeastward than it has thus far been mapped, Missouri River alone might have been diverted southward at Gray's Summit into Meramec River.[76] Hence, until the southeastern limits of Kansan glaciation in northern Missouri have been more accurately mapped, it seems unnecessary to postulate the extension of Nebraskan ice westward across St. Louis County in order to account for this diversion.[77]

BATCHTOWN CHANNEL (KANSAN)

Scattered exposures of a thick deposit of deeply weathered gravel (pp. 75–76) were found at several places near Batchtown along a valleylike depression developed upon the outcrop of the Maquoketa shale. The gravel is coarse-grained and, though some of the pebbles are facetted and striated, the bedding and interlaminated sand layers show that the material was water-laid. The topographic position in which this gravel occurs is such as virtually to demand an ancient stream through the valleylike depression.

The evidence of the gravel seems to be confirmed by that of the physiographic relations. Although the depression is elongated essentially parallel to the strike of the rocks, a closer examination reveals that it cuts obliquely across the structure. The 600- and 650-foot elevations on the headlands on both sides of the depression fall into smooth gently curving lines that delimit a valley with essentially parallel walls. These lines sweep southward across minor irregularities of structure, touch rocks of different ages, and finally cross the present divide at the col in the NW¼ sec. 34, T. 12 S., R. 2 W. The restored 600-foot contour line on the western wall of the old valley, extended southeastward from the col, coincides closely with the northeasternmost 600-foot elevations on the Pennsylvanian uplands in southern Calhoun County. This fact suggests that an ancient stream may have crossed the present divide and continued southeastward approximately along this line. This interpretation is strengthened by a minor detail of the topography: the right-angled turn from a southward to a westward course of the small stream in the NE¼ sec. 33 suggests that Dogtown Hollow may have worked back along the strike of the Cap au Grès flexure and captured part of an old south-flowing drainage system. However, it is possible that the observed relationships of gravel, valley walls, and rock structure might be accounted for equally well by a stream which, instead of continuing southeastward, turned back westward down what is now Dogtown Hollow and rejoined the Mississippi trough (fig. 5).

Reconnaissance examinations seem to show that a lobe of the Kansan glacier entered the trough of Mississippi River in western St. Charles and southeastern Lincoln counties. Hence, an obstruction and damming, either partial or complete, of the stream that drained the unglaciated area north of this lobe would be expected (fig. 4). No unmistakable till was found associated with the gravels in the Batchtown channel, and it is therefore uncertain whether or not the lobe actually encroached upon the eastern side of the Mississippi trough. However, the regional relationships seem to point clearly to the conclusion that the obstruction caused by the ice was sufficient to divert the stream eastward through the temporary spillway. The general coincidence of the old valley with the belt of Maquoketa lowlands would, under this interpretation, be accounted for as the discovery by the ponded stream of the lowest pass across the uplands.

The presence of coarse stream gravels in the Batchtown channel affords some information bearing on the age of the cutting and filling of the Mississippi and Illinois troughs, a problem discussed in other parts of this report (pp. 76, 110, 136). If, as seems likely, the Mississippi trough was cut to near its present depth during pre-Kansan times, then the gravels in the Batchtown channel indicate that, in this locality at least, the principal aggradation of the trough—to an elevation of about 130 feet above present stream levels—was accomplished during the Kansan stage of glaciation.

ILLINOIAN TILL PLAIN

The till plain formed by the Illinoian ice sheet is in all important respects similar to that formed by the

[74] Leverett, Frank, Oldest (Nebraskan?) drift in western Illinois and southeastern Missouri in relation to "Lafayette gravel" and drainage development (abstract): Geol. Soc. America Bull., vol. 35, p. 69, 1924.

[75] Todd, J. E., op. cit., pp. 140, 183, 200, 207.

[76] Shepard, E. M., Underground waters of Missouri: U. S. Geol. Survey Water-Supply Paper 195, p. 155, 1907.

[77] Antevs, Ernst, Maps of Pleistocene glaciations: Geol. Soc. Amer. Bull., vol. 40, fig. 6, 1929.

Kansan ice sheet. However, it extends into the area covered by this report, and it is of more recent age and so is less dissected. Hence, its minor surface features can be described in somewhat greater detail than was possible for the plain formed by the older ice sheet.

The Illinoian till plain slopes gently northward and northeastward from an elevation of about 850 feet in sec. 5, T. 7 N., R. 12 W., 1 mile east of the northeast corner of the Brussels quadrangle, to about 575 feet in the southwest part of the Roodhouse quadrangle, 4 miles east of the northeast corner of the Hardin quadrangle. Within the Hardin quadrangle its elevation commonly ranges between the narrow limits of 700 and 660 feet, but near its margin it slopes westward down many of the smaller valleys.

On the upland where it has not been dissected the surface of the plain is monotonously flat. However, it is not so absolutely featureless as in many other parts of Illinois. Minor swales and gentle billows can be seen upon careful inspection, and here and there distinct drumlinlike mounds rise above the plain as conspicuous land marks. Yet the general aspect is that of a very flat surface, and the local irregularities serve merely to accentuate this dominant characteristic. See pl. 15*C*, 16*B*.)

Between Otter and Macoupin Creeks there are a number of broad low knolls that rise from 20 to 40 feet above the plain. They seem to be arranged crudely into two general trends—several groups on the stream divides trending east-northeast, presumably parallel to the direction of ice movement, and two groups trending north-northwest, approximately parallel to the former ice front. North of Macoupin Creek the mounds are less numerous but more systematic in their shape and arrangement. The most conspicuous one, Witachek Mound, in the NW. ¼ sec. 14, T. 9 N., R. 13 W., is a fairly typical drumlin.[77] It rises about 75 feet above the till plain, is narrow and elongated east-northeast with a steep northeastward and a very gentle southwestward slope, and the partial exposures indicate that, below a thin mantle of loess, it is composed entirely of glacial till (pl. 10*B*). Northeastward from Witachek Mound, for 4 miles along the stream divide, there are several other smaller drumloidal knolls.

Throughout most of the Hardin quadrangle, the margin of the ice sheet lay in the lowlands of Illinois River and Otter Creek where all records of its exact position have been lost. South of Otter Creek, however, a part of the upland was not overspread by the ice, and there the old margin can be traced with reasonable assurance. The limits of the maximum advance of the Illinoian ice sheet upon this unglaciated area are marked by the silted-up basins of several ponds that were formed by till dams in small valleys (pp. 81–82). Within this region there is no suggestion of a terminal moraine at the extreme margin of the till plain.

The till plain is almost solely the result of glacial deposition. Minor valleys were covered with greater thicknesses of glacial debris than the intervening ridges, and the irregularities of the pre-Illinoian topography were thus filled up to a flat plain. Major valleys likewise controlled the thickness of the till, but their former positions are still indicated by broad gentle swales and elongate depressions in the surface of the plain.

There is very little direct evidence of erosion by the ice. The mantle rock—the residual chert and clay present in great thickness on the uplands in the unglaciated parts of the area—was largely removed before the deposition of the till, but no evidence of ice abrasion of the bedrock was noted anywhere. The dominance of chert fragments among the coarser constituents of the till also suggests that residual chert probably made up a large part of the materials eroded by the ice. However, the common occurrence of undecomposed carbonates in the fine-grained portion of the till shows that some limestone was eroded. The only physiographic evidence of erosion by the Illinoian ice is admittedly subject to alternative interpretations. It is the drainage pattern characteristic of parts of Jersey, Greene, and Macoupin Counties where many of the stream valleys trend northeast-southwest parallel to the direction of ice movement. As stated elsewhere in this report (p. 113) it seems possible that this drainage may be preglacial and controlled in part by jointing. However, excavation of those preglacial valleys that happened to lie parallel to the direction of ice movement and the filling of those that lay athwart that direction may have been the principal factor.

At least two features of the Illinoian till plain merit some further discussion. The deposits left in other regions by late Pleistocene continental glaciers commonly form an irregular hummocky topography, and the extreme flatness of the Illinoian till plain is difficult to explain. MacClintock[78] has attributed this flatness to the filling of all irregularities in the preglacial topography by pre-Illinoian drift. As pointed out in another part of this report (p. 76), this suggestion carries with it the corollary that the equally flat and extensive Kansan till plain must likewise be widely underlain by pre-Kansan drift, a deduction that seems to be supported by no independent evidence. A few observations made within the Hardin and Brussels quadrangles may possibly have some bearing on the origin of the flat surface of the till plain. Water-laid gravel, sand, and silt overlie the till gradationally at several places (p. 80), and these deposits suggest that the upper sur-

[77] Alden, W. C., The Quaternary geology of southeastern Wisconsin: U. S. Geol. Survey Prof. Paper 106, pp. 253–254, 1918.

[78] MacClintock, Paul, Recent discoveries of pre-Illinoian drift in southern Illinois: Illinois Geol. Survey Rept. Inv. 19, pp. 56–57, 1929; Physiographic divisions of the area covered by the Illinoian drift sheet in southern Illinois: Illinois Geol. Survey Rept. Inv. 19, pp. 24–25, 1929.

face of the drift sheet may once have been more irregular but that subsequent erosion and filling may have reduced these irregularities to a plain.

Another physiographic feature of the Illinoian till plain, the absence of a terminal moraine, may be merely a special case of its general flatness. If the edge of the ice sheet at any time represented a balance between the rate of supply and the rate of wastage of the ice and if the edge remained long in some one general position, then the debris transported by the moving ice supply should have accumulated at this line of wastage. Absence of such an accumulation of debris at the margin of the till must mean (1) that the balance between supply and wastage represented by a stationary ice margin was maintained by some process other than movement of the ice, or (2) that the ice edge did not remain long at the position of its maximum extent, or (3) that whatever terminal moraine may have been deposited was removed by subsequent erosion.

The common assumption that the balance between supply and wastage was maintained by bodily movement or flow of the ice seems thoroughly justified by the occurrence of well-marked terminal moraines at the limits of Wisconsin glaciation in many parts of North America. But the belief that continental glaciers generally have retreated by a continuation of this same process has recently been challenged by Flint,[79] who contends that in many places stagnant rather than moving ice has controlled the waning phases of glaciation. It is not clear to the writer whether or not an application of the concept of stagnation to the Illinoian ice sheet would adequately account for the absence of terminal moraines.

The possibility that the Illinoian ice sheet did not remain long enough at its position of maximum extent to build up a terminal moraine must also be considered. The relationships of the Illinoian till to the Brussels formation in the Hardin quadrangle and at St. Louis, Mo., seem to show that the maximum extension of the ice was not strictly synchronous throughout the region (pp. 84–85). The glacier may have advanced a few miles at one place while only a short distance away it was retreating. If these advances and retreats occurred frequently, the detritus that otherwise might have accumulated as a terminal moraine may have been scattered over a belt several miles wide. On the other hand, the varves or annual layers in the silts of the marginal pond deposits seem to show that, in the Hardin quadrangle, the ice edge stood for at least 800 and possibly several thousand years (p. 82) in approximately the same position.

The third alternative mentioned, the possibility that a terminal moraine may have been deposited and then removed by subsequent erosion, seems equally unsatisfactory. The coarse materials that would be dumped at the edge of the ice should form a ridge that would be unusually resistant to erosion[80] and it might logically be expected that portions of the moraine would persist even longer than the till plain itself. The correct explanation of the absence of marginal deposits remains unknown.

BRUSSELS TERRACE (ILLINOIAN)

The extensive and well-defined surface (pls. 15*D*, 17, 18) for which the name Brussels terrace is proposed, has been described somewhat more fully along with the Brussels formation (pp. 82–83). The surface of the Brussels terrace lies at an elevation of from 520 to 540 feet above sea level, but it is mantled by 10 to 20 feet or more of loess, and at no place were the water-laid deposits of the Brussels formation found to extend higher than about 510 feet above sea level or approximately 100 feet above the present river levels. The terrace can be recognized at essentially the same elevations in St. Charles and St. Louis Counties, Mo.

At its inner or landward margins, the terrace rises in long gentle slopes onto the sides of the older and higher uplands. These gentle slopes seem to be largely the result of deposition of younger loess, supplemented somewhat by slope wash, and not to be graded slopes built at the time the Brussels formation was accumulating. Small gentle knolls, from a few feet to 10 feet in height, are not uncommon on the surface of the Brussels terrace, but they seem to be composed entirely of loess and so were formed sometime later than the terrace. Sand dunes, now made immobile or "fixed" by the vegetation that grows upon them, are numerous on the surface of the Brussels terrace in the NE¼ sec. 28, T. 9 N., R. 13 W. At this locality they extend up to elevations of more than 600 feet above sea level, and at one place they have dammed up a valley so as to form a small pond. The age of the dunes at this locality is uncertain. They are probably, like the loess, distinctly younger than the Brussels terrace. However, the presence of sands believed to be dune sands interlaminated with the materials of the Brussels formation in parts of the area suggests that these dunes may have formed at the time the terrace was built.

The Brussels terrace is clearly the result of aggradation. The water-laid silts are at least 75 feet and, if they extend below present stream levels, probably much more than 100 feet thick. Hence, between the time of deposition of the gravels in the Batchtown channel and the completion of the Brussels terrace there was in some places at least 130 feet and possibly 250 feet of excavation and at least 100 feet, possibly 200 feet, of filling.

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[79] Flint, R. F., Pleistocene terraces of the lower Connecticut Valley: Geol. Soc. America Bull., vol. 39, pp. 955–984, 1928; The stagnation and dissipation of the last ice sheet: Geog. Rev., vol. 19, pp. 256–289, 1929.

[80] Rich, J. L., Gravel as a resistant rock: Jour. Geology, vol. 19, pp. 492–506, 1911.

A widespread and easily recognized terrace formed in actual contact with the edge of a continental glacier would seem to afford an exceptionally favorable opportunity for detecting any minor warping of the crust or "peripheral bulge" that may have been caused by the load of ice.[81] The thick mantle of loess decreases the value of the Brussels terrace for this purpose but the distances over which the terrace can be traced compensate somewhat for the uncertainty of its elevation at any particular point. A careful examination of data gathered with this possibility of warping along the ice-front in mind revealed no evidence of Illinoian warping or of post-Illinoian recovery. Crustal movements of this sort may have occurred but, if so, they probably were not great enough to be shown by 20-foot contour lines or even to disturb perceptibly the gradients of the larger streams of the area.

METZ CREEK TERRACE (IOWAN OR WISCONSIN)

Along many of the valleys tributary to Mississippi and Illinois Rivers, the Brussels terrace and other parts of the uplands slope gently down to narrow points or spurs. These spurs, which are particularly well marked along Metz Creek in secs. 1 and 2, T. 13 S., R. 2 W., seem to be remnants of a once, more extensive surface that is here called the Metz Creek terrace. The level at which these spurs accord and therefore the level of the terrace is about 485 feet above sea level.

The Metz Creek terrace, like the Brussels terrace, is everywhere covered by loess but only by the upper light-buff member (of early Peorian? age); at no place was the lower reddish-brown (late Sangamon?) member of the loess recognized upon it. This stratigraphic evidence appears to confirm the evidence of the physiographic relations that the Metz Creek terrace is distinctly younger than the Brussels terrace. At several places along Illinois River, the Metz Creek terrace carries on its surface, or more strictly, within the upper part of its mantle of loess, scattered pebbles of igneous and metamorphic rocks (p. 90). The significance of these scattered pebbles is unknown; they may have been transported to their present resting places by man or they may have been deposited by Illinois River in Wisconsin time. This uncertainty affects also the question of the age of the Metz Creek terrace. If it was cut at the time of deposition of the scattered pebbles, it probably is of Wisconsin age; if it was cut before deposition of the Peorian loess, then its age is Iowan.

Unlike other terraces of the region, the Metz Creek is the result not of filling, but of erosion. Its surface cuts across older formations, but it seems to be developed only upon easily excavated materials such as the silts of the Brussels formation.

ALLUVIAL FANS

The cutting represented by the Metz Creek terrace was but part of an era of down cutting that followed the deposition of the Brussels formation. In parts of the area and especially along the eastern line of bluffs that borders Illinois River from sec. 29, T. 8 N., R. 13 W., north to the northern limit of the Hardin quadrangle, there are many alluvial fans that head at the bluffs at elevations of approximately 500 feet above sea level and spread with gentle slopes over the lowland. (See pl. 19*C*.) These fans all seem to be deposits carried from small valleys or ravines. The gradients of these small valleys are concave upward until they reach the bluff line but there they steepen abruptly and become convex upward. It seems very probable that these small streams flowed into Illinois River when its level accorded with that of either the Brussels or the Metz Creek terrace and that the river fell to lower levels more rapidly than these small streams could cut down their valleys.

There is some evidence of minor stream capture along the bluffs, and this suggests that the lack of adjustment that caused the alluvial fans may be more largely the result of lateral recession of the bluffs than of vertical lowering of the river. In the SE¼ sec. 4, T. 8 N., R. 13 W., a steep-sided ravine now slopes directly westward into the lowlands of Illinois River and in doing so it drains uplands that seem once to have been the headwaters of a larger stream that still flows northward through the SE¼ sec. 33, T. 9 N., R. 13 W., into Macoupin Creek. Diversion of this sort, beheading by a mere ravine, can most readily be explained as the result of lateral retreat of the bluffs and consequent oversteepening of the small ravines that drained the bluff face. From other evidence (p. 111), lateral retreat of the bluffs probably was the principal factor in the widening of the river lowlands. This retreat of the bluffs would remove the lower parts of small valleys and so might cause the development of alluvial fans. However, it would not satisfactorily account for the common level of about 500 feet at which many of the fans head.

Other alluvial fans, much larger and presumably much younger than these, are numerous in the Hardin quadrangle along all three of the major bluff lines. Most of these large fans are wide accumulations of detritus built at stream mouths and spread as very gently sloping cones over the remnants of the Deer Plain terrace. (See pl. 1.)

DEER PLAIN TERRACE (WISCONSIN)

The topographic feature known locally as the "Sand Ridge," or the "first bottoms" on the southwest side

[81] Barrell, Joseph, Factors in movements of the strand line and their results in the Pleistocene and post-Pleistocene: Amer. Jour. Sci., vol. 40, pp. 1–22, 1915. Daly, R. A., Oscillations of level in the belts peripheral to the Pleistocene ice caps: Geol. Soc. America Bull., vol. 31, pp. 303–318, 1920; Post-glacial warping of Newfoundland and Nova Scotia: Amer. Jour. Sci., 5th ser., vol. 1, pp. 381–391, 1921.

of Illinois River in the Brussels quadrangle, is here chosen as the type locality of the Deer Plain terrace (pls. 15*D*, 19*A*, *B*), remnants of which are found in many other parts of the area. This terrace is described much more fully and its age and the conditions of its formation discussed in the section of this report that deals with the stratigraphy of the Deer Plain formation (pp. 90–96).

Along Mississippi River the terrace is made up of deposits of coarse gravel, and it stands at an elevation of about 40 or 45 feet above the mean level of the river and 30 feet lower than the Metz Creek terrace. In the valley of Illinois River, the materials of the Deer Plain formation become finer-grained, and the surface of the terrace slopes gently northward. Near the town of Deer Plain the remnants of the terrace that have been preserved from erosion are sufficiently wide to show many features of the original surface. Old sand bars still stand 5, 10, even 15 feet above the flat of black mud that constitutes the general level of the terrace.

The Deer Plain terrace can readily be recognized along the west side of Mississippi River between Winfield and Old Monroe, in Lincoln County, Mo. The two conspicuous terraces, 10 miles southeast of the Brussels quadrangle, along the southeast side of Missouri River, opposite St. Charles, Mo.,[82] may correspond to the Deer Plain and Metz Creek surfaces.

The Deer Plain terrace, like the Brussels terrace, is a record of aggradation. In the trough of Illinois River and, to a lesser extent, in the trough of Mississippi River, it represents the most recent period of extensive filling. The parallel lines of bluffs that border both troughs and the topographic unconformity between bluffs and bottomland, although not dependent upon the presence of the Deer Plain terrace, are greatly emphasized by it.

At the landward margin of the Deer Plain terrace the Brussels terrace was defended locally (p. 96) by outcrops of the St. Louis limestone and at the landward margin of the Recent flood plain the Deer Plain terrace is similarly defended by outcrops of St. Louis limestone in sec. 22, T. 13 S., R. 1 W. and sec. 16, T. 6 N., R. 13 W.

TERRACES ALONG MACOUPIN CREEK

The system of three terraces—the well-defined terraces of aggradation, Brussels above and Deer Plain below, and the poorly defined Metz Creek terrace of degradation between them—fits the evidence of old stream levels throughout most of the Hardin and Brussels quadrangles very well. However, this simple system is at best exceedingly difficult to recognize in the complex group of terraces that are developed in the valley of Macoupin Creek.

The distribution of deposits of till shows that Macoupin Creek now flows in an inherited or resurrected pre-Illinoian valley. The large meander of Macoupin Creek in secs. 25, 35, and 36, T. 9 N., R. 13 W., and sec. 1, T. 8 N., R. 13 W., only a part of which is included within the Hardin quadrangle, seems also to be largely of pre-Illinoian age. This meander exhibits several characteristics which indicate that it is probably an incised rather than an intrenched meander.[83] If so, the stream course has become progressively more crooked, both before and after glaciation, as the valley has deepened below the upland surface. There is some evidence in the topography of the uplands south of Macoupin Creek that a still earlier valley once extended westward from the center sec. 2 to the center sec. 4, T. 8 N., R. 13 W.

When the Illinoian ice sheet advanced into the region it completely covered all these older valleys, and the new streams that developed as the ice disappeared were unable to follow precisely the ancient stream courses. Lee [84] reports that, near its headwaters, Macoupin Creek has found for itself a course somewhat different from its pre-Illinoian valley.

Shortly after the retreat of the ice, during the time when the Brussels terrace was being built, Macoupin Creek seems to have flowed to the north and east of Spankey Hill. This conclusion rests not only upon the position of the old detritus-filled valley, the elevation of its surface, and the lithologic character of the deposits (pp. 83–84) but also upon the northward slope of the till-covered surface near the present mouth of the creek. The diversion, which eventually cut off Spankey Hill from the uplands south of Macoupin Creek, probably took place soon after the Brussels terrace was built, and it may have been caused by lateral erosion of the bluffs by Illinois River.

The identification of the Brussels terrace seems reasonably well established. But from elevations of about 530 feet on the Brussels terrace in the SE¼ sec. 21, remnants can be traced of a surface that slopes southward toward well-defined terraces at about 490 feet in secs. 34 and 35, T. 9 N., R. 13 W., on the southwest side of Macoupin Creek. Furthermore these well-defined terraces on the southwest side of the creek, although they are at an elevation about that of the Metz

[82] Topographic map of part of Bonfils and Alton quadrangles: Missouri Bur. Geology and Mines, 1925. Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, p. 10, 1911.

[83] For discussions of the distinctions between these two types of meanders, see Marbut, C. F., Physical features of Missouri: Missouri Geol. Survey, vol. 10, pp. 98–109, 1896. Davis, W. M., Incised meandering valleys, Phila. Geog. Soc. Bull., vol. 4, pp. 1–11, 1906. Rich, J. L., Certain types of stream valleys and their meaning: Jour. Geology, vol. 22, pp. 469–497, 1914. Tarr, W. A., Intrenched and incised meanders of some streams on the northern slope of the Ozark Plateau in Missouri: Jour. Geology, vol. 32, pp. 583–600, 1924. Moore, R. C., Origin of inclosed meanders on streams of the Colorado Plateau: Jour. Geology, vol. 34, pp. 44–46, 1926.

[84] Lee, Wallace, U. S. Geol. Survey Geol. Atlas, Gillespie and Mount Olive folio (no. 220), p. 11, 1926.

Creek surface in other parts of the region, can be correlated with no terrace of corresponding elevation on the north or east side of the creek. The next terraces below the southward slope that truncates the Brussels formation are at an elevation of about 470 feet in secs. 27, T. 9 N., R. 13 W., and 1, T. 8 N., R. 13 W., on the north and east sides of the creek. Finally, the Deer Plain terrace, which can be identified by careful tracing at accordant levels all the way up Illinois River, occurs on the south side of Macoupin Creek at an elevation of about 435 feet.

In other words, the record of old stream courses, both pre-Illinoian and post-Illinoian, near the mouth of Macoupin Creek is very complex. No postglacial terrace can be traced from one side of the creek to the other and there seem to be at least two terraces between the Brussels and Deer Plain levels. It seems that this system of post-Illinoian terraces must be interpreted, as Davis [85] interpreted similar systems of nonaccordant terraces in New England, by the slow degradation of Macoupin Creek as it swung from one side of its valley to the other. By this interpretation neither of the two intermediate terraces need correspond precisely with the Metz Creek terrace of other parts of the area; they would represent mere passing and accidentally preserved stages in a continuous process of down cutting.

FINAL STAGES IN DEVELOPMENT OF PRESENT TOPOGRAPHY

Most of the significant modifications of the original upland were accomplished during the Pleistocene epoch, but analogous processes have continued on a smaller scale into Recent time. As stated on page 9, the present topography of the Hardin and Brussels quadrangles can conveniently be considered as falling into two major divisions: the uplands and the lowlands. On the uplands there have been only minor topographic changes since the Pleistocene. Dissection had produced a mature surface and a ramifying drainage system before the Recent epoch, and the subsequent developments have been merely a continuation of these processes. In the lowlands the Recent geographic modifications are more conspicuous. They too are similar to changes that occurred often during the Pleistocene, but they are recorded in the wide flood plains of two large rivers and so are more easily recognized.

UPLANDS

The dissection that started with the uplift of the Calhoun peneplain was interrupted many times during and before the Pleistocene epoch. Many valleys that had been cut before the advance of the Illinoian ice sheet were nearly obliterated by the deposits of Illinoian till, Brussels formation, and loess. Subsequent erosion in late Pleistocene and Recent time has tended to reexcavate parts of these pre-Illinoian valleys by removing some of the Pleistocene deposits and rediscovering the old bedrock floors. Many examples of this rediscovery of small pre-Illinoian valleys may be seen in the northwestern part of Jersey County and in the southwestern part of Green County.

Within historic times minor but intense trenching of the upland valleys has continued. On many steep slopes the loess is rapidly being eroded, as is shown by numerous undercut fences, orchard trees, and roads. Small ravines in loess are commonly traversed by a central steep-walled "gully," which during each season of heavy rains lengthens at its head. A gully of this type from 20 to 25 feet deep, in the center SW¼ sec. 10, T. 6 N., R. 13 W., is reported to have receded headward at an average rate of about 15 feet each year for the past 30 years, despite efforts to stop the erosion with piles of brush and debris. This trenching within historic times may be the result of a rejuvenation of the streams by some natural process, such as increased rainfall, but it seems much more likely that it has been caused by the activities of man in the deforesting and cultivating the land.[86]

FLOOD PLAINS

Since the retreat of the Kansan and Illinoian ice sheets, the topography of the lowlands in the Hardin and Brussels quadrangles has been controlled by the work of Mississippi and Illinois Rivers. The present features of the flood plains show that these two rivers have cut vertically and shifted laterally since the Deer Plain terrace was built. However, it is impossible to state with complete assurance whether these streams at the present time are dominantly cutting or filling or simply maintaining their channels.

This uncertainty about the normal regimen of Mississippi and Illinois Rivers is due largely to the disturbing effect of the "river training" or river engineering that has been applied more or less successfully during the past 75 years to improve navigation on these and other major streams of the region. In Illinois River, sand bars were dredged as early as 1852,[87] a system of dams [88]—the lowest of which is at Kampsville, 3 miles north of the Hardin quadrangle—was built to deepen the water, and since 1900 large quantities of water have been diverted into the river from Lake Michigan through the Chicago Drainage Canal.[89] The engineering works on Mississippi River have been far more extensive and much less successful. A great many wing dams or spur dikes have been built, only a few

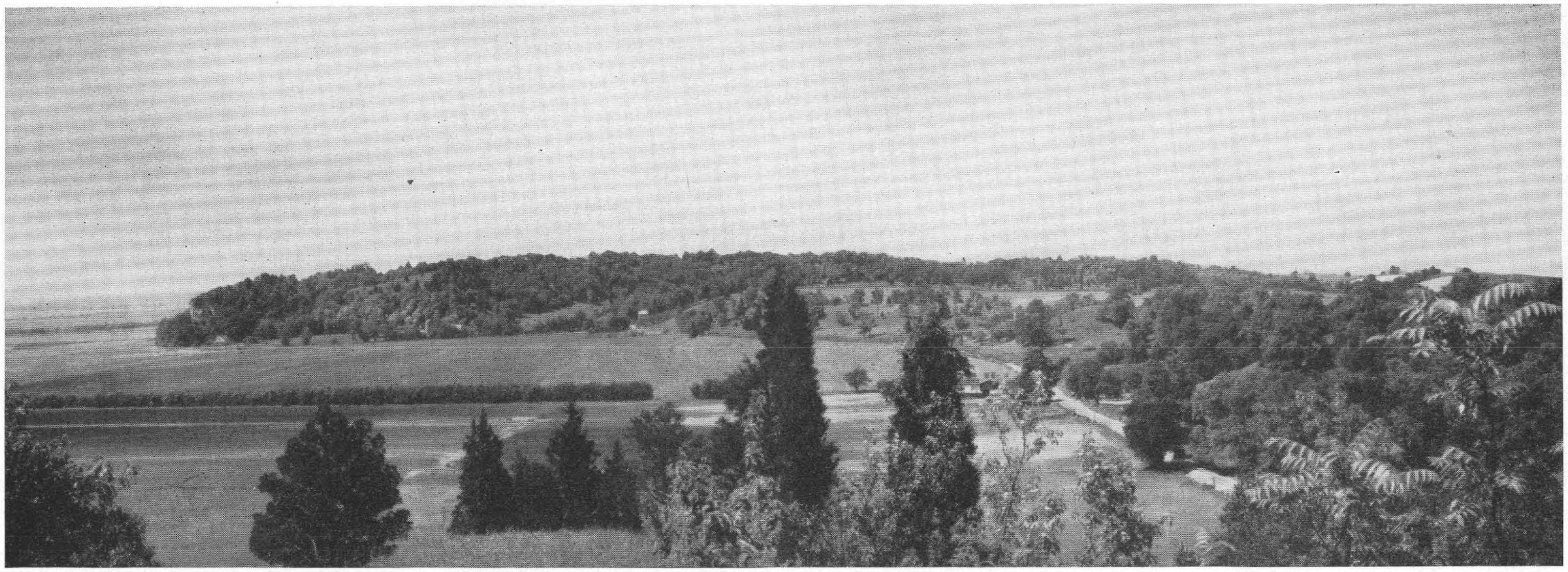
[85] Davis, W. M., River terraces in New England: Geographical Essays, pp. 514–563, 1909.

[86] Sauer, C. O., Geography of the upper Illinois Valley and history of its development: Illinois Geol. Survey Bull. 27, pp. 140–143, 1916.

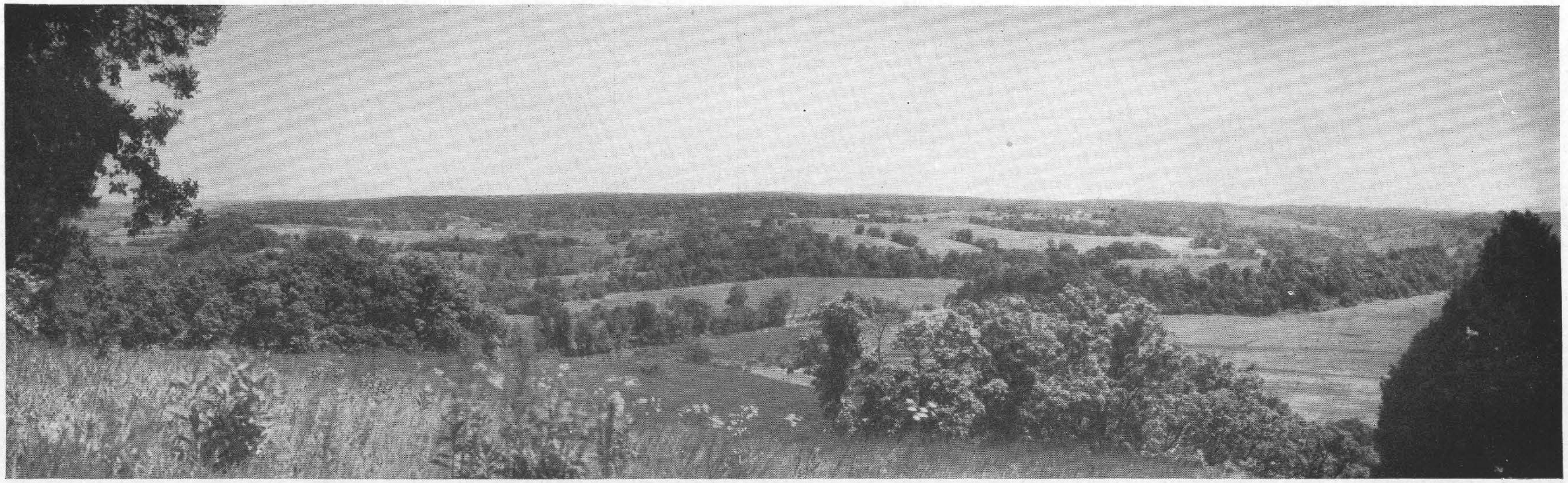
[87] Cooley, L. E., The Lakes and Gulf Waterway, p. 4, 1891.

[88] Leverett, Frank, The water resources of Illinois: U. S. Geol. Survey, 71th Ann. Rept., pt. 2, pp. 744–745, 1896.

[89] Richmond, W. S., in Warren, J. G., and others, Diversion of water from the Great Lakes and Niagara River, p. 176, 1921.

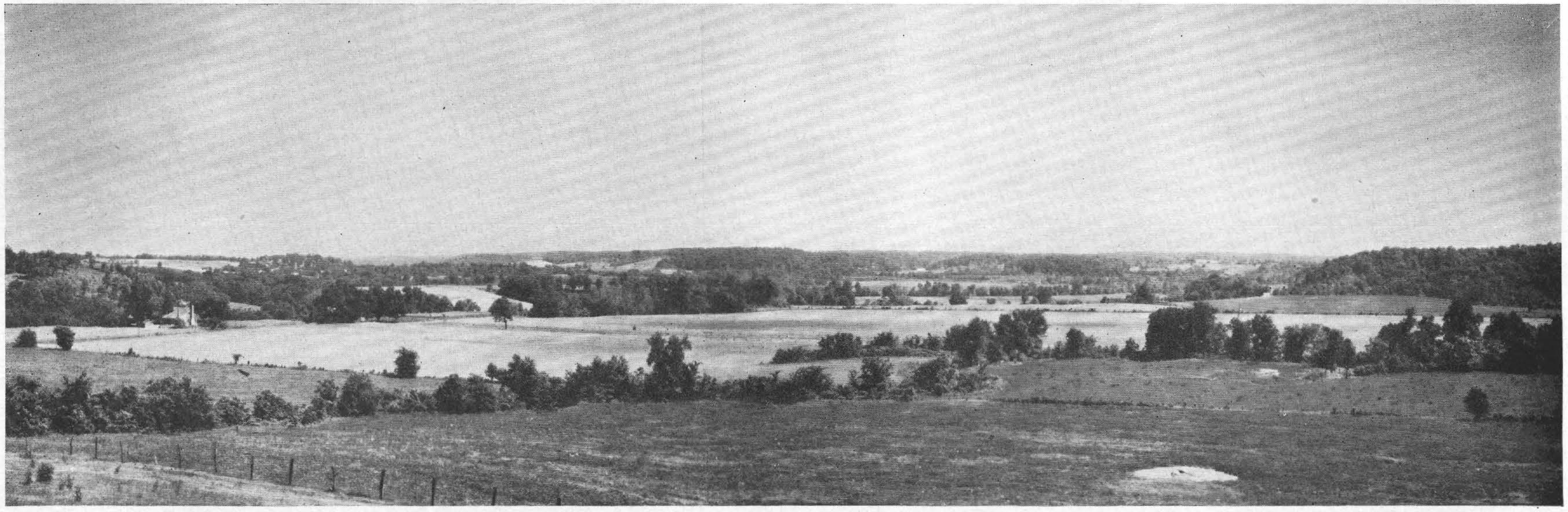


A. VIEW NORTHWARD FROM SPANKEY HILL SHOWING FLOOD PLAIN OF ILLINOIS RIVER AND UPLANDS OF SEC. 21, T. 9 N., R. 13 W.



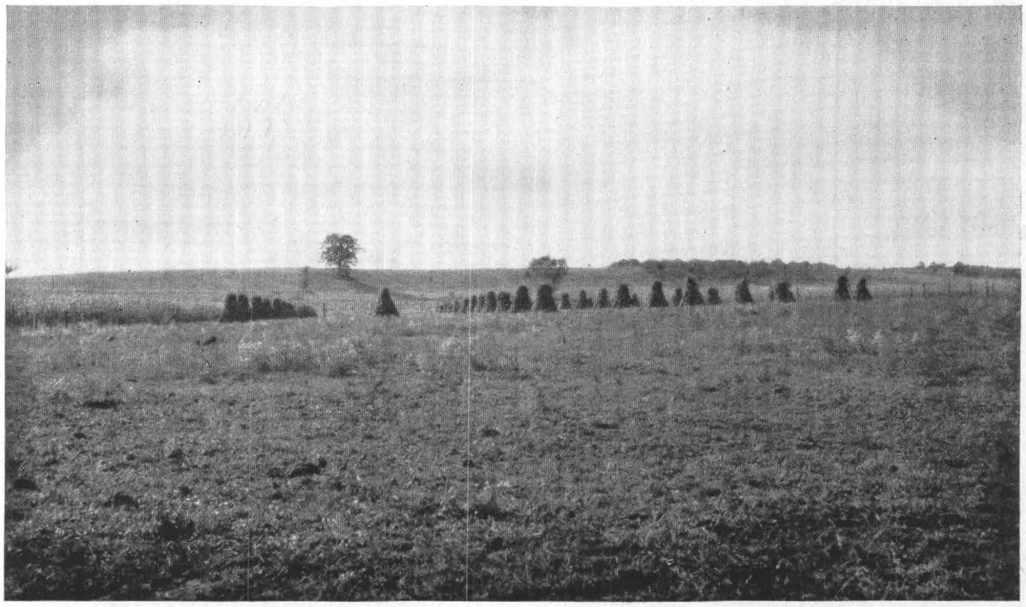
B. VIEW SOUTHEAST AND SOUTH FROM SPANKEY HILL SHOWING LOWER PART OF VALLEY OF MACOUPIN CREEK AND ILLINOIAN TILL PLAIN UPLAND AS THE DISTANT SKY LINE.

A. VIEW SOUTHWARD FROM NW¼SE¼ SEC. 21, T. 9 N., R. 13 W., SHOWING PART OF BRUSSELS TERRACE IN FOREGROUND AND SPANKEY HILL AND FLOOD PLAIN OF ILLINOIS RIVER IN BACKGROUND.

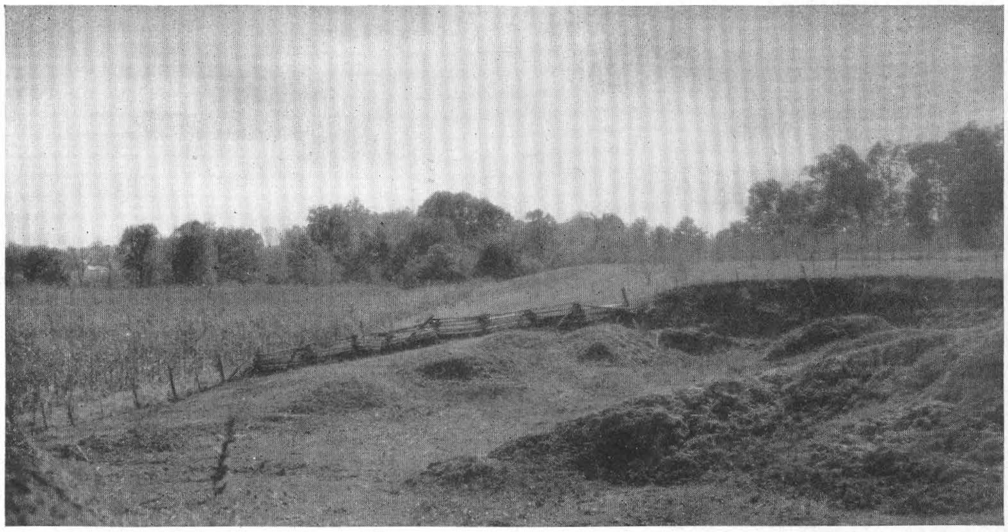


B. VIEW SOUTHEAST, SOUTH, AND SOUTHWEST FROM NE¼SW¼ SEC. 22, T. 9 N., R. 13 W., SHOWING BRUSSELS TERRACE OR ABANDONED STREAM CHANNEL IN FOREGROUND AND VALLEY OF MACOUPIN CREEK AND SPANKEY HILL IN DISTANCE.

A. A PART OF BRUSSELS TERRACE VIEW SOUTHWESTWARD FROM TOWN OF BRUSSELS.

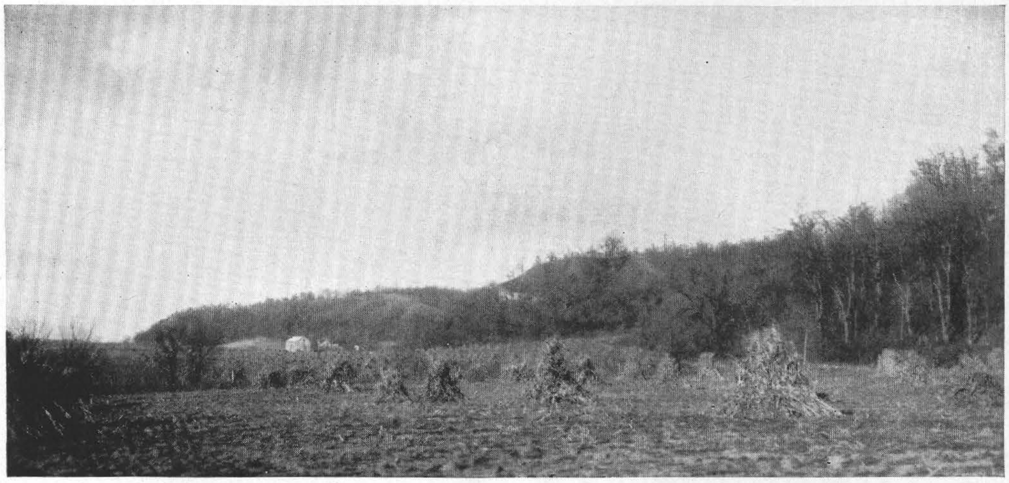


B. MARGIN OF BRUSSELS TERRACE, VIEWED WESTWARD FROM DEER PLAIN TERRACE IN EAST CENTER SE¼ SEC. 17, T. 13 S., R. 1 W.



A. EAST MARGIN OF DEER PLAIN TERRACE IN NE¼ SEC. 21, T. 13 S., R. 1 W.

B. EAST MARGIN OF DEER PLAIN TERRACE, VIEWED NORTHWARD FROM RECENT FLOOD PLAIN IN SW¼ SEC. 22, T. 13 S., R. 1 W.



C. GENTLY SLOPING ALLUVIAL FANS AT FOOT OF BLUFFS ON EASTERN SIDE OF FLOOD PLAIN OF ILLINOIS RIVER. VIEW NORTHWARD FROM CENTER NE¼ SEC. 20, T. 8 N., R. 13 W.

of which are shown on the topographic map of the Hardin quadrangle, and miles of river bank have been revetted with riprap in an effort to force the river into a narrower, deeper, and more stable channel. The natural regimen of both rivers has been more or less upset, and it is consequently difficult to decide just which parts of the present features are the result of natural agencies and how much they have been modified by the river improvement.

The term "regimen" has been used with three distinct meanings: (1) The condition of final equilibrium, or grade, toward which all streams tend to adjust themselves; (2) the general laws or rules of stream dynamics which apply alike to all streams; and (3) the particular reactions of a given stream to these general laws. The first and second meanings seem adequately covered by other more familiar words or phrases, but the last one needs a convenient name and it is a concept for which the word "regimen" has frequently been used. Therefore regimen is here applied simply to the habits or characteristics of individual streams—their particular reactions to the general laws of stream work, whether or not the streams have attained to the condition of equilibrium. One river may have a very different regimen from another because the two streams have responded differently to the same fundamental laws. Their velocities of flow, the slope of their water surfaces, the shape of their channels, or their habits of cutting, filling, or of stability may differ because the conditions of run-off, load, or bank resistance are not the same in the two drainage basins.[90]

Both Mississippi and Illinois Rivers flow in wide flood plains between natural levees. Along the Illinois the natural levees stand higher above the river, and the bordering swamps behind the levees are lower than those along the Mississippi. This difference in height of the levees may be the result of a fundamental difference in the regimen of the two streams. At each flood Mississippi River cuts in some places and fills in others, and it is constantly shifting its channel (p. 101). It has had this unstable habit for many years as is shown by countless flood-plain bars and swales,[91] which record former positions of the channel. (See pl. 15.) Illinois River, on the other hand, is remarkably stable at the present time (p. 101) and, although it once cut and trimmed the Deer Plain terrace by lateral planation, there are no bars and swales on its present flood plain to show that it has shifted laterally for many years. It seems probable that the height of the natural levees is a function of the permanence of the river channels. The levees along Illinois River have grown high by repeated additions in one place; whereas those along Mississippi River have been scattered over the entire flood plain and hence have not been built so high.

This contrast in the surface features of the two flood plains is particularly noticeable where Mississippi River has built its levee across the mouth of Illinois River and forced that stream to turn northeastward to the bluffs before it enters the larger river near Grafton. (See pl. 15 *D*.) The northwestward limit of the deposits of Mississippi River may be recognized by this difference in character of the two flood plains and can be indicated by a line that extends northeastward from the salient point of the Deer Plain terrace near Deer Plain to near Marshall Landing in the SE¼ sec. 3, T. 13 S., R. 1 W.

ALLUVIAL ISLANDS AND CHUTES[92]

In the strict meaning of the term, neither the Mississippi nor the Illinois, in the general region of the Hardin and Brussels quadrangles, are meandering rivers. The only truly meandering stream courses and ox-bow lakes are those of tributaries like Cuivre River, Peruque, Otter, Macoupin, and Apple Creeks, and the stream that drains Michael Hollow. The two rivers are much more nearly comparable with braided or anastomosing than with meandering streams; they follow somewhat crooked courses, it is true, but the curves are due not to meander growth but to division of the channel by large alluvial islands.

The importance of islands in the history and natural economy of large streams like the Mississippi and Missouri Rivers has been neglected by most writers, perhaps because their exact function is not yet understood. However, alluvial islands make up such a large part of the linear distance of both rivers in the area covered by this report that they cannot be ignored. (See pl. 15 *A*, *B*.) The term "alluvial islands" is intended merely to discriminate between the two common types of river islands: rock islands composed of bedrock and alluvial islands composed of alluvium. This discrimination seems important because the two types may have very different origins. Except for short reaches along the Cap au Grès and perhaps near Gilead Landing and Hamburg, that part of Mississippi River included within the Hardin and Brussels quadrangles is almost a network of islands and subordinate channels. Nor is this a purely local feature; for many miles upstream and downstream Mississipi River maintains the same habit, and the lower Missouri River is even more a labyrinth of islands than the Mississippi. Islands are less numerous along Illinois River, but because of the greater stability of the channel there, they are even more impressive than those on the Mississippi. There are no rock islands in the immediate vicinity.

[90] For various uses see Davis, W. M., Base-level, grade, and peneplain, in Geographical Essays, pp. 390–391, 1909. Bryan, Kirk, Erosion and sedimentation in the Papago Country, Arizona: U. S. Geol. Survey Bull. 730, p. 89, 1922.

[91] Johnson, Douglas, Meanders in tidal streams; A review and discussion: Geog. Review, vol. 19, pp. 136, 138, fig. 1, 1929.

[92] Rubey, W. W., Alluvial islands; their origin and effect upon stream regimen (abstract): Washington Acad. Sci. Jour., vol. 22, p. 458, 1932.

If these rivers were clearly examples of heavily aggrading streams, perhaps the significance of the islands would be too obvious to merit any comment. Or, if on the other hand, these rivers were known to be sharply trenching their alluvium, perhaps the islands might be explained as the result of the same process which is believed to produce rock islands. However, the lower Missouri has been cited as the type example[93] of a graded stream. Furthermore, the remarkable stability of the channel of Illinois River (pp. 101, 129) indicates that this stream is in almost perfect equilibrium with its banks. The Mississippi River in this region may possibly be scouring its bedrock floor at times of flood (p. 101) or it may be very slowly aggrading (pp. 98, 116, 136) but, in either case, it is changing so very slowly that it, too, may be said to be essentially at grade. The presence of the alluvial islands in these graded streams therefore calls for some discussion.

In local terminology, the "main river" divides at an island into a wide "steamboat channel" or simply "channel," and a narrower "chute." Old chutes which, because of silting up, no longer carry flowing water except at high stages of the river are commonly called "sloughs." However, most of the chutes show no evidence of silting up and some, like the Dardenne Chute south of Dardenne Island in Mississippi River, are said to be gradually deepening as the channel on the opposite side of the island becomes shallower. Around a few islands the two branches of the river are of so nearly the same size that it is difficult to decide which should be called channel and which chute. For example, Dark Chute on the west side of Diamond Island in Illinois River is narrower but also proportionately deeper than Light Chute on the east side of the island.

It is probably a significant fact that the islands are larger and more numerous at the mouths of tributary streams. In Mississippi River, Cuivre Island is at the mouth of Cuivre River, Peruque Island at the mouth of Peruque Creek, and Dardenne Island at the mouth of Dardenne Creek. Similarly, in Illinois River, Diamond, Tip, Macoupin, and Mortland islands are at the mouth or mouths of Macoupin Creek, and Helmbold and Twelvemile islands are at the mouth of Otter Creek.

This exceptional development of islands at the mouths of tributary streams suggests two possible ways in which the islands may have been formed. A tributary like Cuivre River or Dardenne Creek, which now discharges into a chute behind an island, has in time of local flood two outlets into the river: One down and the other up the chute. Tributaries such as these may once have been forced by the growth of a natural levee to flow parallel to the river for some distance and then, at a time of high flood on either the tributary or the river, the narrow strip of land between the two streams might have been cut across so as to form an island. There is some doubtful support for this interpretation in the local tradition that Dardenne Island was once part of the Missouri mainland, but this tradition is not confirmed by any of the early maps available to the writer.

An alternative interpretation explains most of the islands much more satisfactorily. Tributary streams commonly have steeper gradients and carry more debris per unit volume of water than the river; hence they deposit part of their load as deltas and as submerged bars across the tributary mouths. Some of the sand bars and flats built at times of flood stand well above the water level at low and normal stages of the river. It is true that most of the bars built in Mississippi River are temporary features. Nevertheless, a few escape erosion during the next few floods, become mud-covered, and support a growth of willow trees. They then become, in local terminology, "willow bars." Willow bars, being protected by vegetation, are somewhat more resistant to erosion, and they check the currents more effectively and cause the deposition of more debris than do the sand bars. Consequently, a few of the willow bars are able not only to escape complete destruction by occasional floods but also to grow gradually larger. With each layer of mud added during floods, a growing bar is built higher above the normal stages of the river and, the longer it escapes destruction, the more firmly are its materials held together by ramifying tree roots and so protected against future floods. As a result, some of the willow bars grow larger and higher until they become "timber islands," the surface of which is built to the level of the mainland flood plain and covered with dense growths of large hardwood trees. Once an island reaches this stage it becomes an essentially permanent feature. Occasional floods may scour away part of its upstream end but this loss is compensated by new deposits and growths of willow trees at the lower end.

This interpretation of the normal history of river islands is based largely upon the presence in Mississippi and Missouri Rivers of all stages and sizes in a complete sequence of sand bars, mud flats, willow bars, and wooded islands. It is also supported by the fact that the high wooded islands in Illinois and Mississippi Rivers are nearly all bordered by natural levees, which indicates that, whether or not any of the original island nuclei were ever cut away from the mainland by floods, most of the islands have been enlarged by aggradation. It therefore seems probable that the abundance of islands at the mouths of tributary streams may be explained as the result of repeated deposition of bars there and the consequent likelihood that, on some of these bars, trees would gain a foothold.

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93 Gannett, Henry, U. S. Geol. Survey Topog. Atlas, Physiographic types: folio (no. 2), 1900. Davis, W. M., Geographic Essays, p. 397, 1909.

As an island grows wider, the chute and channel become farther apart, one of the two mainland banks is forced back, and the river is deflected laterally. However, the development of islands across the mouths of tributary streams only shifts the site of deposition out to the ends of the chutes, and consequently, new bars begin to build up within the deflected channel. Some of these bars likewise escape erosion and grow to become large islands that deflect the river channel even more. Hence the river is crowded farther and farther away from the mouths of tributary streams. Probably the first islands tend to migrate slowly downstream and to become gradually smaller as they get farther from the source of supply. But this tendency is masked by the more rapid growth of new islands. The continued deflection of the river channel eventually causes part of the original chute to fill up with sediment, and the first islands therefore become part of the mainland.

The result of continued island growth may be seen very clearly in airplane photographs that show the plexus of old sloughs or silted-up chutes in the flood plain of Illinois River near the mouth of Macoupin Creek and in the Mississippi flood plain near the mouths of Bobs and McLean Creeks—shown on the topographic map of the O'Fallon quadrangle—and Bryants Creek, which enters the river west of Kritesville, Ill. The results of this process are also shown at Hardin, where Illinois River has been forced against the west wall of its trough by the islands at the mouth of Macoupin Creek, and, even more conspicuously, where Mississippi River is crowded against the inner or Illinois wall rather than the outer or Missouri wall of its curving trough opposite the mouths of Cuivre River and Bobs, Peruque, and Dardenne Creeks.

An apparent exception to this general conclusion deserves some attention. Marbut [94] pointed out that there are several examples in Missouri where major streams are deflected toward or even a short distance into the mouths of tributaries. An examination of maps of the Missouri, Mississippi, and Illinois Rivers in the States of Illinois and Missouri shows that this relationship holds at the mouths of several of the larger tributaries. However, opposite the gaps in the bluff line where the small and medium sized tributaries debouch onto the flood plains, the rivers are commonly deflected away from the tributaries. The exceptions to the general rule may probably be explained as the result of the lower gradient of the larger tributaries and the consequent likelihood that many of the larger and more gently sloping tributaries that drain limestone areas may carry a lesser load per unit volume of water than the main rivers and that consequently erosion predominates over deposition at the mouths of such large tributaries.

[94] Marbut, C. F., Physical features of Missouri: Missouri Geol. Survey, vol. 10, p. 104, 1896.

Whether or not the foregoing interpretation correctly sums up the ordinary sequence of events in island growth, a distinct and a more intangible problem remains in the ultimate effect of the islands upon the regimen of the streams. The general conception of graded streams (p. 129) would lead us to believe that no changes can be permanent that do not somehow increase a stream's stability or aid it to maintain an approximate balance between erosion and deposition. In other words, a stream adjusts itself to an increased load by building a steeper slope or by making some other change that increases its power of transportation. Hence, a stream that received a proportionate increase of load from tributaries and thus became so heavily loaded that it built up permanent islands within its channel should theoretically, by this splitting up, have made for itself a more efficient channel in order to take care of this increased load. But it is not immediately apparent why a river that in building an island has divided into two smaller streams and has been deflected into a more roundabout course, is then any more efficient as an agent for the transportation of its load than it was before. Nevertheless, the possible alternative, that the river is then less efficient and that island making is not an approach to but a greater departure from the condition of equilibrium, would mean that island growth and channel subdivision, once started, would continue to increase without limit.

The problem involves a consideration of many factors, and a more detailed knowledge of the river conditions near islands is needed before any explanation can be considered as proved. Nevertheless, one hypothesis may be offered. The islands in the part of Illinois River within the Hardin and Brussels quadrangles are far more stable in their outlines and areas, and hence they are perhaps more significant, than those in the Mississippi. In fact, very few changes in their outlines can be detected on comparing maps made in 1842 with those made in recent years. (See also p. 101.) Accordingly, measurements were made from a very detailed map of Illinois River [95] of the dimensions of cross section at flood or bankfull stages of the chutes and channels and of the undivided river above and below the six large islands in the area (Hurricane, Diamond, Mortland, Helmbold, Twelvemile, and Sixmile). These measurements indicate that on the average the river above and below the islands maintains approximately the same width and mean depth and consequently the same area of cross-section. Inasmuch as the volume of water remains essentially the same above and below the islands, the mean velocity of the river also remains unchanged. The tributary streams, including even the very large Macoupin Creek, that enter

[95] Woerman, J. W., U. S. Corps Engineers, Map of the Illinois and Des Plaines Rivers from Lockport, Ill., to the mouth of Illinois River, sheets 2, 4, and 6, U. S. War Department, 1902–1904.

near these six islands are not normally large enough to increase the total discharge of the river more than about 3 percent. However, the measurements disclose several significant changes through the chutes and channels opposite the islands. The total width of the two branches is increased about 16 percent, and the mean depth is decreased about 10 percent. Hence, the total area of cross section is increased about 4 percent and the mean velocity consequently decreases about 4 percent. The mean depth-width ratio of the divided stream, considered as one whole, is decreased about 22 percent but this ratio in each of the two branches is increased about 55 percent. Similarly, the total wetted perimeter of a divided stream—roughly, total width + 4 × mean depth—is increased about 18 percent and the mean hydraulic radius (area ÷ perimeter) is decreased about 12 percent. Prof. L. G. Straub of the University of Minnesota informs the writer that the changes in channel dimensions near islands in Missouri River in the vicinity of Kansas City, Mo., are very similar to those noted here.

The detailed river map from which these measurements were taken does not show clearly any significant changes in the slope of the water surface opposite the islands, but it suggests that, on the average, the slope opposite islands is steeper by something like 5 or 10 percent. This suggested steepening of slope is not, as might at first appear, inconsistent with a slight decrease in velocity. In fact, theoretical considerations would lead us to expect a steepened slope opposite the islands in order to overcome the increased frictional resistance if the wetted perimeter increases much more rapidly than the area of cross section. (See p. 131.)

The channel measurements given above indicate that, where the river splits into two branches, it makes two changes large enough to be considered unmistakable and important: first, the relative depth (the depth-width ratio) in each of the two branches, considered separately, becomes much greater than it was in the undivided river, and second, the total wetted perimeter of the two branches becomes somewhat greater than the wetted perimeter of the undivided river. Even without these measurements, there seems to be little question that, as a river divides, the relative depth of each branch and the total wetted perimeter of the stream must increase. An inspection of maps of nearby parts of Illinois, Mississippi, and Missouri Rivers shows that the total width of water on both sides of islands is generally equal to or somewhat greater than the width of water on the undivided river. Consequently, unless the area of total cross section opposite the islands becomes much smaller—that is, unless the water that passes the islands flows much more swiftly than that above and below—the mean depth must remain nearly the same and, with division of the width, the relative depth of each branch and the total wetted perimeter of the two branches must increase. Furthermore, it can readily be shown from the accepted laws of flow in open channels that, if the discharge and slope of a stream remain constant, the velocity of the water must decrease as the perimeter increases. The fundamental question, therefore, is: If the velocity commonly decreases opposite islands, can the same load be transported there?

The changes noted above may possibly afford some basis for interpreting the part played by alluvial islands in the regimen of a stream. Division of the channel greatly increases the depth-width ratio in each of the two branches. Gilbert[96] found that the load a stream can carry varies as some power of the most efficient depth-width ratio; that is, he found that the efficiency of a stream as a transporting agent increases with the adjusted proportionate depth. (See pp. 132–133). Therefore, it is conceivable that the transporting power of a graded and adjusted river might be increased opposite islands merely by the proportionate deepening or relative narrowing of each branch. (See also pp. 129–136.) However, the complete explanation is probably not so simple, for the volume of water in each of the two branches is obviously less than that in the undivided river, and the slope is probably somewhat different. Therefore, some other important factor must also be operative.

The measurements offer some suggestion of what this other important factor may be. Division of the channel seems to increase the wetted perimeter of the cross section; that is, it brings the same volume of water into contact with a larger surface of channel walls. An increased rubbing surface increases the friction and so reduces the velocity of flow; but, according to the formulas used by hydraulic engineers (p. 131), the mean velocity decreases only as some *fractional* power of the wetted perimeter. That is, the wetted perimeter increases at a greater rate than the velocity decreases. If, for example, quadrupling the perimeter reduces the velocity by only one-half, then a given quantity of water in the retarded stream is still brought into contact with a doubled channel surface. And, if the channel walls are made of erosible materials, this increased exposure to the effects of running water would presumably cause some erosion. Or, in somewhat different terms, lengthening the wetted perimeter of a stable stream would, it is true, decrease the mean velocity of the entire stream, but it would not necessarily decrease the marginal velocities near the channel walls. Hence, despite the decreased mean velocity, the crowding of water filaments against a larger channel surface might give a net effect of increased erosion.

This tentative conclusion, based merely on the unmistakable increase of wetted perimeter opposite islands,

[96] Gilbert, G. K., The transportation of débris by running water: U. S. Geol. Survey Prof. Paper 86, pp. 129–130, 135–136, 1914.

suggests a possible explanation of another but much less conspicuous change that was indicated by the measurements. The relatively slight increase in the total area of cross-section opposite the islands must, if the river is substantially in equilibrium with its banks, mean that at some time there has been either actual erosion or at least nondeposition opposite the islands. Consequently, this slightly increased area of cross section and the proportionately decreased velocity opposite the islands may be just sufficient to balance the increased channel perimeter there. In other words, the exceptional stability of the channel of the Illinois River may mean that the velocity of flow and hence the transporting ability of both the divided and the undivided portions of the river are neatly adjusted to any differences in channel cross section such as the total length of wetted perimeter.

This interpretation may be tested by several independent methods. Formulated mathematically, it is somewhat as follows:

Let

P_u = wetted perimeter of the undivided river.

P_i = total wetted perimeter opposite the islands

$P_i/P_u = 1.18$

v_u = mean velocity of the undivided river

v_i = mean velocity opposite the islands

$v_i/v_u = 0.96$

If the ability of the stream to transport debris varies as some power, n, of the mean velocity, and the total load carried varies as the product, Pv^n, then, in adjacent sections of a graded stream where the load remains constant,

$$P_i(v_i)^n = P_u(v_u)^n$$

and

$$\frac{P_i}{P_u} = \left(\frac{v_u}{v_i}\right)^n$$

or

$$1.18 = \left(\frac{1}{0.96}\right)^n$$

Therefore $n = 4.2$

That is to say, the measurements, thus interpreted, would mean that the ability of the river, per unit width, to transport debris varies approximately as the fourth power of the mean velocity.

This calculated value of the exponent n may be compared with the values of the "synthetic index "I"—a measure of the average exponent relating the variation of load to mean velocity—found by Gilbert [97] in laboratory experiments. The arithmetical average of the 171 published values of this exponent is 4.3, but other and perhaps more nearly representative methods of averaging give means of 3.2, 3.7, and 4.0.[98] The individual values vary widely from the average or averages, and they vary in systematic relation to the slope, discharge, grain size, and proportionate depth of the artificial streams. These systematic variations are such that, on Illinois River, the grain size and discharge would lead us to expect an exponent smaller than the average by some unknown amount; whereas, the slope and depth-width ratio would indicate an exponent larger than the average by some other unknown amount. The comparison merely indicates that the value, 4.2, of the exponent is of about the right order of magnitude.

The interpretation may also be tested by a comparison with Kennedy's formula [99]—or rather, by a modification [1] of this formula in terms of mean hydraulic radius instead of mean depth—for the design of nonsilting, noneroding canals. According to the modified Kennedy formula, the velocity of mean flow required to maintain a stable channel in canals varies as $R^{0.5}$, the square root of the mean hydraulic radius. From the inverse relation of wetted perimeter to mean velocity found to apply on Illinois River, it can be shown that, in graded streams with constant discharge and load, the velocity would vary as $R^{\frac{1}{4.2-1}}$ or $R^{0.31}$, approximately the cube root of the mean hydraulic radius.

The interpretation may also be compared with the simplification of Gilbert's empirical equation of general stream equilibrium presented on page 132 of this report. Starting with the relation $L \propto Pv_m^{4\frac{1}{4}}$, substituting for v_m from the Chézy formula and from the definition $v_m = \frac{Q}{A}$, and taking X, the proportionate depth, as essentially equal to $\frac{R}{P} = \frac{A}{P^2}$ in natural channels, the equation $SX^{\frac{1}{6}} \propto \frac{L^{\frac{2}{3}}}{Q^{\frac{5}{6}}}$ may be derived, using the notation adopted on pages 131–132. The general form and even the value of the exponents in this derived equation are similar to those of the empirical equation based on Gilbert's experiments, except that D, the diameter of the particles making up the load, is omitted.

COMPARISON OF REGIMEN OF MAJOR RIVERS OF AREA

The volume of water carried by rivers like the Illinois, Missouri, and Mississippi varies greatly with different stages. In the lower Illinois River, the discharge or volume of water has been known [2] to vary at Pearl, Ill., from a maximum of 115,000 cubic feet per second at extreme flood stages to a minimum of 11,000 cubic feet per second at very low water. In the lower Missouri River the proportionate variation is even greater, maximum and minimum discharges of 546,000 and 24,000 cubic feet per second having been recorded [2]

[97] Gilbert, G. K., op. cit., pp. 157, 159–160.

[98] Gilbert, G. K., op. cit., pp. 11, 161.

[99] Kennedy, R. G., The prevention of silting in irrigation canals; Inst. Civ. Eng. Proc., vol. 119, pp. 281–290, 1895.

[1] Lacey, Gerald, Stable channels in alluvium: Inst. Civ. Eng. Proc., vol. 229, pp. 262–268, 1930.

[2] Mississippi River Commission. Results of discharge observations, Mississippi River and its tributaries and outlets, 1838–1923, pp. v, vii, viii, 1925.

at St. Charles, Mo. Maximum and minimum discharges measured at different times,[2] in Mississippi River at Hannibal, Mo., above the mouth of Illinois River, are 273,000 and 22,000 cubic feet per second; at Grafton, Ill., below the Illinois and above the Missouri, 366,000 and 25,000 cubic feet per second; and at St. Louis, Mo., below the mouth of Missouri River, 1,146,000 and 24,000 cubic feet per second.

With these extreme fluctuations in flow between flood and low water, there are related changes in the velocity, load, grain size, slope, and channel dimensions, and it is difficult to choose figures that give a basis for a fair comparison of the normal habits of the different streams. It is a truism among geologists that the chief work of a stream is done during times of flood; the general character of the channel is established then, and between floods the stream is able to make only minor and temporary modifications. But the high floods that come regularly each year probably exert more of a controlling influence upon the general character of the channel than the great floods that come only once in a decade or once in a century. Perhaps the fairest basis that might be chosen for a comparison between different streams is the bankfull stage or the approximately equivalent average yearly flood.[2a]

However, no assembled data on the average flood or bankfull stages of the rivers of the region were found, and it was necessary to adopt some other basis of comparison. The only readily available data that seemed useful for this comparison are those on the average yearly discharge. This average stage, though much less significant than a normal flood stage, can be combined with other information to determine approximately the mean width, depth, and velocity of the different streams. The accompanying table gives these data together with the average slope and suspended load. No quantitative determinations seem to have been made of the bottom load—the amount of material rolled along the bottom of the rivers—and the only precise information that was found about the mean grain size of transported material was in Lugn's size analyses of the sediments of Mississippi River (pp. 99–100). The suspended load may indicate very roughly the bottom load, but the writer would estimate that the Illinois River carries less detritus than the upper Mississippi instead of slightly more as the published data indicate. Judged by the materials exposed in river banks and on sand bars, Missouri River carries the coarsest-grained and Illinois River the finest-grained detritus.

Normal characteristics of parts of major streams of area

	Average discharge [1] (Q) or volume of water (cu. ft. per sec.)	Mean velocity (v) at average discharge [2] (ft. per sec.)	Normal surface width [3] (w) (ft.)	Mean depth (d) at average discharge, velocity, and width (ft.)	Average form ratio or proportionate depth $\left(100\frac{d}{w}\right)$, in percent	Average "muddiness" (U) or suspended load per unit discharge [1] (parts per million)	Average slope [4] (S) (in. per mile)
Illinois River from Kampsville, Ill., to mouth	[5] 15,000	1.3	1,100	11.0	1.0	140	[6] 1
Missouri River, from St. Charles, Mo., to mouth	83,000	4.4	2,700	7.0	.3	1,900	9
Mississippi River from Quincy, Ill., to mouth of Illinois River	77,000	2.4	3,000	11.0	.4	120	6
Mississippi River from mouth of Illinois River to mouth of Missouri River	92,000	2.3	2,900	14.0	.5	[7] 120	6
Mississippi River from mouth of Missouri River to Jefferson Barracks, Mo.	180,000	3.8	2,600	18.0	.7	960	10

[1] Dole, R. B., and Stabler, H., Denudation: U. S. Geol. Survey Water-Supply Paper 234, pp. 87, 89, 1909. Data for some modification of the figures used in this column of the table are given in a paper—Vogel, H. D., Sediment investigations on the Mississippi River and its tributaries prior to 1930, War Department, Engineer Corps, U. S. Waterways Exper. Sta. Paper H, p. 76, 1930—which came to the writer's attention after this report was written. However, the relation of these data to normal flow of the rivers is uncertain, and no revision has been attempted.

[2] Data on relationships prior to 1900 of discharge, area of cross section, and mean velocity from Results of discharge observations, Mississippi River and its tributaries and outlets, 1838-94, p. 116, Mississippi River Commission, 1895; idem, 1838-1923, pp. 46–59, 228, 237–240, 1925.

[3] Scaled from topographic maps.

[4] Gannett, Henry, Profiles of rivers in the United States: U. S. Geol. Survey Water-Supply Paper 44, pp. 39, 60, 69, 1901.

[5] Corrected for diversion from Lake Michigan through Chicago Drainage Canal. [Richmond, W. S., in Warren, J. G. (Division Engineer, Corps of Engineers) and others, Diversion of water from the Great Lakes and Niagara River, p. 176, 1921.]

[6] Horton, A. H., Water resources of Illinois: Illionis Rivers and Lakes Commission Rept. p. 318, 1914.

[7] Estimated from suspended load in Mississippi and Illinois Rivers.

The table gives only approximate values but it serves to bring out several significant relationships. The apparent correlation between steep slopes and large suspended loads is particularly striking. The table also indicates that in many respects the lower Illinois and the lower Missouri represent the two extreme types of the different stretches of river considered here. The velocity and slope of the Illinois River are very low, whereas its cross section is relatively deep; the velocity and slope of the Missouri River are high, whereas its cross section is relatively flat. These differences are associated with greatly different discharges, suspended loads, and mean grain sizes, and also with very different Pleistocene histories, but it is difficult to determine just which of these different factors has been most effective in controlling the velocities, slopes, and cross sections.

PECULIARITIES OF ILLINOIS RIVER

Upon comparison with other streams, the regimen of Illinois River is seen to be abnormal in many respects. The most outstanding peculiarity of the river is its extremely flat gradient or slope. In its lower 228 or 261 miles, from Utica[3] or Peru[4] to the Mississippi,

[2a] Cooley, L. E., The Lakes and Gulf Waterway, p. 51, 1891.

[3] Horton, A. H., Water resources of Illinois: Illinois Rivers and Lakes Commission Rept., pp. 318–319, 1914.

[4] Gannett, Henry, Profiles of rivers in the United States: U. S. Geol. Survey Bull. 44, p. 60, 1901.

Illinois River has an average slope of less than 1½ inches to the mile.[5] This gradient is flatter than that of the lower Mississippi River, which in its lower 862 miles, from Memphis, Tenn., to the Gulf, has an average slope of more than 2 inches to the mile.[6]

Two other unusual features of Illinois River make this exceptionally flat gradient seem all the more remarkable. The flatness is due not at all to a meandering, roundabout stream course. Instead, the river is noticeably straighter and more direct in its route than any of the other major streams of the general region. Furthermore, the current as marked by the main channel or deepest part of Illinois River has the almost unique characteristic of flowing, not like most streams against the outside, but close against the inside of the curves in the river's course. This peculiar feature is well exemplified at Mortland Island, at Helmbold and Twelvemile Islands, and at the large curve south of Gilbert Lake, where the main channel follows the most direct line possible by hugging the inside of the bends.

The channel of Illinois River is proportionately much deeper than the channels of any of the other rivers of the region. Within the Hardin and Brussels quadrangles the normal channel width of the Illinois is only about one-third that of the Mississippi, yet the mean depths of the two streams are approximately equal. In fact the deepest water anywhere in the area is reported to be usually in the upper part of Dark Chute in Illinois River, where depths of more than 20 feet remain throughout the driest seasons.

As a result of the flat gradient, the water in Illinois River normally flows much more slowly than that in Mississippi and Missouri Rivers. This low velocity no doubt explains at least in part the remarkable stability of channel mentioned elsewhere (pp. 101, 123, 125). However, it is difficult to decide whether the fineness of the material carried by Illinois River (pp. 98, 100, 128) is a result or a partial cause of the low gradient and velocity.

Several possible explanations of these abnormal features may readily be dismissed as inadequate. These features clearly are not the result of diversion of water from Lake Michigan into the river or of dredging and dam building, because the reports of early travelers and surveyors show that the present peculiarities were recognizable long before river improvement began.[7] Furthermore, the possibility that the river is entirely out of adjustment with its present slope and cross section may also be dismissed. If this were true, that is, if the present river were simply a ponded slough through which water flowed sluggishly in a channel inherited from some earlier stream, it seems that the river should now be depositing heavily upon its old floor and building up a steeper gradient competent to transport the present load. However, even though the absence of erosion and the presence of natural levees and marginal swamps indicate that the river is now probably aggrading somewhat, there is no evidence that it is building for itself a steeper slope. Its channel is remarkably stable. The river flows in a channel of its own deposits from above Hennepin to its mouth, and the maximum depths to the old bedrock floor, unlike those along Mississippi River, seem to be about the same throughout this distance (p. 98). And, entirely aside from the evidence of the bedrock floor, this possible explanation meets other grave difficulties. It demands either that the earlier river had a gradient even flatter—and therefore more difficult to explain—than the present one or that the earlier stream was tilted northward by movements that did not disturb the gradient of the parallel Mississippi River. It therefore seems necessary to conclude that, since the time that the bedrock floor was cut, the aggradation in the upper and lower parts of the valley has been essentially equal and consequently that the present river is approximately graded or adjusted to the slope on which it flows.

CONCEPT OF ADJUSTED CROSS SECTIONS OF STREAM CHANNELS[8]

The conclusion that the present Illinois River is not perceptibly out of adjustment with its slope, velocity, and cross section or, in other words, that the river is essentially graded, may be examined in the light of some general principles of hydraulics and of some experimental studies and observations of stream work.

The concept of the graded slopes of streams was made familiar by Gilbert's classic essay.[9] For example, an underloaded stream tends to cut into and lower its bed, thereby increasing its load and lowering its slope and velocity until the load becomes as great as can be transported. A strictly analogous concept of adjusted cross sections of stream channels is more elusive and for that reason probably not equally familiar, but it is no less vital to a proper understanding of the laws of river work. The concept has been discussed in a later paper by Gilbert,[10] and it has played an important part in the theory and practice of canal design.[11]

[5] Leighton, M. O., Pollution of Illinois and Mississippi rivers by Chicago sewage: U. S. Geol. Survey Water-Supply Paper 194, pl. 2, 1907. Barrows, H. H., Geography of the middle Illinois Valley: Illinois Geol. Survey Bull. 15, fig. 7, p. 7, 1910. Sauer, C. O., Geography of the upper Illinois Valley and history of development: Illinois Geol. Survey Bull. 27, fig. 3, p. 18, 1916.

[6] Gannett, Henry, op. cit., p. 39.

[7] Cooley, L. E., The Lakes and Gulf Waterway, p. 58, 1891.

[8] Rubey, W. W., The Illinois River, a problem in channel equilibrium (abstract): Washington Acad. Sci. Jour., vol. 21, pp. 366–367, 1931.

[9] Gilbert, G. K., Report on the geology of the Henry Mountains: U. S. Geog. and Geol. Survey Rocky Mountain Region, pp. 102–114, 1877.

[10] Gilbert, G. K., The transportation of debris by running water: U. S. Geol. Survey Prof. Paper 86, pp. 120–136, 190–192, 222–223, 1914.

[11] Kennedy, R. G., The prevention of silting in irrigation canals: Inst. Civ. Eng. Proc., vol. 119, pp. 281–290, 1895. Griffith, W. M., A theory of silt and scour: Inst. Civ. Eng. Proc., vol. 223, pp. 243–314, 1927. Buckley, R. B., Irrigation Pocket Book, 4th ed., pp. 167–170, 207–215, 1928. Lacey, Gerald, Stable channels in alluvium: Inst. Civ. Eng. Proc., vol. 229, pp. 259–384, 1930. Ramser, C. E., Erosion and silting of dredged drainage ditches: U. S. Dept. Agri. Tech. Bull. 184, 1930.

The concept of adjusted cross-section is essentially the concept that a stream tends to make for itself a channel that is neither too deep nor too shallow. Water flowing in a channel, the depth of which is much greater than the width (fig. 11, sec. A), is dragged against and so tends to erode a much larger side-wall surface than an equal volume of water flowing in a channel somewhat wider and shallower. If the too closely crowded walls are made of erosible material, the channel consequently becomes wider; but there are limits to this widening. The frictional resistance between the channel walls and floor and the flowing water not only causes erosion but lowers the velocity. Hence, water flowing in an exceedingly wide and shallow stream (fig. 11, sec. B) comes in contact with and so has its velocity checked by a larger frictional surface than an equal volume of water flowing in a somewhat narrower and deeper stream. Inasmuch as the water in the shallowest margins is checked most by the friction, it drops its load there and makes the channel narrower. In other words, a stream tends to adopt a cross section of some proportion intermediate between extreme depth and extreme width.

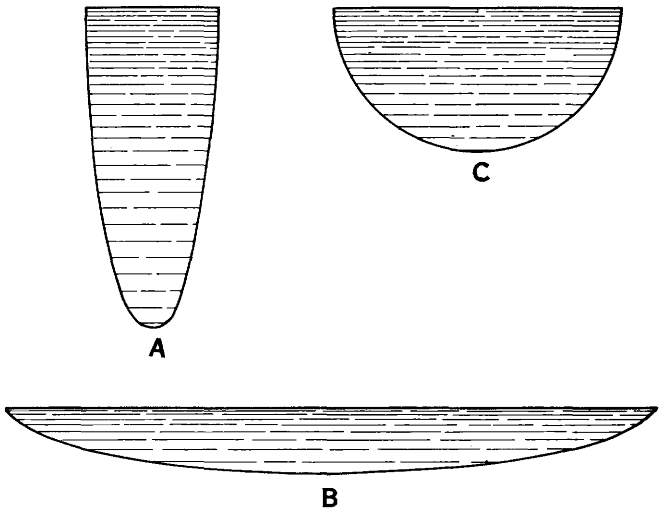

FIGURE 11.—Three channel cross sections of equal area. Section C contains this area within the smallest possible wetted perimeter, and it therefore opposes the least frictional surface to the running water.

It can be demonstrated mathematically that a channel of semicircular cross section (fig. 11, sec. C) has the largest possible hydraulic radius, that is, it opposes the least rubbing surface per unit area; and, within nonerosible walls, water flows fastest and most efficiently in a channel of this shape. However, a stream flowing with any perceptible current between erosible banks is unable to maintain so narrow a cross section. The enertia of water moving in irregular crooked channels and the greater velocity of the current near the surface of a stream—the vertical velocity curve [12] cause lateral erosion, and consequently, natural streams in erosible banks tend to develop cross sections many times wider than the theoretical semicircle. The stream makes for itself the channel of maximum hydraulic radius or maximum efficiency of flow that it is able to maintain under its conditions of character of bed, amount of load, and other controlling variables.

The usual statement of the adjustment of stream slopes to changes of load might then be extended to include the adjustment of cross sections, as follows: An underloaded stream tends to erode either at the bottom or at the sides of its channel, or in both places; consequently, the load is increased. Cutting on the bottom increases the load of downstream parts of the stream and so eventually lowers the slope and decreases the velocity. Cutting at the sides widens the cross section, thereby decreasing the relative depth, and so reduces the efficiency of the stream. In either case the load increases and the capacity decreases until an approximate balance is struck between the two. Conversely, an excessive load causes deposition on the bottom or at the margins of a stream or at both places. Deposition on the bottom, being greater upstream than down, tends to steepen the slope and thus to increase the velocity. Deposition at the sides of the channel, such as sand bars, mud flats, and natural levees, narrows the cross section, thereby increasing the relative depth, and so increases the efficiency of the stream.

The problem may be approached from another angle. The factors that control slope and cross section are many. A stream flowing in an alluvial channel—one made of materials approximately the same size as the debris being carried—must adjust itself to a certain set of conditions or duties over which it has very little control. These imposed conditions are, essentially, the volume of water and the quantity and texture of load that must be carried. The volume of water to be discharged from a drainage basin is clearly an imposed duty over which the stream itself has very little if any control; whatever changes the stream may undergo have very little effect upon the discharge of the drainage basin. Although the relationship is not so direct and immediate, the quantity and texture of load are likewise imposed upon a stream by its environment. A stream may for a time receive more and coarser detritus than it is able to transport and by dropping part of this detritus, it may be said to control, but only for a time, the volume and size of its load. The very fact that this deposition tends ultimately to adjust the streams to its excessive load shows that, in terms of geologic time, load may be considered a controlling independent factor.

It is true that each of these various factors may vary seasonally or even daily and therefore that the stream may never actually attain complete adjustment. Nevertheless, with changing conditions, the stream is

[12] Unwin, W. C., Hydraulics, in Encyclopedia Brittanica, 9th ed., vol. 12, pp. 496–498, 1892.

constantly cutting or filling and modifying its slope, velocity, and cross section so as eventually to accomplish the imposed work with the least expenditure of energy. The recurrent floods of each season carve out or build up a channel that the stream is unable to destroy at lower stages. For example, the longitudinal profile of many streams at low water is an irregular succession of pools and riffles, but the highwater profile is commonly a smooth curve that suggests an essential adjustment. In short, the stream constantly approaches, even though it rarely attains and even then is unable to maintain, a condition of equilibrium in which the capacity for and resistance to corrasion[13] or the cutting and filling are exactly equal. This equilibrium, which the stream constantly approaches, is one in which the imposed load is transported without either gain or loss.

This complex system of adjustments of slope and cross section to discharge and load is accomplished by simultaneous changes in the velocity of the water and in the width and depth of the channel. The given conditions of water volume and of quantity, size, and sorting of detritus determine not only the distribution of velocities at the bottom, sides, and surface of the water but also the extent of erosion or deposition on the bottom and sides of the channel. The erosion or deposition control the slope and cross section of the stream channel and these in turn affect the velocities. Summarizing, if discharge, load, grain size, and sorting are considered the controlling factors, then velocity, slope, width and depth of channel are dependent variables that are affected not only by the independent variables but also by one another.

The complex interrelations among these dependent variables may be simplified somewhat.

First, by definition,

$$Q = Av_m = wd_m\ v_m \quad \ldots\ldots\ldots\ldots\ldots \quad (1)$$

where Q = discharge

A = area of channel cross section

v_m = mean velocity

w = surface width of channel

d_m = mean depth of channel.

That is, for a given discharge and a given velocity there is only one area of cross section.

Secondly, the two dimensions of the channel may be combined as the proportionate depth of cross section,

$$X = \frac{d_m}{w} \quad \ldots\ldots\ldots\ldots\ldots \quad (2a)$$

or as the mean hydraulic radius or depth,

$$R = \frac{A}{P} \quad \ldots\ldots\ldots\ldots\ldots \quad (2b)$$

where P = wetted perimeter, which for rectangular cross sections,

$$= w + 2d_m.$$

It is important to note that in very wide flat streams R becomes essentially equal to d_m. Furthermore, for channels of known shape—whether rectangular, semi-elliptical, or any other—if A and either X or R are known, so also are the width and the depth.

Thirdly,

$$v_m = c\sqrt{RS} \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

where S = slope of water surface

c = a constant.

This is the fundamental Chezy formula of hydraulic engineers.[14] Qualitatively it means that velocity increases as either the mean hydraulic depth—the distance from the frictional surface—or the slope increases. But, inasmuch as frictional resistance becomes greater at higher velocities, the exponent of R and S is less than unity. Theoretically, this exponent is ½, but the values found in many empirical studies of open streams and canals range from approximately ⅓ to ¾ with the exponent of R somewhat greater than that of S.[15] Yet, despite this uncertainty about the precise value of the exponent, the equation represents a fundamental relation between v_m, R and S.

By combining the three equations, (1), (2a) or (2b), and (3), the group of dependent variables—width, depth, velocity, and slope—can be reduced without serious error to only two. Some writers have implied or assumed that the several dependent variables are not truly interrelated, that for any given discharge and load there is one and only one solution, and that the velocity, cross section, and slope of a stream are determined separately. However, it seems impossible to the writer to reduce the number of mutually dependent variables, as this assumption demands, to less than two.

The conclusion that there must be two or more dependent variables, both or all of which are determined not separately but jointly, is in fact consistent with the beliefs commonly held by geologists and river engineers. If the dependent variables were determined separately, diastrophic movements that did not appreciably alter the discharge and load of a stream and any differences in rock resistance along a stream course would have no effect upon the graded slopes; for, then, the graded slopes would be the same whether the region were drowned or uplifted or made of quartzite or clay. Likewise, if the dependent variables were actually determined separately, river engineering would be nearly useless, because rivers with a certain discharge and load would require certain slopes, velocities, and cross sections that no amount of improvement would be able to alter.

[13] Gilbert, G. K., Report on the geology of the Henry Mountains: U. S. Geog. and Geol. Survey Rocky Mountain Region, p. 113, 1877.

[14] Humphreys, A. A., and Abbott, H. L., Report upon the physics and hydraulics of Mississippi River: U. S. Corps Engineers Prof. Paper No. 13, pp. 214–215, 1861, reprinted 1876. Buckley, R. B., Irrigation Pocket Book, 4th ed., pp. 174–206, 1928.

[15] Lacey, Gerald, Stable channels in alluvium: Inst. Civ. Eng. Proc., vol. 229, pp. 372–375, 1930.

The validity of this conclusion and of the generalized statements upon which it is based may also be tested by the results of experimental studies and observations of streams. The relationships found by Gilbert[16] in his extensive experiments on the transportation of debris by small streams in artificial troughs may be summarized approximately in the formula

$$S_G{}^a X_A = K\frac{L^b D^c}{Q^e} \qquad (4)$$

where

S_G=graded slope of the stream or water surface, measured after adjustment to load, discharge, and other controlling variables,[17]

X_A=optimum form ratio, the proportions of adjusted cross section, or the depth-width ratio, which gives to a stream its greatest capacity for traction,[18]

L=the stream's load, the quantity transported through any cross section in unit time,

D=average diameter of particles that make up the load,

Q=volume of water discharged through any cross section in unit time,

K, a, b, c, *and* e=constants.

The steps by which Gilbert's general equation,[19]

$$C=b(S_G-\sigma)^n(Q-\kappa)^o(F-\phi)^p\left(1-\frac{m}{m+1}\,\frac{X}{X_A}\right)X^m,$$

has been thus simplified and transposed so that slope and cross section become the dependent variables are outlined herewith. The constant κ obviously becomes less important as Q increases. The constants σ and ϕ are found to decrease as Q becomes larger.[20] Also, the term

$$\left(1-\frac{m}{m+1}\,\frac{X}{X_A}\right)X^m=(1-\alpha X)X^m,$$

where m and α are numerical constants,[21] can be simplified for natural streams because if wide streams with a very low ratio of depth to width, instead of narrow troughs, are considered, αX is negligibly small, and the term reduces to X^m. Or, if an adjusted instead of an imposed cross section is used—that is, if $X=X_A$—then the term becomes[22]

$$\frac{1}{m+1}\,X_A{}^m.$$

Hence, for large and essentially adjusted streams,

$C=K_1S_G{}^nQ^oF^pX_A{}^m$, approximately,

where C=capacity of a stream for traction of debris, determined as the quantity transported through any cross section in unit time;[23] therefore here equal to the load L;

F=linear fineness of debris or the reciprocal of average diameter, that is, $\left(\frac{1}{D}\right)$;

and

K_1, n, o, p, and m=constants.

Substituting L for C and $\frac{1}{D}$ for F and taking Gilbert's experimental values of the exponents,[24]

$$L=\frac{K_1S_G{}^{1.59}Q^{1.02}X_A{}^{0.47}}{D^{0.58}}$$

or

$$L=K_1\,\frac{S_G{}^{3/2}QX_A{}^{1/2}}{D^{1/2}},\ \text{approximately.}$$

Transposing and squaring,

$$S_G{}^3X_A=K_1\,\frac{L^2D}{Q^2},\ \text{approximately.}$$

The effect of differences in the degree of sorting is omitted from this equation, but Gilbert found that well-sorted debris behaved much as if it were coarser-grained.[25]

This empirical formula may be used as a convenient basis for discussion of the relations between dependent and independent variables. It states that, when form ratio is constant, the graded slope increases with increase of load or grain size or with decrease of discharge, and it is therefore merely a restatement of the familiar conditions of the slope of equilibrium. The analogous increase of the adjusted form ratio or proportionate depth, when slope is constant, with increase of load or grain size or with decrease of discharge is less familiar; it simply means that as a stream becomes more heavily loaded, lateral erosion becomes less important, the channel is torn out less frequently, and a narrower cross section, one approaching more nearly to the theoretical semicircular shape, can be built up.

The general validity of the formula may be tested roughly by comparison with the normal behavior of natural streams. From head to mouth down most streams, the load, grain size, and discharge gradually change. Because of the confluence of tributaries, the discharge of a stream increases downstream. Because of decreasing local relief, the load that is being added per unit volume of water tends to decrease downstream. And because of mutual abrasion and attrition, the particles transported by a stream tend to become finer-grained downstream. Hence, as discharge increases and grain size decreases, the graded slope tends to become flatter downstream, provided the form ratio remains approximately constant. Similarly, the proportionate depth tends to become less downstream, or the proportionate width greater, provided the slope remains constant. Nearly all natural streams become flatter downstream; unquestionably, most streams also become wider and probably a great many become pro-

[16] Gilbert, G. K., The transportation of debris by running water: U. S. Geol. Survey Prof. Paper 86, 1914.
[17] Gilbert, G. K., op. cit., p. 22.
[18] Gilbert, G. K., op. cit., pp. 129–130, 135–136.
[19] Gilbert, G. K., op. cit., p. 191.
[20] Gilbert, G. K., op. cit., pp. 66–67, 153.
[21] Gilbert, G. K., op. cit., pp. 125, 129–130.
[22] Gilbert, G. K., op. cit., pp. 129–130.
[23] Gilbert, G. K., op. cit., p. 24.
[24] Gilbert, G. K., op. cit., pp. 132–134, 187.
[25] Gilbert, G. K., op. cit., pp. 11, 169–185.

portionately wider downstream, although data bearing on this point are not as complete as might be wished. It thus appears that, if either slope or proportionate depth alone is considered, the empirical formula accords in a general way with normal stream behavior.

But the formula also indicates that a given value of load, grain size, and discharge may be satisfied by an almost infinite number of possible combinations of slope and cross section. If the load, grain size, and discharge remain essentially constant, any change of the slope is made at the expense of the proportionate depth, and, in that case, a flattening of slope must be accompanied by a deepening of cross section. The formula thus accords with the previous conclusion that slope and cross section are determined not separately but jointly by the independent variables.

Earlier experimental studies [26] had also shown that the adjusted channel becomes shallower and broader as the graded slope increases. Gilbert explained [27] the relationship as follows:

> The two factors which, in ultimate analysis, determine capacity for traction are velocity of current along the bed and width of bed. When discharge and slope are such as barely to afford competence with the most favorable form ratio, that ratio is one giving the highest velocity, namely, 1:2. The other factor, width of bed, is evidently favored by lower values [of the form ratio]; and therefore, as the conditions recede from the limit of competence, the optimum form ratio becomes smaller. This line of reasoning might, in fact, have been used to show a priori—what has actually been shown by the experiments—that the value [of the optimum form ratio] varies inversely with slope, discharge, and fineness.

The relation may also be interpreted qualitatively by combining equations (1) and (3), (p. 131) the definition of discharge and the Chezy formula, which gives

$$Q = c\,w\,d_m\sqrt{RS} = c\,w\,d_m^{3/2}S^{1/2}, \text{ approximately.}$$

That is to say, in portions of a large stream, where Q and w are approximately constant and R is essentially equal to d_m, it is obvious that depth and slope must vary inversely.

Artificial canals are scoured out or filled up until the dimensions of cross-section and the slopes become adjusted to the discharges, silt-sizes, and silt-loads that must be carried. Therefore, old canals that have been in operation long enough to establish stable channels afford data on the conditions of equilibrum. Many studies have been made of the canals in India, Burma, and Egypt and several empirical relationships between different variables offered as a guide in engineering practice. In a recent summary of these studies, it is reported [28] that the following general relationship holds:

$$S^2R = K_2D^{3/4} \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad . \quad (4a)$$

That is, if the silt size is constant, the slope and mean hydraulic depth vary inversely. Inasmuch as R is roughly comparable with X, this accords with the results of Gilbert's experiments.

Observations on natural streams and rivers that flow in alluvial beds also seem to show the same inverse relation between slope and proportionate depth. It is true, however, that this type of evidence is always open to dispute; no two natural streams are exactly alike, and all have had complex histories. Therefore, almost any relationship that may be cited fails to demonstrate conclusively because it is possible to attribute the example to some special features or irregularities in the histories of the particular streams chosen. Nevertheless, if a general relationship is found to hold true on many different streams in different regions, it cannot be dismissed lightly as accidental.

The table on page 128 indicates that, among the different sections of Mississippi, Missouri, and Illinois Rivers compared there, slope tends to vary inversely with proportionate depth. Likewise, early data [29] on 16 sections of Illinois River from Utica to the mouth show that, as the slope changes somewhat irregularly from one section to another, the same general relationship holds. On 8 sections [30] of the Mississippi from St. Louis to the mouth of Ohio River at low-water, mean, and bankfull stages in 1884–89 and 1907, the slope changes irregularly from section to section, and these changes are accompanied by commensurate inverse changes in the proportionate depth. That this inverse relation between slope and depth is not an uncommon one is indicated by the familiar fact that in streams of all sizes the quiet reaches or pools tend to be deep and flat whereas the riffles tend to be shallow and steep.

Most natural streams probably become proportionately wider downstream, but observations indicate that, beyond a certain point, many rivers begin to become proportionately deeper again as their slopes continue to decrease. The mean dimensions of cross section of Mississippi River in four sections from the mouth of Ohio River to the Gulf show [31] that, before extensive improvements were attempted, the river became progressively narrower downstream and that the depth increased more than the width decreased. Hence, while the slope became flatter downstream, the proportionate depth increased severalfold. More recent measurements [32] of the mean depths and slopes in five sections of the same river from St. Louis to New Or-

[26] Parker, P. à M., The control of water, p. 770, London, 1913.

[27] Gilbert, G. K., The transportation of débris by running water: U. S. Geol. Survey Prof. Paper 86, p. 136, 1914.

[28] Lacey, Gerald, Stable channels in alluvium: Proc. Inst. Civ. Eng., vol. 229, pp. 283, 373, 1930.

[29] Cooley, L. E., The Lakes and Gulf Waterway, p. 60, 1891.

[30] U. S. Engineer Corps, Survey of Mississippi River from St. Louis, Missouri, to its mouth: 61st Cong., 1st sess., H. Doc. 50, pp. 76–77, 1909.

[31] Humphreys, A. A., and Abbott, H. L., Report upon the physics and hydraulics of the Mississippi River: U. S. Corps Engineers Prof. Paper no. 13, pp. 107, 122, 1861, reprinted 1876.

[32] U. S. Engineer Corps, Survey of Mississippi River from St. Louis, Missouri, to its mouth: 61st Cong., 1st sess., H. Doc. 50, pp. 11, 34, 1909.

leans also show the same relationship. Barton [33] indicates that on Brazos River in Texas the depth increases as the slope decreases. Griggs [34] reports that the Buffalo River in Minnesota has a relatively shallow channel and meandering course where the slope is steep but that downstream it changes to a deep, relatively straight, and canallike stream where the slope flattens.

It is reported [35] that in many rivers, especially those of India, the velocity remains approximately constant throughout the middle and lower reaches and the proportionate depth increases as the slope flattens.[36]

This apparent contradiction—the gradual widening downstream to some point, then a reversal and progressive deepening farther downstream—demands a brief consideration that involves some of the fundamentals of stream dynamics. If we ignore for the moment any effects of change of proportionate depth, then the graded slope at any point along a stream's course depends upon the volume of water and the amount and kind of load being carried there. (See p. 132.) None of these factors is influenced by the distance from or elevation above the stream's base level, and the graded slope at that point is therefore determined, not by the conditions downstream but by duties imposed from upstream. And, inasmuch as the longitudinal profile of a stream is simply a continuous series of all the slopes at different points, the shape of the entire profile is likewise determined not by the distance from or elevation above base level but by these imposed duties, discharge and load. Here the objection may quite properly be raised that a stream is necessarily graded with respect to its actual base level. This is of course correct but only in the sense that the altitude rather than the shape of the curve, or in mathematical terms the constant of integration, is fixed by the altitude of the local base level. The slopes at different points and the shape of the profile are controlled by duties imposed from upstream, but the elevations at each point and the actual position of the profile are determined by the base level downstream. (See fig. 12.) This distinction may seem merely academic but its importance lies in the corollary that the profile of a graded stream may intersect the base level at an appreciable angle. In fact, it would rarely happen that the profile graded to fit the imposed duties, discharge and load, would also happen to approach the base level asymptotically.

However, a sharp angle at the intersection between the graded slope above and the base level below obviously cannot be maintained. Where the slope becomes zero, the water ceases to flow and so dams up the river above, thereby raising the water level just enough to maintain the flow. The effects of this damming die out gradually in both directions from the intersection and a transition curve is developed. Or, stated in other words, water flowing down an appreciable slope has a greater velocity than this same water after it has reached the horizontal base level and, with a greater velocity, the same volume in cubic feet per second then occupied a narrower or a shallower channel. That is, the slope of the water surface controls the velocity ($v \propto S^{1/2}$), which in turn determines the area of cross section ($wd = Q/v$); but the changed area modifies the

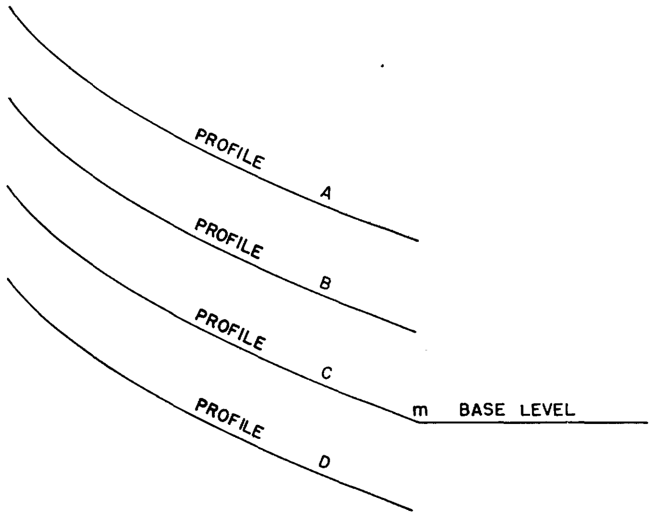

FIGURE 12.—Relationship of profile of equilibrium to base level. Although the graded slopes of a stream and the shape of its profile may be determined by the volume and load, the actual elevations and position of the profile are fixed by the base level. A group of possible profiles all of which satisfy the conditions of grade, but only one, profile C, that meets the actual base level at the point *m*.

original slope and velocity and so on until there is developed a transition curve that merges into the water surface on the graded slope above and the base level below. (See fig. 13.) This transition curve or the slope of the water surface above any kind of obstruction or dam is known to engineers as the "backwater curve" and several formulae [37] have been proposed for calculating it.

The significance of this transition or "backwater" curve in the present connection is the fact that it is not actually a part of but is distinctly different from the graded stream profile as determined by the discharge and load. The part of the stream's course affected by

[33] Barton, D. C., Meandering in tidal streams: Jour. Geology, vol. 36, pp. 622, 628, 1928.

[34] Griggs, R. F., The Buffalo River: an interesting meandering stream: Amer. Geog. Soc. Bull., vol. 38, p. 168, 1906.

[35] Ward, Sir Thomas, in discussion of The works for the augmentation of the supply of water to the city of Capetown, South Africa: Inst. Civ. Eng. Proc., vol. 216, p. 352, 1923. Lillie, G. E., Discharge from catchment-areas in India, as affecting the waterways of bridges: Idem, vol. 217, pp. 302–303, 1924.

[36] Griffith, W. M., A theory of silt and scour: Idem, vol. 223, pp. 251–252, 312, 1927; Discussion by J. M. Lacey: Idem, p. 295, 1927. Elam, W. E., Discussion, Flood control with special reference to the Mississippi River: a symposium: Amer. Soc. Civ. Eng. Trans., vol. 93, pp. 945–946, 1929.

[37] Unwin, W. C., Hydraulics, in Encyclopedia Brittanica, 9th ed., vol. 12, pp. 499–501, 1892. Buckley, R. B., Irrigation Pocket Bock, 4th ed., pp. 89–104, 1928.

the backwater curve would be made flatter than the graded slope. (See fig. 13.) Therefore if slope were the only dependent variable, this lower portion of the stream would no longer be able to transport the load delivered to it by the upper stream, and deposition would result.

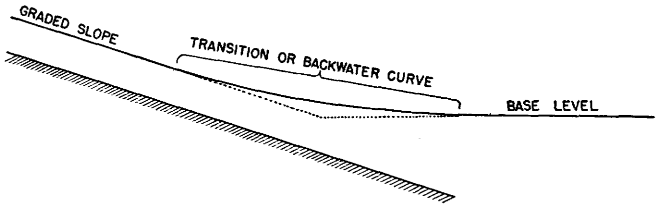

FIGURE 13.—"Backwater curve" transitional between graded slope and base level.

If slope were the only dependent variable this deposition would necessarily result in building up the slopes, first near the mouth and then progressively back upstream, until the whole stream had been aggraded by an equal amount throughout so that the graded profile would exactly approach the level as its asymptote. But if proportionate depth is also a dependent variable, then the graded condition can be maintained by proportionate deepening in that part of the stream which has been overflattened by the backwater curve. The proportionate deepening in the lower parts of many rivers may therefore be explained as the result of overflattening by the backwater curve and adjustment of the channel cross section to this imposed slope.

The observations of canals and streams that have been cited seem to be consistent with the results of experimental studies. Apparently slope and proportionate depth are determined jointly and not separately. If a stream is made unduly wide and shallow by a floor of rock or large boulders, friction along this floor builds up an increase of slope that tends to maintain or approach the equilibrium between capacity and resistance. On the other hand, if the slope is overflattened by drowning, by approach to base level, or by the building forward of a delta, the equilibrium between cutting and filling can be maintained most readily by deposition at the edges of the stream so that the proportionate depth increases. That is, either slope or cross section may locally or temporarily become a controlling factor and thus be a more or less independent instead of a truly dependent variable.

It is not improbable that the precise form taken by the adjustment is governed by something like the principle of least work and depends upon whether equilibrium can most readily be maintained by a change of slope or a change of cross section. Change of slope is accomplished by a greater deposition or a greater scouring upstream than down, whereas change of cross section is accomplished by essentially equal deposition or scouring throughout the stream. It seems probable that local conditions would determine which of these two changes could be accomplished most readily.

Missouri River, for about 2,000 miles from Great Falls to its mouth, has a smooth profile [38] and appears to be essentially graded [39] yet, despite local complications and variations, the river flows throughout this distance at approximately the same interval below the older uplands that border it. One is forced to believe either that the discharge and load of the present Missouri River are such that they almost exactly fit the slopes of these old upland surfaces, which obviously were cut by an earlier stream, or, as seems more likely, that the profile of the present stream has been greatly influenced by the slope of the earlier surfaces on which it began its work. It likewise seems possible that the Platte River of Nebraska, notorious for its width, shallowness, and steep gradient, may be an example not so much of a stream that flows through a region of unconsolidated strata,[40] which is "overloaded" by waste from mountains and by aridity,[41] and which loses water to underground drainage [42] but rather of a stream so greatly oversteepened by the pre-existent slope inherited from earlier streams that equilibrium can more nearly or more readily be attained by the development of a very shallow cross section than by the erosion of a flatter gradient.

If there were no such possibility of alternative solutions, and if the slope of a stream were determined inflexibly by the discharge and load, streams would be unable to adjust themselves as closely as they do to structural slopes and to earlier land surfaces. Without some such a means of adjustment to preexistent slopes—if a certain discharge and load necessarily meant a certain stream profile—it seems that the flat slopes that would be required for some streams would make gorges and canyons far more numerous than they actually are in many regions and, conversely, that many rivers would be compelled to build steep slopes that would raise their banks high above the intermediate lowlands which they traverse.

The concept of the adjusted cross section of stream channels thus seems to carry with it the corollary that graded slopes are not determined solely but only within rather broad limits by the imposed conditions of discharge, load, grain size, and degree of sorting. Even if these imposed conditions are precisely the same for two streams, it does not necessarily follow that their graded slopes must be equal. Hence it seems an almost

[38] Gannett, Henry, Profiles of rivers in the United States: U. S. Geol. Survey Water Supply Paper 44, pl. 8, 1901.

[39] Gannett, Henry, U. S. Geol. Survey Topog. Atlas, Physiographic types folio (no. 2), 1900.

[40] Gilbert, G. K., The Colorado Plateau province as a field for geological study: Amer. Jour. Sci., 3d ser., vol. 12, pp. 100–101, 1876.

[41] Gannett, Henry, U. S. Geol. Survey Topog. Atlas, Physiographic types folio (no. 2), 1900.

[42] Lugn, A. L., Ground-water hydrology and Pleistocene geology of the Platte River Valley and adjacent areas in Nebraska: Nat'l Research Council, Amer. Geophys. Union Trans., p. 225, 1931.

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hopeless task to attempt to deduce the former conditions of discharge and load when only the old slope, and not the cross section, of a stream is known.

APPLICATION OF CONCEPT TO ILLINOIS RIVER

The preceding discussion of the adjusted cross section of streams affords a basis for reconsidering the abnormal features of the regimen of the lower Illinois River. If graded stream slopes are determined within only broad limits by the discharge and load and if the adjusted cross section is actually another variable in the equilibrium, then the very low gradient but exceptional stability of Illinois River is susceptible of a rational interpretation. Essential equilibrium is maintained, despite the extreme flatness, by the greater proportionate depth.

Yet by itself the concept of mutual dependence and inverse relationship between slope and cross section does not explain why one of these variables dominates over and controls the other, why stability is attained more readily by building a narrow and deep channel than by building a steeper slope. However, the depth to the bedrock floor beneath Illinois and Mississippi Rivers furnishes an additional clue. The maximum thickness of the alluvial fill in the Illinois Valley seems to remain approximately constant from near the Great Bend at Hennepin to the mouth of the river, whereas the alluvial fill in the Mississippi Valley seems to become progressively thicker upstream (p. 98).

This relationship suggests that, since the time that the bedrock floor was cut, Mississippi River has gradually built up a steeper slope, and in doing so has raised the base level or drowned the mouth of Illinois River. By this interpretation the Illinois River, flowing on or near its very gently sloping bedrock floor, was checked most and so deposited most heavily in its lowermost reaches. Heavy deposition in the lowermost reaches of a stream would tend to form an even flatter rather than a steeper slope, and therefore a narrower channel would be built. But Illinois River was already flowing on a gradient so low that further flattening would be difficult to compensate. Hence deposition in the lower reaches would cause deposition in the middle and eventually in the upper parts of the stream. That is, the river would build up its bed vertically throughout its course and maintain essentially the same gradient that it had before its base level was raised, because the new backwater curve (pp. 134–135) approximately coincided with the preexistent gradient.

According to this interpretation, Illinois River inherits its low gradient from the much earlier stream that established the flat bedrock floor. However, the dimensions of the old channel are not known, and it is impossible to deduce more than the most general conclusions about the nature of the earlier stream and the conditions under which it flowed. It was unlike the present lower Illinois River in that it scoured the bedrock floor and therefore probably carried a smaller or a finer-grained load or a larger volume of water. Of these three possibilities one seems most probable. That it carried a much finer-grained load seems very unlikely, and a smaller quantity of detritus seems almost equally improbable. However, at the times when the pre-Illinoian Mississippi and Rock Rivers and again when the late Wisconsin Lakes Chicago[43] and Kankakee discharged through Illinois River (pp. 96, 115), it very probably carried much larger volumes of water. The earlier river was probably larger than the present stream, but with present knowledge it is impossible to say whether it was a very large, wide, and flat torrent or only a moderately large but narrow and deep river.

The following table summarizes in a very arbitrary form the geologic history of the region as recorded by physiographic evidence.

[43] Barrows, H. H., Geography of the middle Illinois Valley: Illinois Geol. Survey Bull. 15, pp. 48, 53–54, 57, 1910.

Physiographic record of geologic events in and near the Hardin and Brussels quadrangles, Illinois

Period	Epoch	Stage	Erosion	Deposition
Quaternary	Recent		Dissection of the uplands; lateral planation by the streams	Flood plains
	Pleistocene	Wisconsin.	[1].	Deer Plain terrace.
		Wisconsin (?) and Peorian.	[1].	Deposition of loess.
		Wisconsin or Iowan.	Metz Creek terrace.	
		Sangamon.	[1].	Deposition of loess.
		Sangamon (?) and Illinoian.	[1].	Brussels terrace.
		Illinoian.	Dissection of the unglaciated uplands.	Deposition in ponds marginal to the Illinoian ice. Illinoian till plain.
		Yarmouth.	?	?
		Kansan.	Dissection of the unglaciated uplands.	Kansan till plain and Batchtown channel.
		Aftonian.	?	?
		Nebraskan.	Dissection of the unglaciated uplands.	Deposition of Nebraskan drift.
Tertiary	Pliocene (?).		Sharp trenching and dissection.	
			Intermediate postmature upland surface.	
	Miocene (?).			Deposition of stream gravels (Grover gravel).
	Miocene or Oligocene.		Calhoun peneplain.	

[1] Dissection of the uplands and lateral planation by the streams probably continued in parts of the area.

STRUCTURE

The rock strata of the central Mississippi Valley region dip away from the broad Ozark dome into the coal basins of northern Missouri and central Illinois, but throughout most of the region their angles of inclination are much too gentle to be detected by the unaided eye. Locally, however, these very gentle dips are interrupted by small folds and faults and in a few places by narrow zones of more intense deformation. One of the most sharply defined of these narrow zones of deformation [44] lies along the northeast flank of the Ozarks and makes the south limb of a large asymmetrical anticline in northeastern Missouri and west-central Illinois. This narrow zone of deformation, the Cap au Grès faulted flexure, crosses the Brussels quadrangle; and the large anticline of which it is a part brings to the surface the older Paleozoic rocks that are exposed within the area.

STRUCTURE-CONTOUR MAP

Relatively simple geologic structure like that of the rocks in the central Mississippi Valley can be shown more clearly by structure-contour maps than by any other method of representation. Accordingly, a structure-contour map of the Hardin and Brussels quadrangles (pl. 2) was prepared from the data gathered in preparation of the areal geologic map. Elevations of the contacts between Paleozoic formations were determined at many places by Locke levelling from points, such as roads and upland ridges, where the elevations shown on the topographic maps had been established by traverses rather than by sketching. These relatively accurate elevations were supplemented by a few barometric readings in the less accessible parts of the area. All of the elevations of the contacts between different formations were then reduced—by adding or subtracting the thickness of intervening beds—to the elevation of the one contact that is most widely exposed throughout the area—that between the Kinderhook and Osage groups. The final elevations reduced to this key bed are probably accurate within about 25 or 35 feet. In the uplands where bedrock is exposed the key bed elevations were rather closely spaced—approximately five to the square mile—and structure contour lines, drawn from these elevations and from local dip and strike readings, are believed to be not more than 50 feet in error. However, in the river lowlands rock exposures and borings are very scarce, and the contour lines are little more than one individual's interpretation of what the structure there may be.

In order to show the regional setting of the structural features of the Hardin and Brussels quadrangles, and especially to show the relationship to the structure in Lincoln County, Mo., the completed structure-contour map of the two quadrangles was reduced to the scale of Krey's reconnaissance structure map of the region.[45] Figure 14 is a portion of Krey's map extended to include and modified to fit the structural data gathered in and near the Hardin and Brussels quadrangles.

[44] Weller, Stuart. The geological map of Illinois: Illinois Geol. Survey Bull. 6, p. 12, 1907.

GENERAL STRUCTURE

The structure-contour maps show that the area of the Hardin and Brussels quadrangles falls naturally into three structural units—two extensive areas in which the rocks are inclined gently northeastward separated by the third unit, a narrow east-west zone, in which the rocks dip steeply southward. The northern unit covers the Hardin quadrangle and the northern edge of the Brussels quadrangle. In it the rocks dip northeastward at an average inclination of about 45 feet to the mile, but this regional dip is interrupted by many small anticlines, synclines, and other structural irregularities. In general, the dip becomes flatter and more easterly to the north. The southern unit includes most of the Brussels quadrangle. In it the rocks dip about 20 feet to the mile in an east-northeastward direction, and no irregularities of structure, such as those in the northern unit, were recognized. The narrow zone of steep southward dips extends nearly due east through the northern part of the Brussels quadrangle. Along it the beds dip at angles ranging from 5° to vertical and are even overturned; and there are also numerous large and small strike faults.

The general structure of the Hardin and Brussels quadrangles may also be summarized in other terms. The northern unit of gentle but irregular dips is part of the wide northern limb of the Lincoln anticline,[46] upon which are superposed many minor folds. The southern unit of even gentler and much more uniform east-northeastward dips makes the wide southern limb of the Troy-Brussels syncline.[47] The intervening zone of steep southern dips, the Cap au Grès faulted flexure, is the narrow south limb of the Lincoln anticline and the north limb of the Troy-Brussels syncline.

MINOR FOLDS ON LINCOLN ANTICLINE

The rock exposures within the Hardin and Brussels quadrangles are far too incomplete to permit a recognition of all the smaller structural features of the area, yet those minor folds that were found superposed upon the flank of the Lincoln anticline seem to fall into fairly systematic groups.

[45] Krey, Frank. Structural reconnaissance of the Mississippi Valley area from Old Monroe, Mo., to Nauvoo, Ill.: Illinois Geol. Survey Bull. 45, pl. 1, 1924.

[46] Krey, Frank, op. cit., pp. 45–46.

[47] Krey, Frank, op. cit., pp. 46, 49–50.

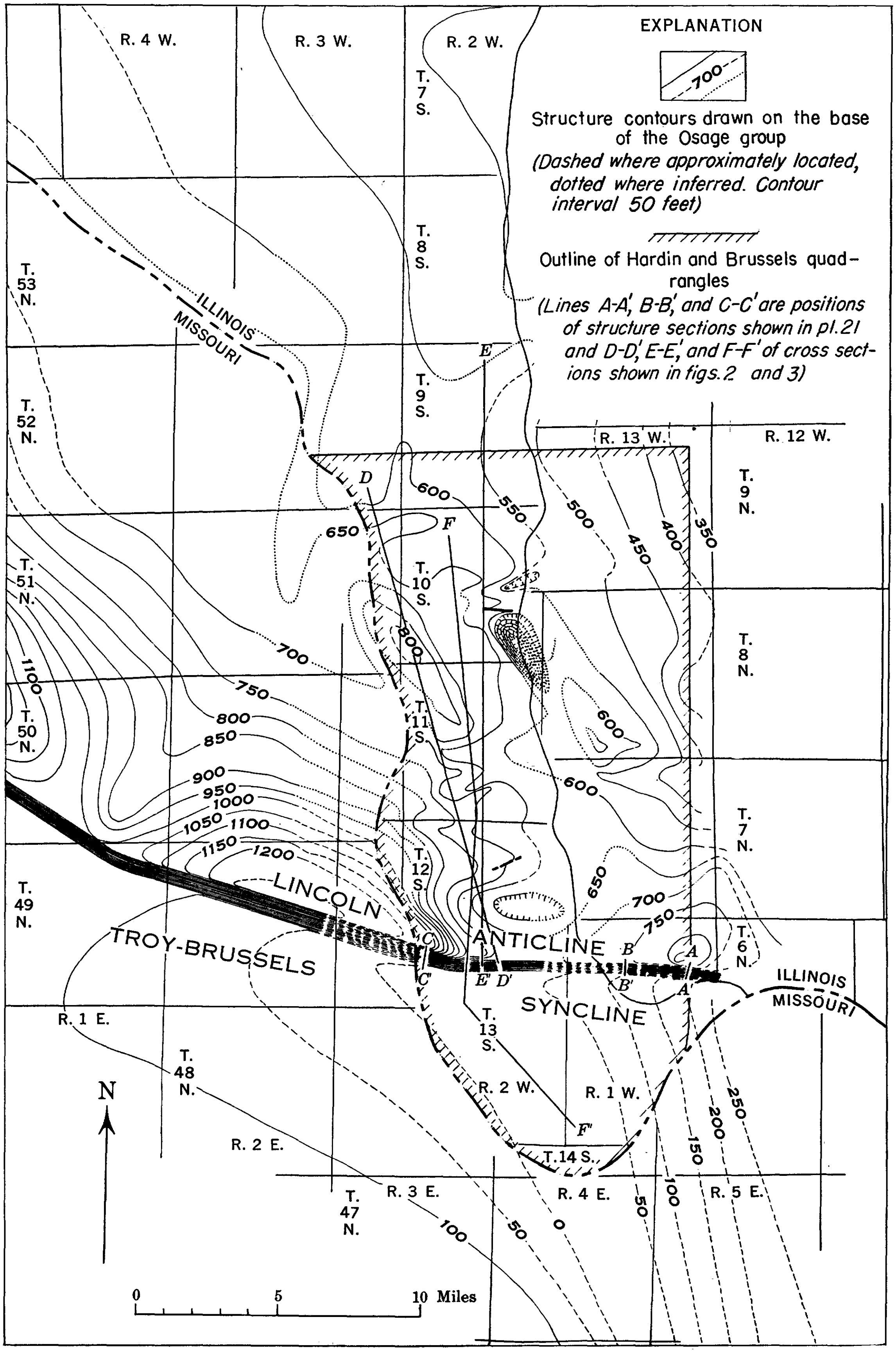
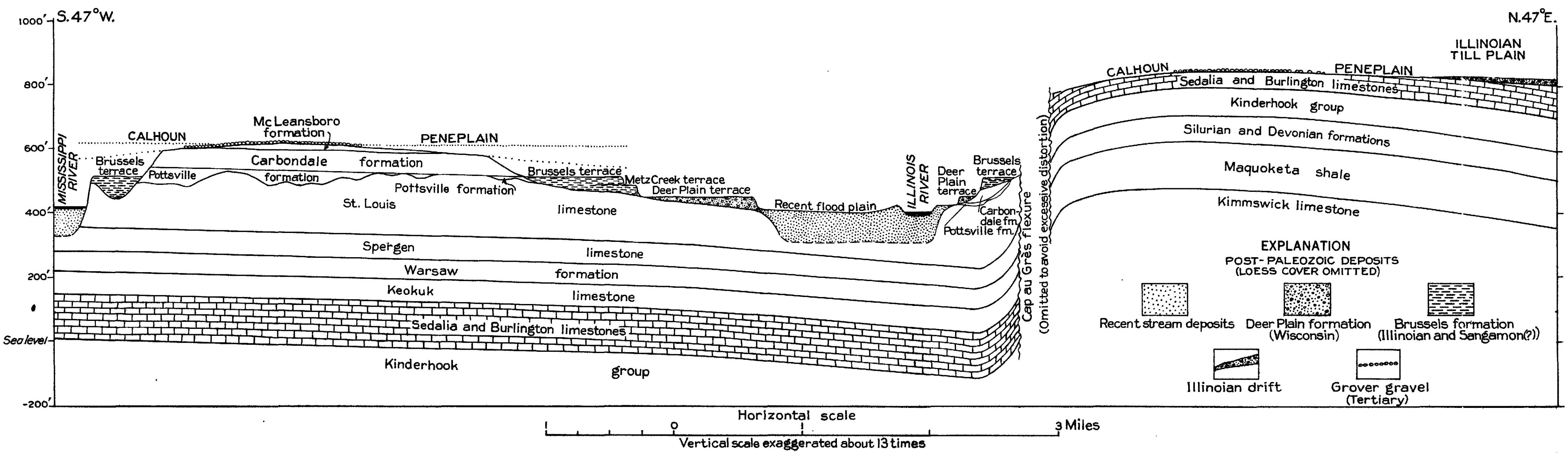


FIGURE 14.—Regional structure-contour map of a part of western Illinois and eastern Missouri, embracing the Hardin and Brussels quadrangles. Modified and extended after Krey.



GENERALIZED CROSS SECTION NORTHEASTWARD FROM THE LOWER END OF PERUQUE ISLAND TO THE NORTHEAST CORNER OF THE BRUSSELS QUADRANGLE, SHOWING THE BEDROCK STRUCTURE, THE DEFORMED CALHOUN PENEPLAIN, THE INTERMEDIATE POST-MATURE UPLAND SURFACE, THREE RIVER TERRACES, AND THE RECENT FLOOD PLAINS OF THE MISSISSIPPI AND ILLINOIS RIVERS

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There are irregularities along the main anticlinal axis. In the vicinity of Dogtown Landing and West Point Ferry, near the crest of the anticline, the rocks dip about 5° ENE. No rocks are exposed immediately to the westward, and the apex of the subordinate anticline there may lie only a few hundred feet to the west under the Mississippi River or it may lie several miles farther west in the larger anticline near Foley in Lincoln County, Mo. Near the northeastern corner of the Brussels quadrangle, the crest of the regional anticline rises again in a minor fold that is here called the Deer Lick dome. Between Dogtown Landing and this Deer Lick dome the crest of the anticline sags down into a saddle about 2 miles south of a shallow basinlike depression that for convenience is designated the Meppen syncline. The structure of the eastern portion of this syncline is hidden underneath the alluvial valley of Illinois River.

About 7 miles north of and roughly parallel to the main anticlinal axis is the Otter Creek syncline, a gentle eastward-plunging fold which is recognizable on both sides of Illinois River. Immediately north of this syncline lies a group of fairly well defined "en echelon" anticlines and synclines that are elongated about N. 35° W. or approximately at 45° to the axis of the Lincoln anticline. Unfortunately not one of these folds is completely exposed in the uplands; all extend out into the river valleys so that their exact form cannot be determined. The most conspicuous fold in this group is the Hardin syncline, on the flanks of which the rocks dip at angles of from 5° to 12°. Parallel to this syncline but on the opposite side of the Illinois River is the much gentler sided Nutwood anticline. Rock exposures on the western side of the Calhoun County upland, supplemented by the records of a few borings nearby, seem to show the presence there of an analogous pair of folds, the Gilead anticline and the Kritesville syncline. The distribution of Keokuk and Burlington faunas in the limestones of the Osage group immediately north of Fieldon indicate the presence of a synclinal depression several miles east of Illinois River, which may be a member of this group of folds.

The en echelon folds appear to die out about 6 miles north of the Otter Creek syncline. Just north of the Hardin syncline two other structural irregularities were noted. One is the largest fault found on the north flank of the Lincoln anticline; it trends about N. 80° W., essentially parallel to the Otter Creek syncline and the axis of the Lincoln anticline, and it is downthrown about 40 feet on the northern side. The other structural feature lies about 1 mile farther north—in Poor Farm Hollow. Its exact character is not known; the rock exposures there may be explained by the presence of either a fault or a narrow steep-sided syncline, the trend of which is also roughly parallel to the axis of the Lincoln anticline. In the main, however, the rocks in the area north of the group of en echelon folds appear to lie relatively undisturbed, and they dip rather uniformly east-northeastward at an inclination of about 30 feet to the mile.

TROY-BRUSSELS SYNCLINE

The rocks that lie south of the Cap au Grès flexure in the Brussels quadrangle and adjacent regions are heavily mantled with Recent alluvium, Pleistocene stream deposits, and loess, and consequently the structure of the area is known less perfectly than that north of the flexure. Nevertheless, the available exposures seem to show definitely that the strata dip very gently and uniformly east-northeastward into an extremely asymmetric syncline that plunges eastward. Deep-well records near Orchard Farm, Mo., and Grafton, Ill., appear to confirm the evidence of the rock outcrops that this synclinal axis plunges eastward more steeply in the eastern than in the western part of the area.

The failure to find minor flexures along the south limb of the Troy-Brussels syncline may possibly be the result of an extensive overlap of Pennsylvanian rocks in that region. However, it seems more probable that it is the result of an actual absence of these minor flexures and a real difference in the type of deformation north and south of the Cap au Grès flexure.

CAP AU GRÈS FAULTED FLEXURE

The most varied and interesting assemblage of structural features within the Hardin and Brussels quadrangles are those along the Cap au Grès monoclinal flexure. This flexure extends continuously from western Pike County, Mo., southeastward through Lincoln County, then east across southern Calhoun County, Ill., and into southwestern Jersey County at least a mile east of the Brussels quadrangle, where it disappears beneath the broad alluvial valley of the Mississippi River. Throughout its length the flexure is a narrow zone along which the rocks dip steeply southward or southwestward. Its average trend across the Brussels quadrangle is nearly due east-west—about N. 87° W.—but it curves gently to either side of this average trend and, at least locally it is offset by small transverse faults.

The total uplift or "structural relief" along the flexure—the difference in elevation of a given bed on the anticlinal axis to the north and in the synclinal axis to the south—averages about 1,000 feet, but it varies from place to place, apparently in systematic relation with the variations in trend of the zone. Near Dogtown Landing the structural relief is about 1,100 or 1,200 feet and near Deer Lick dome about 1,000 or 1,100 feet, and at both places the zone is gently convex to the south. But between these two places, along the saddle opposite the Meppen syncline, the structural relief is only about 750 feet, and the zone is concave to the south.

FOLDING

The horizontal distance between the axis of the Lincoln anticline and the trough of the Troy-Brussels syncline is approximately a mile, but the zone in which the rocks dip at angles steeper than about 5° is only about 1,000 or 1,500 feet wide. The steepest dips in the flexure normally lie near the middle of this narrower zone. Throughout most of the length of the flexure, the steepest dips noted were about 65° or 70°. However, in the N½ sec. 34, T. 12 S., R. 2 W., opposite the Meppen syncline, no dips steeper than 20° were found, whereas in the NW¼ sec. 32, T. 12 S., R. 2 W., near Dogtown Landing, and in the NW¼NW¼ sec. 13, T. 6 N., R. 13 W., near Deer Lick dome, the rocks locally dip at angles of 85° or 90° and in the SE¼SE¼ sec. 11, T. 6 N., R. 13 W., on the west side of Deer Lick Hollow, they are overturned so that they dip about 65° northward. (See pls. 21*A*, 7*C*.)

An interesting minor feature of the folding is the abruptness with which the steep dips flatten at the southern limit of the flexure. Along the river's edge near Dogtown Landing and in the bluffs half a mile north of Winfield in Lincoln County, Mo., the beds in the St. Louis limestone flatten abruptly from dips of more than 20° to less than 5° within a horizontal distance of only a few feet, yet there is very little fracturing of the rock at either exposure.

FAULTING

Along part and perhaps along most of its length the monoclinical flexure is broken by faults. Incomplete exposures make it exceedingly difficult to determine the extent and continuity of these faults, but it is interesting to note the progressive change of interpretations as successive geologists have studied the structure in greater and greater detail. Worthen [48] apparently considered the entire flexure as one continuous fault. Weller [49] recognized that the disturbance is represented by "a monoclinical fold in the southwestern corner of the bluffs in Jersey County," [50] but he concluded that the folding near Dogtown Landing was caused by drag movement along a "great fault." Krey's [51] interpretation of the structure restricted the extent of the faulting along the flexure even farther, for he found the rocks unbroken in sec. 9, T. 6 N., R. 13 W., Jersey County, and very slightly if at all broken on the eastern side of Calhoun County.

[48] Worthen, A. H., Geology and paleontology of Illinois; Jersey County: Illinois Geol. Survey, vol. 3, pp. 104–105, 1868; Idem, Calhoun County, vol. 4, p. 2, 1870.

[49] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, pp. 220–221, 1907; The geological map of Illinois: Illinois Geol. Survey Bull. 6, p. 12, 1907.

[50] Weller, Stuart, op. cit., p. 220.

[51] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Missouri, to Nauvoo, Illinois: Illinois Geol. Survey Bull. 45, p. 47, 1924.

The disturbed zone is marked throughout its entire length by steeply inclined strata, and at least locally these abruptly folded strata are unfaulted; hence the writer purposely adopted the conservative policy of mapping a fault only where the presence of one is demanded by local exposures. This policy may tend to minimize the extent of faulting along the flexure; yet it is a more discriminating method, and it seems to yield more dependable results than the extrapolation of a few observed faults throughout the entire length of the flexure.

A detailed example of the application of this method will serve to show the criteria that were considered necessary to prove the presence of a fault. The alluvial valley of Dogtown Hollow lies along and obscures a critical part of the flexure. At the river's edge the St. Peter sandstone is exposed immediately north and the Chouteau limestone immediately south of this alluvial cover. Worthen [52] found "the exact line of this fault hidden in the valley of a small stream." Weller [53] interpreted the southern edge of the alluvium—the northern limit of the Chouteau exposures—as the position of a fault. Krey [54] reported an actual contact between St. Peter sandstone and Maquoketa shale at the northern edge of the alluvium. Careful search in 1928 and 1929 failed to reveal any actual exposure of such a fault anywhere in the immediate vicinity, and it seems possible that the Recent or Pleistocene clay in contact with the St. Peter sandstone may have been mistaken by Krey for the Maquoketa shale.

Followed eastward for about 1,500 feet the alluvial valley of Dogtown Hollow becomes narrower, but no evidence of a fault could be found. The Plattin limestone is exposed immediately to the north, and a steep ridge which probably marks the outcrop of the Silurian dolomite bounds the southern margin.

In the absence of actual exposures of a fault plane, the probable presence or absence of a fault at each locality along the flexure was decided from the local dip of the strata on both sides of the covered interval and the horizontal distance and normal stratigraphic interval between these strata. Near Dogtown Landing the southernmost exposures of the St. Peter sandstone dip about 12° southward; the northernmost exposures of the Chouteau limestone dip about 75° southward; the horizontal distance between the two outcrops is about 875 feet; and, from measurements nearby, the normal stratigraphic interval between the two beds is about 475 feet.

If the dip were the same on both sides of the covered interval it would be a simple matter to determine whether or not the normal stratigraphic interval could

[52] Worthen, A. H., Geology and paleontology of Illinois, Calhoun County: Illinois Geol. Survey, vol. 4, p. 2, 1870.

[53] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey, Bull. 4, pp. 221, 227, 1907.

[54] Krey, Frank, op. cit., p. 47.

be included between the two exposures. If the 12° dip on the St. Peter sandstone continued southward across the valley to the Chouteau exposure, it could readily be determined that a fault with a vertical throw of 300 feet and downthrown on the south side must lie between the two exposures. If, on the other hand, the 75° dip on the Chouteau limestone continued northward across the valley to the St. Peter exposure, computation would show that the two exposures must be separated by a fault with a vertical throw of 1,400 feet and downthrown on the north instead of the south side.

However, it is certainly more logical to adopt some interpretation intermediate between these two extremes, one which takes into account the dips on both sides of the alluvial valley. Actually, the beds of St. Peter sandstone can be seen to curve so that the dip becomes progressively flatter northward from the alluvial valley and, for a short distance, the dip also becomes progressively steeper southward from the Chouteau exposure. Hence, the most accurate estimate of the concealed structure could probably be made by continuing these observed curves beneath the alluvial valley. But this method, if applied to each exposure, would require an inordinate amount of computation or of difficult graphic construction, and it was not considered worth while to attempt it.

The method adopted was the one commonly used for determining the thickness of folded strata.[55] This common method is based upon the fairly well established generalization that the folding of strata takes place with the least possible internal deformation of the rocks. This generalization is expressed in two corollary assumptions: (1) that strata tend to be folded into curves of the longest possible radii—in other words, approximately circular arcs between any two points of observation—and (2) that the thickness of strata tends to remain constant during folding—in other words, that the folding is of the parallel or concentric type.

It is obvious that neither of these two assumptions can be rigorously exact. Between two exposures the dip may actually change abruptly rather than uniformly along a circular arc as assumed, and so the computed interval would be much greater or much less than the true interval. Furthermore, incompetent strata are commonly thinned where folded; that is, they are thrown into similar instead of parallel folds.[56] Although the competent limestones in the Hardin and Brussels quadrangles appear to maintain their normal thicknesses where steeply folded, the relatively incompetent Maquoketa and Hannibal shales seem to be greatly thinned. Consequently, even though two outcrops should be too close together to include the normal stratigraphic interval between them, it is still possible that the beds are not broken by a fault, but simply stretched and thinned. Nevertheless, despite these uncertainties, the assumptions commonly made in measuring thicknesses of folded rocks seem to be the safest ones to make in the closely related problem of testing the presence of faults.

One finds by this method of calculation that as much as 710 feet of strata could be included between the southernmost outcrop of the St. Peter sandstone and the northernmost outcrop of the Chouteau limestone at the mouth of Dogtown Hollow without an abrupt change of dip or a fault. Inasmuch as the normal stratigraphic interval between these beds is about 475 feet, it follows that no fault is required to explain the observed relationships. Similar computations made at sections across other parts of the alluvial valley of Dogtown Hollow likewise showed no necessity for a fault. Hence it is concluded that present exposures do not prove the existence of any large strike faults along the valley of Dogtown Hollow, and the beds are therefore interpreted as unfaulted on the geologic map (pl. 1) and in the structure section *C′–C′* (pl. 21*C*).

STRIKE FAULTS

Along parts of its length the Cap au Grès flexure is broken by faults that trend parallel to the strike of the rocks. The longest one of the faults that could be traced with reasonable certainty lies just south of Deer Lick dome. It is downthrown on the southern side and has an average trend of N. 80° W., but it is gently concave to the south. It extends from the small valley in the SW¼ sec. 11, T. 6 N., R. 13 W., at least as far as the line of borings at the proposed site for a railroad bridge in the NE¼ sec. 13, T. 6 N., R. 13 W. Through this distance of 2 miles no actual exposures of the fault plane itself were recognized with certainty, but the presence of a fault is shown clearly by the omission of strata in four valleys and by the drill cores from the line of borings. The stratigraphic displacement along this fault—the component of movement measured normal to the bedding—is directly determinable and ranges from about 125 to 250 feet. The fault is downthrown on the south side, and the vertical throw, determined from the stratigraphic displacement and from reconstructions of the fold, seems to be about 250 or 300 feet.

Another and probably much less extensive fault was recognized near Twin Springs in the NW¼SE¼ sec. 9, T. 6 N., R. 13 W. Here the actual fault is exposed as a chert breccia that cuts across the Burlington and Sedalia formations and curves down the steep hillside in such a way as to show that the fault surface is either gently concave in horizontal plan to the south or more sharply concave in vertical section to the north or is

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[55] Hayes, C. W., Handbook for field geologists, pp. 31–32, 1909. Hewett, D. F., Measurements of folded beds: Econ. Geology, vol. 15, pp. 368–369, 1920.

[56] Van Hise, C. R., Principles of North American pre-Cambrian geology: U. S. Geol. Survey 16th Ann. Rept., pt. 1, pp. 599–600, 1896. Rubey, W. W., Determination and use of thicknesses of incompetent beds in oil field mapping and general structural studies: Econ. Geology, vol. 21, pp. 333–351, 1926.

curved both in plan and section. This fault is downthrown on the south side, the stratigraphic displacement is only about 65 feet, and the vertical throw is probably about 150 feet. (See pl. 21 *B*.)

Westward along the flexure, the next fault recognized is opposite the Meppen syncline in the N. center sec. 34, T. 12 S., R. 2 W., Calhoun County. It trends about N. 85° E. and is downthrown only about 40 feet but on the north instead of on the south side.

Weller [57] reported a minor fault "a few rods south of the major fault line upon the bank of the Mississippi River" near Dogtown Landing "where the shaly beds of the Warsaw formation should be exposed." Exposures at this locality in 1928 and 1929 showed a small strike fault that cuts at an acute angle across the bedding planes in the lower part of the Spergen limestone (pl. 21*C*). This fault appears to be a small reverse bedding fault that probably was caused by slippage between beds near the abrupt southern margin of the flexure.

Reconnaissance examinations in Lincoln County, Mo., demonstrate to the writer that faulting along the Cap au Grès flexure is also discontinuous there. In the W½ sec. 13, one mile north of Winfield, and in the W½ sec. 9 T. 49 N., R. 2 E., half a mile north of Argentville, the beds are broken by a fault along which there has been a stratigraphic displacement of about 325 to 400 feet and a vertical throw, downthrown on the south side, of approximately 450 feet. However, in the SE¼ sec. 35, and the SE¼ sec. 34, T. 50 N., R. 1 E., half a mile east and west, respectively, of Brussels, Mo., the beds appear to be unbroken.

A huge slump block in the SW¼SW¼ sec. 8, T. 6 N., R. 12 W., Jersey County, 1½ miles east of the Brussels quadrangle, was at first thought to be a part of the Cap au Grès flexure. However, careful examination revealed the fact that the northward dips of from 30° to 60° in the Silurian and Devonian rocks there are clearly the result of superficial sliding of a large block which broke off from the bluffs above and slid down over the exposure of Maquoketa shale.

With the single exception of the small bedding fault near Dogtown Landing, all of the strike faults observed along the Cap au Grès flexure dip at angles steeper than 45°. However, their exact angle and even the direction of their inclination are very difficult to determine, and the meager evidence that is available appears to be contradictory. The chert breccia along the fault at Twin Springs (pl. 21*B*) is nearly vertical, but it appears to curve so that it dips steeply southward in the upper part of the exposure and steeply northward in the lower part of the exposure. At two localities the evidence suggests a moderate southward inclination. In the NE¼NE¼ sec. 14 and the NW¼NW¼ sec. 13, T. 6 N., R. 13 W., exposures of brecciated rock near the position of the fault dip from 50° to 60° SSW. However, only a short distance away, on the west side of Deer Lick Hollow, in the SW¼SE¼ sec. 11, T. 6 N., R. 13 W., the exposures strongly suggest that the fault plane dips about 60° or 70° NNE.

There is one general relationship between the strike faults and the flexure that suggests a steep northward dip of the fault plane. At each exposure where the flexure appears to be broken, the fault breaks across the fold several hundred feet north of the place where the dips are steepest, and detailed reconstructions of the fold at each of these exposures show that the emergence or surface trace of the fault coincides very closely with the emergence of the axial plane of the flexure. If this relationship is really a general one and the fault therefore lies in the axial plane, it means that the strike faults are high-angle reverse faults that dip about 60° northward. This possible interpretation seems to be supported by the related fact that, the older the beds exposed along the crest of the anticline nearby, the older the beds through which the fault cuts. However, no evidence was found that is sufficiently conclusive to establish the general inclination of the strike faults, and it seems safer to adopt the noncommital interpretation that all are essentially vertical. A possible interpretation of the apparently contradictory evidence bearing on the direction of inclination of the fault planes is mentioned on page 150.

Two other possible relationships of the strike faults seem worthy of mention even though neither of them can be proved definitely from the observations made. The first is the relative amount of uplift along the flexure that is attributable to folding and to faulting. At no place does a strike fault account for more than about one-third of the total amount of uplift. Furthermore, it is an interesting and perhaps significant fact that at every exposure where a strike fault was recognized, approximately 750 or 800 feet of the local structural relief is due to folding and the remainder, if any, is due to the vertical throw of a fault. This empirical observation suggests, though it by no means proves, that there may be a hidden fault at those places, such as Dogtown Hollow, where the structural relief exceeds 800 feet.

The other possible relationship is based upon very few observations. However, it is interesting to note that the differences in elevation, north and south of the Cap au Grès flexure, of land surfaces believed to represent the Calhoun peneplain in southern Calhoun County and southwestern Jersey County, Ill., and in southeastern Lincoln County, Mo., are approximately equal to the amount of vertical throw along the strike faults. This possible relationship therefore suggests that the folding occurred before and most of the faulting after the peneplain was formed.

57 Weller, Stuart, op. cit., p. 221.

TRANSVERSE FAULTS IN DEER LICK HOLLOW

At the mouth of Deer Lick Hollow in the SW¼SE¼ sec. 11 and the N½NE¼ sec. 14, T. 6 N., R. 13 W., a group of small transverse faults has broken directly across the Cap au Grès flexure and the rocks on the west side of the valley are offset so that they now crop out about 200 feet farther north and somewhat higher than those on the east side. The large strike fault that cuts the flexure is offset somewhat more than 300 feet horizontally, and the rocks immediately south of the strike fault and west of the group of transverse faults are overturned so that they dip about 65° north-northeastward (pl. 21*A*).

One fairly large transverse fault and many very small breaks parallel to it are exposed on the west side of this valley. The fault surfaces strike between N. 25° E. and N. 35° E. and dip from 40° to 50° NW. Reconstructions of the folds show that the west side of this group of transverse faults has moved relatively northward and upward. The horizontal component of the motion appears to have been much greater than the vertical and the net or combined motion about 500 feet northeastward obliquely up the fault plane at an angle of approximately 20°. The transverse faults therefore seem to have been flaws—the loci of essentially horizontal movement—that broke somewhat obliquely across the flexure about opposite the crest of the Deer Lick dome.

PERIODS OF DEFORMATION

The rock strata of the central Mississippi Valley have moved gently but repeatedly, and their deformation might be said to have continued intermittently throughout the Paleozoic and into later times. Yet in some localities and at some periods the movements were more intense. Local evidence shows that the area of the Hardin and Brussels quadrangles shared in this common structural history. Gentle preliminary warping in the middle Paleozoic culminated there with sharp folding in the late Paleozoic and waned with minor movements in the Tertiary or the Mesozoic and Tertiary.

There has been some confusion about the exact age of the folding in this general region. The earliest investigators recognized only one period of disturbance—that "anterior to the coal epoch."[58] Most later writers[59] have seen clearly the evidence of repeated movements, but the fact that Pennsylvanian strata are somewhat disturbed and the concept of widespread and simultaneous diastrophism led a few to conclude that the period of principal folding throughout the entire region came after the close of Pennsylvanian deposition.

This conclusion is demonstrably false within the Hardin and Brussels quadrangles. The principal folding along the Cap au Grès flexure was post-St. Louis (Mississippian) and pre-Pottsville (Pennsylvanian), but there were other movements at both earlier and later periods. Krey[60] reported steeply dipping Pennsylvanian shale along the road in sec. 14, T. 6 N., R. 13 W., and concluded therefrom that the principal folding was post-Pennsylvanian. To the writer the distance of these exposures of Pennsylvanian shale, in the NW¼NW¼ sec. 14 and the NE¼NE¼ sec. 15, T. 6 N., R. 13 W., from the flexure and their extremely variable dip and strike prove conclusively that the dips of from 15° to 25° are merely the result of superficial slumping. But whether or not this interpretation is valid and even if Pennsylvanian rocks should later be found involved in the folding of the flexure, the evidence cited by Worthen[61] and Weller[62]—the overlap of Pennsylvanian rocks from the St. Louis limestone south of the flexure onto the Burlington limestone north of the flexure—clearly demonstrates that most of the deformation was pre-Pennsylvanian. It is true, as was first pointed out by Weller,[63] that there was also post-Pennsylvanian movement along the flexure, but this later movement was distinctly subordinate. (See fig. 3B, C.)

Nor does it follow that, the principal folding along the Cap au Grès flexure being determined as post-St. Louis and pre-Pottsville, therefore the principle folding of other structures in the general region must be of the same age. In fact, careful studies[64] show that the most nearly comparable structural feature in the region, the approximately parallel faulted zone in Ste. Genevieve County, Mo., 75 miles to the south, underwent two periods of major deformation—late Devonian and post-Pennsylvanian—neither of which were contemporaneous with the major deformation of the Cap au Grès flexure.

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[58] Worthen, A. H., Geology and paleontology of Illinois: Calhoun County: Illinois Geol. Survey, vol. 4, p. 3, 1870. Potter, W. B., Geology of Lincoln County: Missouri Geol. Survey, Prelim. Rept., Iron Ores and Coal Fields, p. 222, 1873.

[59] Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 2, pp. 58–59, 1904. Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, pp. 229–230, 1907. Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, pp. 42–43, 45, 1911. Hinds, Henry, and Greene, F. C., The stratigraphy of the Pennsylvanian series in Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 13, pp. 209, 213–214, 1915. Cady, G. H., The structure of the La Salle anticline: Illinois Geol. Survey Bull. 36, pp. 175–176, 1920. Wilson, M. E., The occurrence of oil and gas in Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 16, p. 28, 1922. Branson, E. B., Paleozoic formation margins in Missouri: Amer. Jour. Sci., 5th ser., vol. 8, pp. 321–322, 1924. Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Mo., to Nauvoo, Ill.: Illinois Geol. Survey Bull. 45, pp. 50–52, 1924. Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Mo.: Missouri Bur. Geology and Mines, 2d ser., vol. 22, pp. 299–311, 1928. Rubey, W. W., Structural history of the Cap au Grès faulted flexure, Illinois (abstract): Geol. Soc. America Bull., vol. 41, pp. 52–53, 1930.

[60] Krey, Frank, op. cit., p. 47; pl. 12*A*.

[61] Worthen, A. H., op. cit., p. 3.

[62] Weller, Stuart, op. cit., pp. 229–230.

[63] Weller, Stuart, op. cit., pp. 229–230.

[64] Weller, Stuart, and St. Clair, Stuart, op. cit., pp. 264–265, 299, 311–312; fig. 3.

PRELIMINARY WARPING

The evidence of pre-St. Louis deformation in the Hardin and Brussels quadrangles is almost entirely stratigraphic, and it has been described in the discussion of Paleozoic stratigraphy. Nevertheless, some of the general conclusions stated in that discussion will be repeated here in order to bring into proper sequence the structural history of the region.

Early Paleozoic tilting.—Rocks older than the Maquoketa shale are not exposed over sufficiently wide areas and well records are too widely scattered and difficult to correlate in and near the Hardin and Brussels quadrangles to afford reliable information about regional variations in thickness. Hence, little or nothing is known about the location and direction of the early Paleozoic tilting or warping that is indicated by unconformities in the stratigraphic section.

The Maquoketa shale, however, thins greatly southwestward through the area of its exposures, and well records indicate that, where buried in the Troy-Brussels syncline, it continues to thin progressively toward the Ozark uplift. This systematic variation in thickness suggests that there was regional tilting away from the Ozark dome immediately before, after, or during, the Maquoketa deposition and also that the Lincoln anticline had not yet come into existence.

Silurian warping.—The Edgewood limestone thins southward and northward toward a central broad area that lies 5 to 10 miles north of the Cap au Grés flexure. Stratigraphic relations and unconformable contacts seem to show that this broad area was being warped both at the time of Edgewood deposition and during the interval between Edgewood and Brassfield deposition. (See fig. 2*A*.)

Devonian overlap.—The overlap of Devonian strata from the Joliet limestone southwestward onto the Brassfield and at one locality onto the Edgewood limestone shows that there was uplift and truncation of at least 40 feet of strata some time after Joliet and before Cedar Valley deposition. This conclusion is confirmed by the increasing sandiness of the Devonian strata toward the southwest and by the fact that the Devonian sandstone fills deep joint cracks in the underlying Silurian dolomite. (See fig. 2*B*.)

Devonian warping.—The Cedar Valley limestone thickens northward and southward toward a narrow central zone and the stratigraphic relations suggest that this downfolding occurred during the deposition of the formation. The position of this narrow zone of thickest Devonian rocks coincides rather closely with the center of the broad area in which the Edgewood formation is thinnest, a fact which seems to show that the area of broad upwarp in Silurian time became the site of downfolding in the Devonian. (See fig. 2*B*.)

Kinderhook overlap.—No evidence was found that the Lincoln anticline had come into existence before the beginning of Kinderhook time. The Silurian and Devonian rocks show merely that there was regional tilting northeastward, presumably away from the Ozarks, and irregular local warping in the area that later was to become the northern flank of the Lincoln anticline. There is no evidence that the Troy-Brussels syncline had yet begun to yield as a structural unit separate from the Lincoln anticline. Hence Branson's [65] interpretation that the earlier uplifts in Lincoln, Pike, and Ralls Counties, Mo., were along the southwest side of the Cap au Grès belt might also be applied in the Hardin and Brussels quadrangles.

But with the beginning of Kinderhook time the pattern of deformation began to change somewhat. The local warping conspicuous in the Silurian and Devonian had virtually ceased, and the area became integrated into a larger structural unit. The presence of the Glen Park formation on opposite sides of the Lincoln anticline, the thickness relations of the Chouteau limestone, and the distribution of early Kinderhook faunal provinces indicate that by that time the Troy-Brussels syncline had begun to sink and the Lincoln anticline to stand intermittently as a barrier separating the seas to the north and south.

The Kinderhook formations overlap progressively southwestward upon the flanks of the Lincoln anticline, so that the Hannibal, which overlies the Glen Park and Louisiana formations in the northeastern part of the Hardin and Brussels quadrangles, comes to rest directly upon the Devonian and Silurian rocks on the higher parts of the anticline. (See fig. 2*C*.)

Weller [66] concluded from a study of the faunas "that in early Kinderhook time there were two distinct faunal provinces within the present Mississippi Valley region, a northern province and a southern province, separated by an east and west line at a point near the mouth of the present Illinois River." Branson [67] called this line the St. Louis barrier. Williams [68] has proposed to explain the distribution and stratigraphic relations of the Louisiana limestone in the area north and west of the Hardin quadrangle by its deposition in the basin north of the Lincoln anticline and south of the Pittsburgh-Hadley anticline.

Kinderhook warping.—Not only do most of the Kinderhook formations exhibit overlap relations onto the anticline, but they also thicken northeastward down its flank in such a way as to show that there must have been further upwarping of the fold between the deposi-

[65] Branson, E. B., Paleozoic formation margins in Missouri: Amer. Jour. Sci., 5th ser., vol. 8, pp. 321–322, 1924.

[66] Weller, Stuart, Kinderhook faunal studies, IV; The fauna of the Glen Park limestone: St. Louis Acad. Sci. Trans., vol. 16, p. 468, 1906.

[67] Branson, E. B., Geology of Missouri: Missouri Univ. Bull., vol. 19, no. 15, Eng. Exper. Sta. ser. 19, pp. 64, 66, 1918.

[68] Williams, J. S., Stratigraphy and fauna of the Louisiana limestone of Missouri: U. S. Geol. Survey Prof. Paper 203, pp. 49–52, 1943.

tion of the Louisiana, Glen Park, and Hannibal formations. (See fig. 2*C*.) The distribution, thicknesses, and lithologic character of the Hannibal and Chouteau formations seem to indicate (pp. 40–41) that when these formations were being deposited the sea was again shallower over the crest of the anticline than it was to the north and south.

Osage warping.—Complete thicknesses of formations younger than the Kinderhook are not widely exposed in the Hardin and Brussels quadrangles. Consequently, regional variations in thickness of these younger beds, which might suggest the sites of differential warping, cannot be determined readily. Nevertheless, other stratigraphic evidence indicates rather definitely that there were recurrent movements of the Lincoln anticline and the Troy-Brussel syncline. In the eastern part of the area there is at least locally a slight angular unconformity along the Cap au Grès flexure between the Chouteau and Sedalia formations and in the same area the Fern Glen formation seems to pass laterally into the lower beds of the Burlington limestone along the line of the flexure. Furthermore, the Burlington and Sedalia formations are much thicker far down the northeastern flank of the anticline than they are along the flexure near the crest of the anticline.

MAJOR FOLDING

Exposures of the Keokuk, Warsaw, and Spergen formations are not sufficiently widespread to show whether or not there was continued movement during the time of their deposition, but the areal distribution and lithologic character of the St. Louis and Ste. Genevieve limestones suggest that the position of the Troy-Brussels syncline was established and the uplift of the Lincoln anticline well started before the end of the Mississippian period. These formations thicken eastward down a trough that is essentially indistinguishable from that of the present syncline. The beds of conglomeratic, fragmental, and sandy limestone in the St. Louis formation, together with the appearance in the upper part of the unit of sand grains from some new source, seems to indicate that movement had become relatively rapid before the end of St. Louis deposition.

Local evidence does not permit a very exact dating of the actual culmination of folding. The St. Louis limestone is the youngest formation clearly involved in the steep folds, and the Pottsville formation is the first one later than this folding that overlaps onto the anticline. It is not known whether the Ste. Genevieve limestone or any of the overlying Chester formations was ever deposited within the area and if so whether these beds were earlier or later than the main folding.

It is interesting to note that the folding along the Cap au Grès flexure must have taken place under very shallow cover. Even if the Ste. Genevieve and overlying Chester formations were once present in the area, their total thickness could hardly have exceeded 500 or 600 feet. It is indeed difficult to understand why beds of brittle limestone under such a light load of superincumbent strata should have been deformed by folding rather than by breaking and brecciation.

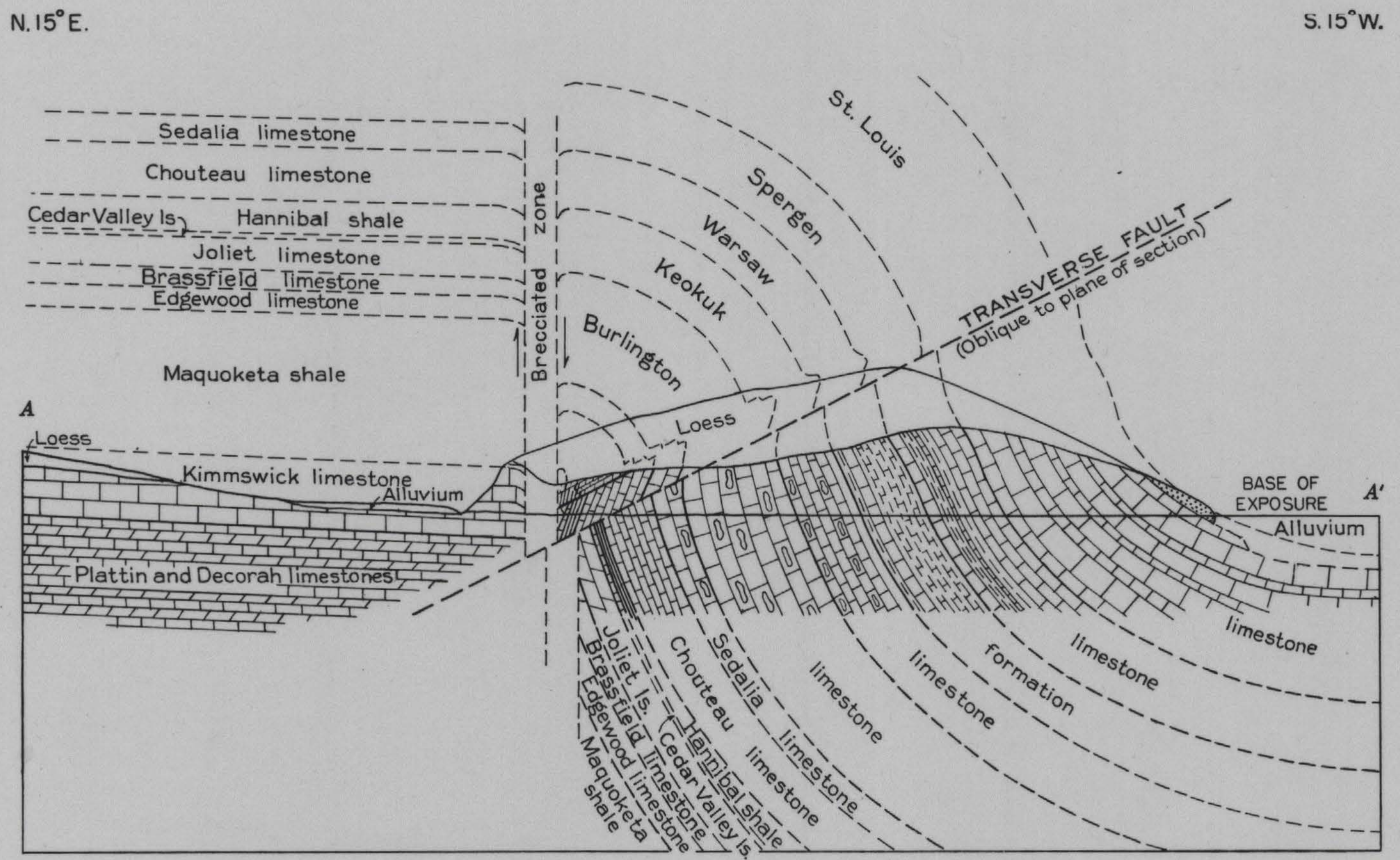
During or after the period of major deformation, streams cut deeply into the limestone uplands, removing all formations younger than the Burlington limestone from the crest of the Lincoln anticline and cutting narrow valleys into the St. Louis limestone south of the flexure.

WANING STAGES

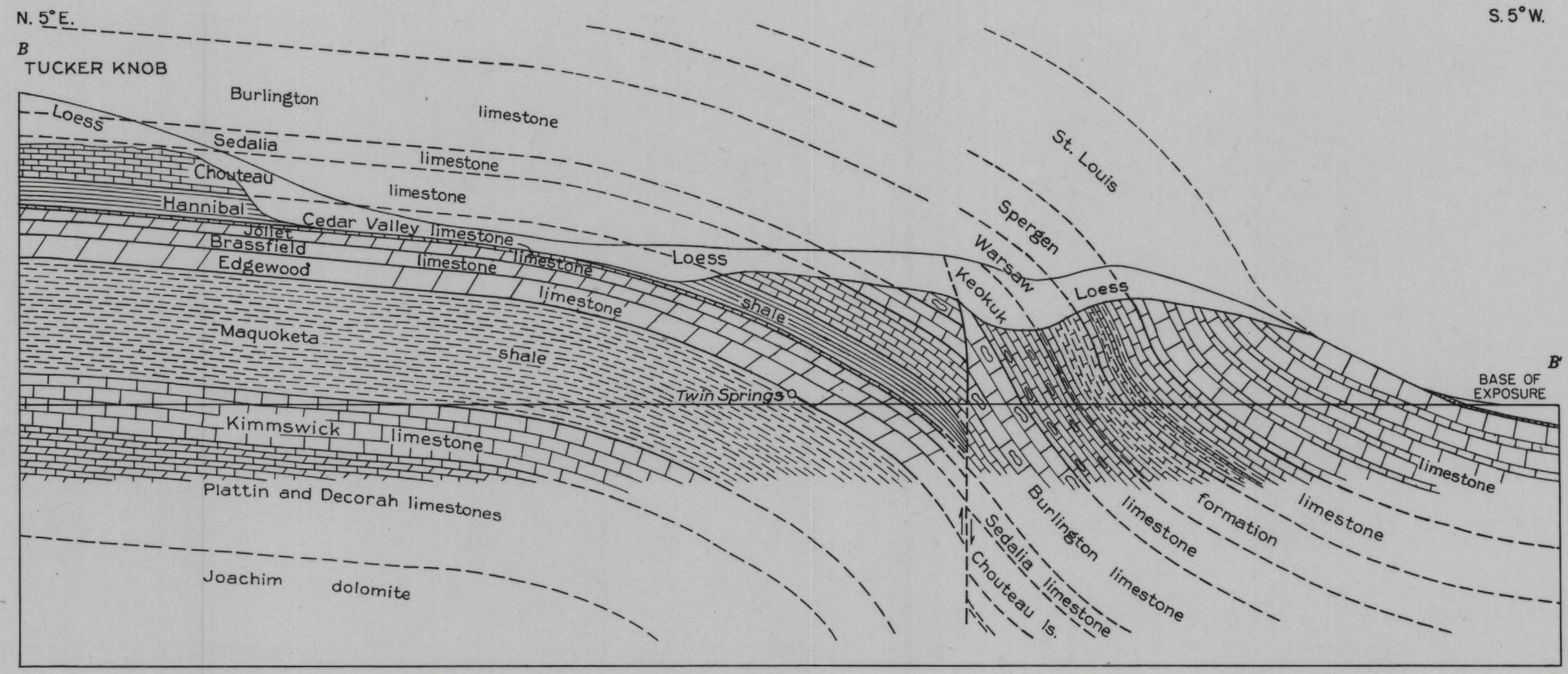
The later uplifts along the Cap au Grès flexure, like those that followed the periods of major deformation in many other regions, are recorded largely in the land forms and in physiographic relations and only subordinately by stratigraphic evidence. They have therefore been treated at some length in the chapter on Physiography but, at the risk of needless repetition, they are again summarized here to make a coherent statement of the structural history of the region.

Post-Pennsylvania, prepeneplain movement.—Some time after the overlap onto the Lincoln anticline of the Pottsville, the Carbondale, and presumably the McLeansboro formations, but before the final cutting of the Calhoun peneplain, there were one or more periods of renewed uplift. This later movement is shown by the fact that the Calhoun peneplain bevels across the edges of tilted Pennsylvanian strata (pl. 10*A*) and by the fact that the remants of Pottsville and Carbondale north of the flexure now stand at much higher elevations than the main body of these formations south of the flexure (pl. 10*A*; fig. 3*C*). The exact date of this movement cannot be determined from local evidence. Deformation is reported in other parts of the Mississippi Valley region during and at the close of the Pennsylvanian and in the Cretaceous, and the renewed uplift of the Lincoln anticline may have taken place at either or both of these periods or at some other time. The amount of uplift during this movement was much less than that during the post-Mississippian, pre-Pennsylvanian deformation.

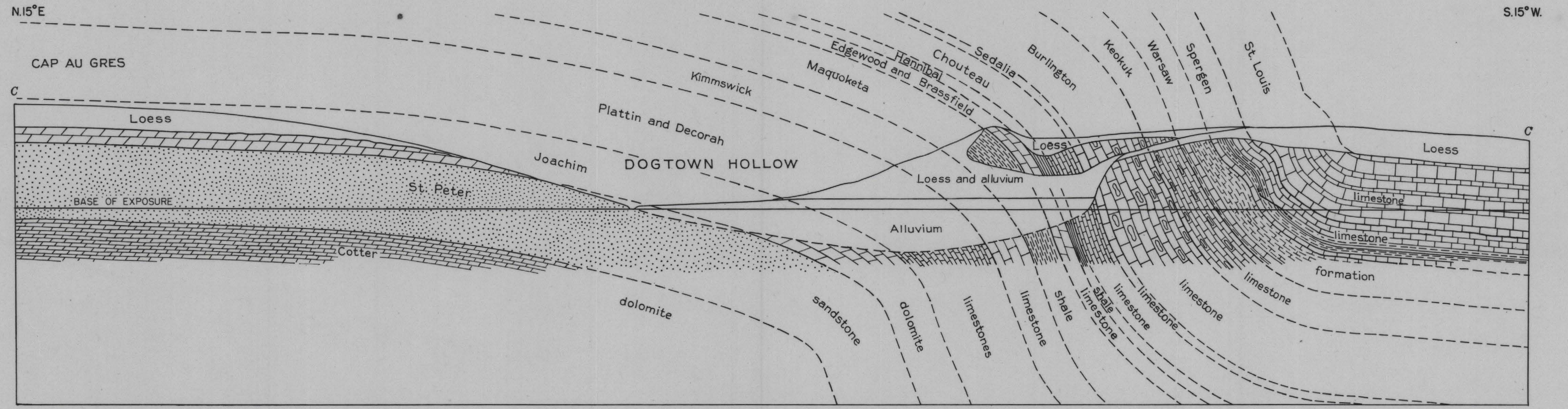
Late Tertiary (?) movement.—A second period of renewed or post-Pennsylvanian uplift is shown by the abrupt displacement of the Calhoun peneplain and the Grover gravel along the Cap au Grès flexure, by the warping of this surface and gravel north of the flexure in Calhoun and Jersey Counties, Ill., and by their northeastward tilting, against the direction of cross bedding, in St. Louis County, Mo. (pp. 104–105). It seems possible to date this movement more closely than the one that preceded it. Certainly most of it took place after the deposition of the Grover gravel (Miocene?), for streamlaid gravels of this formation occur on the highest parts of the uplift. Nevertheless, there



A. SECTION AT THE WEST SIDE OF DEER LICK HOLLOW



B. SECTION AT TWIN SPRINGS



C. SECTION AT CAP AU GRES AND THE MOUTH OF DOGTOWN HOLLOW, SUPPLEMENTED IN RIGHT CENTER BY DATA FROM RIDGE 1,000 FEET EAST OF LINE OF SECTION

Horizontal and vertical scale

100 0 100 400 Feet

Position of structure sections shown on plate 2 and figure 14

STRUCTURE SECTIONS ACROSS THE CAP AU GRES FLEXURE

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are reasons for believing that the uplift started during the deposition of the Grover (pp. 72–73) and the present attitude and elevations of the intermediate postmature upland surface (Pliocene?), which apparently was unaffected by this warping, indicate that it did not continue for so very long thereafter. The amount of uplift at this time was approximately equal to that of the post-Pennsylvanian, prepeneplain movement, and the combined effect of these two periods of subsequent uplift seems to have been distinctly less than that during the major post-Mississippian, pre-Pennsylvanian deformation alone (fig. 3*B*, *C*, *D*).

Late Tertiary to Recent events.—Another late Tertiary rejuvenation followed the development of the intermediate upland surface and brought about the pre-Nebraskan trenching. This very late Tertiary movement seems to have been not a renewed uplift of the Lincoln anticline but a rejuvenation that affected the entire area equally. It may have been part of a broad regional uplift or it may have been caused by a general climatic change or a lowering of sea level.

No evidence was found within the area of any deformation of Pleistocene deposits such as Shaw[69] reported in southern Illinois and southeastern Missouri. It is true that there were alternations of trenching and filling and that the widespread and thick mantle of loess might readily obscure differences in elevation of a few feet or even a few tens of feet of the earlier Pleistocene land surfaces. Nevertheless, the Brussels terrace seems to stand no higher on the crest of the Lincoln anticline than in the trough of the Troy-Brussels syncline; also, the distances over which this terrace can be traced make it seem improbable that there were significant crustal movements or a "peripheral bulge" caused by the loading and unloading of Illinoian ice. Furthermore, the surface of the Deer Plain terrace, which is not covered by loess, seems to continue undisturbed across the line of the Cap au Grès flexure in the NE$\frac{1}{4}$ sec. 36, T. 12 S., R. 2 W.

Earthquakes in historic time.—The Mississippi Valley from New Madrid north to St. Louis, Mo., is one of the most active earthquake regions in the United States east of California. Until recently there were inadequate facilities for instrumental measurement of the seismologic activity in this region, and the records are therefore largely dependent upon the testimony of eyewitnesses. Normally, the quakes of this region affect very wide areas with nearly uniform intensities. This characteristic, generally believed to indicate deep-seated movements, makes it difficult to locate the position of epicenters accurately from newspaper reports. A careful study of the available records led Finch[70] to conclude that one recent earthquake in this region had probably centered along the fault zone of Ste. Genevieve County, Mo.

An examination of the published record of larger earthquakes in the Middle West[71] suggests that several of the quakes may have centered north of St. Louis along the line of the Cap au Grès flexure. Specifically, these are the earthquakes of October 8, 1857, September 27 and October 15, 1882, January 24, 1902, February 8 and November 4, 1903, July 18 and August 16, 1909, and May 1, 1920. Inquiry of residents in the area and at newspaper offices added nothing to the published record. Quakes of moderate intensity have been felt near Hardin and Jerseyville, Ill., but no report that clearly indicates a local epicenter was found.

MECHANICAL INTERPRETATION OF THE STRUCTURE[72]

The narrow zones of deformation, such as the Cap au Grès flexure, are of especial interest to structural geologists not only because they are uncommon but also because they are the structural features of greatest disturbance within the central Mississippi Valley region. Hence any information or generalizations that bear upon the mechanics of their origin have an especially significant bearing upon the interpretation of the structural history of the region.

Faulted flexure versus drag along faults.—Some geologists have interpreted the narrow belts of steep dips, of which the Cap au Grès zone is an example, as the result of drag along normal faults. But to the writer the evidence seems to be entirely opposed to this interpretation and to suggest instead subordinate faulting along a monoclinal flexure that was caused by horizontal compression.

The concept of drag along normal faults attributes the steep dips to plastic deformation caused by friction along the fault surface. However, thick limestones like those involved in the Cap au Grès flexure are not plastic at ordinary pressures, and so they would not yield readily to this type of deformation. These rocks have much greater strength under compression than under tension, and the mere fact that they have formed steep folds under very light loads along suggests compression rather than tension.

If the steep dips were caused by drag movements along the fault, it seems that folding should be distinctly subordinate to faulting. Instead, faulting is everywhere subordinate to folding, and at least locally the flexure seems to be unbroken or even downthrown on the north or wrong side to account for the drag (p. 142). The relative amount of folding and faulting

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[69] Shaw, E. W., Quaternary deformation in southern Illinois and southeastern Missouri: Geol. Soc. America Bull., vol. 26, pp. 67–68, 1915.

[70] Finch, R. H., The Missouri earthquake of April 9, 1917: Seis. Soc. America Bull., vol. 7, pp. 91–96, 1917.

[71] Heck, N. H., Earthquake history of the United States exclusive of the Pacific region: Dept. Commerce, Coast and Geod. Survey Spec. Pub. 149, pp. 35–48, 1928.

[72] Rubey, W. W., Structural history of the Cap au Grès faulted flexure [abstract]: Geol. Soc. America Bull., vol. 41, pp. 52–53, 1930.

suggests not that the faulting preceded and caused the steep dips but that the monoclinal flexing came first and was broken somewhat later by strike faults here and there.

Similarly, the concept of drag seems to demand that the steepest dips should lie immediately alongside the fault surface. Actually, however, the observed faults all break through the flexure several hundred feet north of the steepest dips.

If the Cap au Grès flexure were caused by drag along a normal fault, there must have been a net horizontal extension or pulling apart of the strata. This extension would mean either great stretching and thinning of the folded strata or else that the heave or horizontal pulling apart along the fault more than compensates the shortening taken up by folding. The first of these two alternatives clearly does not apply. The amount of thinning of folded beds that is necessary merely to maintain the original horizontal span without any extension whatever is much too great. Dips of 60° or more would demand thinning to 50 percent or less, and a dip of 45° a thinning to 71 percent of the original thickness.[73] The only thinning found along the Cap au Grès flexure was in two shale formations; nearly all the rocks involved in the folding maintain their normal thicknesses even where overturned.

The second alternative—that the rocks may have pulled apart along normal faults more than they have been shortened by folding—can be tested only by careful measurements along the reconstructed folds. A series of such measurements indicate that the shortening by folding at different parts of the flexure was at least 250 to 400 feet. (See p. 150.) The pulling apart along normal faults that would be necessary to offset this shortening depends, of course, upon the inclination of the fault plane. With reverse faults there would be shortening, with vertical faults the shortening or extension would be zero, and with flatter and flatter normal faults the extension would become progressively greater. Inasmuch as the exact inclinations of the fault planes are unknown it was considered safest for the purposes of this test to assume the flattest normal faults consistent with the local observations. For most of the structure sections this was an inclination of about 45° southward. But even under these extreme assumptions—the minimum shortening by folding and the maximum possible extension by normal faulting—the estimated extension by faulting at no place exceeded one-half of the minimum estimate of shortening by folding there. In other words, careful measurements seem to show clearly that the Cap au Grès flexure was caused by horizontal compression and not by tension.

Furthermore, the field relationships of minor structural features also point to compressional rather than tensional deformation. The details of structure in the zone of steep dips, such as beds overturned 25° past the vertical, the transverse faults or flaws in Deer Lick Hollow, and the parallel folds superposed upon the regional anticline, are all most simply explained as the result of compressional disturbance.

In summary, the type of rocks involved in the folding, the discontinuity and relative subordination of faulting, the horizontal shortening instead of horizontal extension of the strata, and the field relationships of minor structural features make it seem impossible to explain the Cap au Grès flexure as the result of drag along a normal fault. Instead this evidence seems to prove that the structure is the result of compressive stresses, and it suggests that the faulting may be somewhat later than the folding.

Possibility of a deep-seated reverse fault.—It is noteworthy that none of the foregoing arguments against attributing the flexure to drag along normal faults would apply as arguments against deformation along steep reverse faults. In fact, some of them seem greatly to favor that interpretation. High-angle thrust faults have been reported from nearby parts of Missouri [74] and it may seem probable that similar features would be expected along the Cap au Grès flexure. Nevertheless, despite the several indirect suggestions that some of the faulting in this area is of the reverse type (p. 142), it seems much safer to follow the more definite evidence that some of the faults are of the steep normal type and for the purposes of this discussion to assume that all of the breaks are essentially vertical.

However, this conclusion does not eliminate the possibility that the observed faults may be merely superficial breaks and that the zone of steep flexure may mark the emergence from the deeply buried rocks of a steep reverse fault or a zone of such faults. In fact, several bits of evidence seem to support this interpretation. The tilted-block character of the Lincoln anticline and the Troy-Brussels syncline and the straightness and abruptness of the intervening Cap au Grès flexure strikingly resemble the surface expression of two tilted blocks. Furthermore, the apparent correlation between the amount of "structural relief" along the flexure and the direction of curvature of the zone in plan (pp. 139–140) suggest that the Lincoln anticline block is bounded on the south by a surface or zone that dips northward.

If there is such a deeply buried fault or zone of weakness, it must have cut the basement rocks far beneath

[73] Rubey, W. W., Determination and use of thicknesses of incompetent beds in oil field mapping and general structural studies: Econ. Geology, vol. 21, pp. 338–339, fig. 2, 1926.

[74] Flint, R. F., Thrust-faults in southeastern Missouri: Amer. Jour. Sci., 5th ser., vol. 12, pp. 37–40, 1926. Weller, Stuart, and St. Clair, Stuart, Geology of Ste. Genevieve County, Mo.: Missouri Bur. Geology and Mines, 2d ser., vol. 22, pp. 264, 1928.

the cover of Paleozoic sediments. Any structural inhomogeneities in these older basement rocks—planes of weakness blocked out long before the earliest Paleozoic rocks were deposited—would tend to localize the lines of fracturing and deformation much later in the Paleozoic. The parallelism of the Otter Creek syncline to the Cap au Grès flexure and the elongation of the en echelon folds at an angle of about 45° to these two lines seem to suggest that there were such preexistent lines of weakness in the region and that Paleozoic or later deformation may have caused differential movements horizontally or vertically along them.

Surface-volume relations of deformed blocks.—The conclusion that the Cap au Grès flexure and the Lincoln anticline were formed by horizontal compression and yet that most of the strike faults along the flexure are probably vertical or normal faults does not of necessity carry with it the corollary that the structural history is therefore one of compression followed by a later period of complete relaxation and change to crustal extension. Such an inference could be made only upon the assumption that normal faulting is necessarily inconsistent with continued horizontal compression.

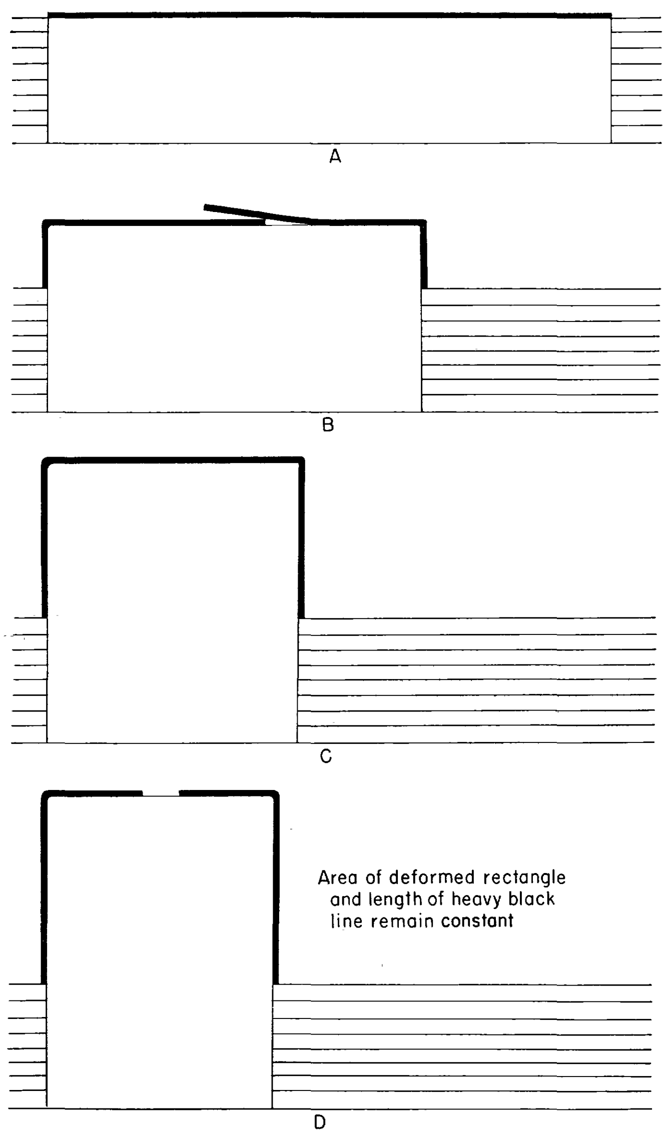

FIGURE 15.—Changing relationships of volume and upper surface in a deformed rectangle.

The structural history of the Lincoln anticline—the preliminary warping, the culmination of folding, and the recurrent uplifts later—suggests that the deformation was all part of one process, intermittent it is true, but cumulative in its effects. A mechanical hypothesis that involves this idea of the normal continuation of some one general process rather than of abrupt alternations of compression and tension would seem to afford the simplest explanation of present observations.

Theoretically, tensional faults may be caused by the stretching of surficial beds across the arch of a rock mass that has been squeezed upward by horizontal compression. Figure 15 represents diagrammatically the changing relationships of volume and surface of a block that is being deformed by lateral squeezing. If the volume or, in cross section, the area of a block remains constant but the horizontal extent decreases, the block must lengthen vertically. During this vertical lengthening the surface area or, in cross section, the surficial perimeter of the block changes greatly. Taking the heavy black line as the original surface length, it can be seen that progressive squeezing of the block makes this original length at first much too long for the area of rock volume squeezed up, then at some one width just long enough, and finally too short to contain the uplifted area. If this heavy line be taken as the length of a rock stratum, it can be seen that continued horizontal compression results first in thrust faulting or folding and finally in tensional faulting.

No one would expect folded rocks to unfold after the period of maximum crumpling, in the manner implied in figure 15. Considering the low tensile strength of rocks, it seems much more probable that normal faulting would start as soon as the stage of maximum crumpling was passed. Figure 16 has been drawn with this probability in mind. In it the surface of the deformed block is bounded by curves or folds instead of by straight lines, but the principle is the same. The position of the base is held constant, and all the vertical lengthening is assumed to be upward. The original line is first too long for the area uplifted, and the surface-volume relations are therefore maintained by folding, but with continued compression the area uplifted finally becomes too great to be contained within the original line and tensional faulting ensues. The position and inclination of the normal faults shown in figure 16 are purely diagrammatic. They are drawn so as merely to satisfy the geometrical requirements of a certain volume uplifted and a given length of the line AB. These requirements might have been satisfied equally well by larger vertical faults or by putting all the movement on one fault or distributing it among

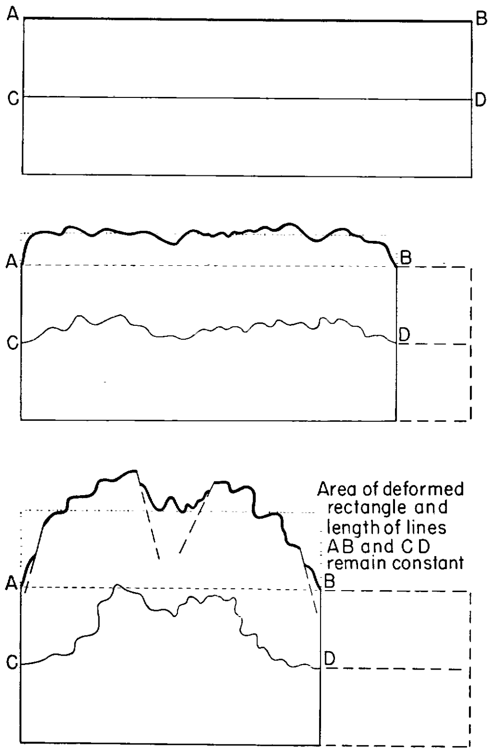

FIGURE 16.—Diagrammatic representation of the changing surface-volume relationships of a deformed block.

twenty. Figure 16 is intended to illustrate also a corollary of this postulated mechanism—that the normal faults due to this stretching would die out with increasing depth.

Many other modifications are necessary before the idealized block could be made to simulate an actual mass of deformed rocks. All thickening of the compressed block has been assumed to be upward. If, instead, there is isostatic compensation and therefore sinking as the block narrows and thickens, the period of crumpling would continue much longer before tensional faulting became necessary, but eventually the effect is the same (fig. 17). Many other necssary modifications doubtless come to mind, but those that have been discussed may serve to illustrate the fundamental principle that is involved and to indicate that further modifications do not necessarily alter these surface-volume relations.

The critical feature of this hypothesis is the eventual change from surficial crumpling to surficial tension and normal faulting as a block is bulged upward by continued squeezing. The point at which this change takes place obviously depends upon the relative width and depth of the block that is being deformed. A very wide but shallow plate would need to be compressed tremendously before the stage of maximum crumpling is passed and that of surficial tension reached. On the other hand, compression of a narrow but very deep block might cause almost immediate tensional faulting. It thus appears that the conditions under which these surface-volume relations would hold true are not merely those of some one special case. They would apply so long as the gross volume or rock density of a deformed mass and the stratigraphic thicknesses—and therefore lengths— of even a few of the more competent beds remain essentially unchanged. In other words, these surface-volume relations would apply to the mechanism that is commonly cited [75] to explain folding and uplift by horizontal compression.

The Lincoln anticline is sharply delimited along only its southwestern flank, and for that reason it cannot be

[75] Becker, G. F., in Willis, Bailey, Physiography and deformation of the Wenatchee-Chelan district, Cascade Range: U. S. Geol. Survey Prof. Paper 19, pp. 95–97, 1903. Chamberlin, T. C., and Salisbury, R. D., Geology, vol. 2, pp. 125–126, 1906. Chamberlin, R. T., The Appalachian folds of central Pennsylvania: Jour. Geology, vol. 18, pp. 228–251, 1910. Chamberlin, R. T., The building of the Colorado Rockies: Jour. Geology, vol. 27, pp. 145–164, 225–251, 1919.

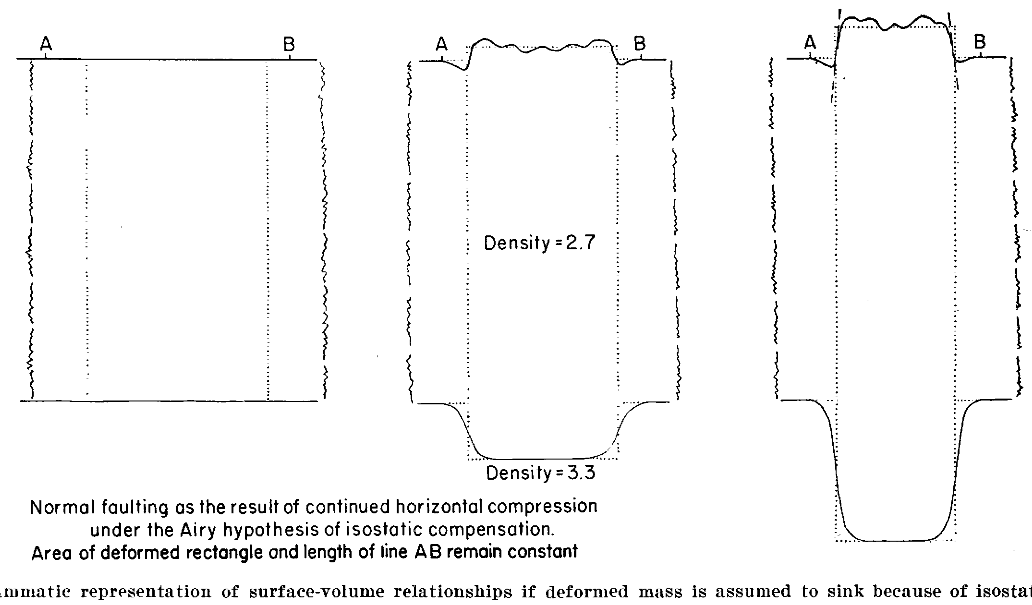

FIGURE 17.—Diagrammatic representation of surface-volume relationships if deformed mass is assumed to sink because of isostatic compensation

compared directly with the idealized blocks just discussed. Yet, if the syncline southwest of the Pittsfield-Hadley anticline [76] is taken as its northeastern limit, then from the width of the Lincoln anticline the volume of rock uplifted can be calculated, and a fair analogy with the idealized block can be made. Theoretically, it is possible to determine, from these two quantities and from the amount of shortening represented by the folded strata, the remaining element of the deformed block—the depth to which the rocks are involved in the folding. Actually however, it is very difficult to determine this depth of folding with any accuracy. For one thing, the amount of shortening, a quantity required in the calculation, is measured from small-scale reconstructions of the folded beds, and comparisons show that the apparent or measurable shortening depends to a great extent upon the scale of these reconstructions. From actual measurements of the length of folded beds on structure sections of areas in Illinois and Wyoming, the writer finds that the apparent shortening is significantly greater on structure sections plotted on larger scales than it is on smaller-scale structure sections of the same areas. This paradoxical result arises from the unavoidable smoothing out of minor irregularities in plotting and from the neglect of other irregularities in measuring the length of folded beds on the smaller scale structure sections. Almost certainly, the largest scale structure sections that were used in these measurements still involve the same error—a smoothing out of structural irregularities that are actually present in the field. The measurements of shortening from structure sections are therefore simply minimum estimates. Even if the amount of shortening could be measured accurately, it remains uncertain how much should be allowed for possible changes of density of the deformed rocks and how much for isostatic sinking of the deformed block.

However, the practical difficulties that prevent an exact determination of the depth of the deformed block do not stand in the way of a qualitative application of the concept of surface-volume relations. Applied thus, the concept seems to afford a possible basis for interpreting the structural history of the Lincoln anticline. It would mean that the region, acting as a segment of the earth's crust at least several miles thick, was subjected to horizontal compression repeatedly during Paleozoic and later times. As would be expected under this hypothesis, the earliest movements resulted in local warping with very little vertical uplift. Later these local areas became integrated into a larger structural unit, and the Lincoln anticline began to rise. Near the close of the Mississippian period the folding reached its culmination, and vertical uplift became conspicuous for the first time. Decreased compression in the region or increased rigidity of the deformed block made the subsequent movements less intense, but in each subsequent movement the vertical component predominated over folding, and tensional fractures may have developed then along the zones of earlier crumpling.

There remains to be pointed out one important corollary of this hypothesis of normal faulting due to continued horizontal compression. Normal faults developed along the margin of a rising uplift would themselves be tilted and overturned by continued compression. Hence the curved fault plane (pp. 141–142) and the apparent alternation back and forth along one fault from a steep normal to a steep reverse character (p. 142) may be the result of local deformation of an earlier normal fault.

GEOLOGIC HISTORY

In its broadest sense, the geologic history of a region might mean a systematic statement of all that is known about the geologic events that have taken place in or near the region; but, as commonly used, the term means both more and less than this. History is not merely chronology; it seeks to recount the events with some regard to their relative importance or significance. And it is just this selection of the particularly important that is most difficult. It is perplexing to choose the incidents of greater significance when the geologic record is known to be extremely fragmentary, when many of the observed facts are subject to conflicting interpretations, and when the very criteria of what is most significant vary somewhat from one writer to another. Geologic history is at best only partial, incomplete history.

Nevertheless, the broad outlines of geologic history in the central Mississippi Valley region, particularly of the Paleozoic era and of the Pleistocene epoch, have long been known; and to this knowledge many workers are each year adding the results of further investigations. The history of this general region starts with an obscure record of the events in pre-Cambrian time; it includes a complex story of many alternating advances and retreats of the sea during the Paleozoic era; it then is broken by a missing interval of erosion during most of Mesozoic and Tertiary time; and it ends with an elaborate chronicle of several ice sheets that in the Pleistocene epoch, immediately before the geological Recent, successively advanced into and melted away from the region. The earlier train of events was dominated by the gradual growth and uplift of the Ozark dome and related structural features, and that of the later history by the development of the Mississippi River and its system of tributaries.

The area covered by the Hardin and Brussels quadrangles shared in this regional history. However, the local record is chiefly that of the subordinate Lincoln

[76] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Mo., to Nauvoo, Ill.: Illinois Geol. Survey Bull. 45, p. 49, pl. 1, 1924.

anticline—its integration and rise in the Paleozoic, its rejuvenation in the Mesozoic and Tertiary, and its resistance throughout late Tertiary and Pleistocene to carving by the rivers and to overriding by the continental ice sheets. The geologic events that pieced together make up this local history have been discussed, along with the evidence on which they are based, in the preceding chapters on Stratigraphy, Physiography, and Structure. In this section of the report the more-outstanding events are brought together somewhat arbitrarily so as to form one continuous story. The critical reader will readily detect in this summary a considerable mixture of inference with fact, a severe pruning of most details, and perhaps an overemphasis of others; he is referred to the preceding chapters for a somewhat more discriminating treatment of the evidence.

Pre-Cambrian time.—The oldest rocks exposed in the Ozark region are mainly of igneous origin. That is, they represent chiefly great masses of once-molten rock, some of which flowed out upon an early land surface and some of which were intruded in among even older rocks. At a few places there are remnants of old water-laid sediments within this igneous complex.

The formation of these pre-Cambrian rocks was followed by a prolonged period of erosion during which thicknesses of many hundreds of feet of igneous and metamorphic rocks must have been removed from the region.

Cambrian period.—Erosion continued for a time into the Paleozoic era, cutting down the older rocks to a flat peneplain in the northern Mississippi Valley region but leaving a rough hilly land surface in the Ozarks. Then in the later part of the Cambrian period the sea spread into the region and drowned the valleys and lower hills so as to make temporarily an archipelago of small islands. Many of these islands persisted until they were cut away by erosion and the intervening straits became filled with sand. Limy muds then were deposited widely over the flat sea floor. These sands and muds eventually hardened into rocks: sandstone, dolomite, and shale.

Ordovician period.—After deposition of the Cambrian sediments, the region was moderately uplifted, and the sea withdrew. However, it soon returned, and a thick series of limy muds and sands began to be laid down in the shallow sea. This sedimentation was interrupted by frequent oscillations of sea floor or sea level, which may have been early stages in the growth of the Ozark uplift. The oscillations brought the sea floor sometimes well above water level and into the realm of active erosion, and at other times they merely shallowed the sea so that further deposition was for a while prevented. These sediments, upon hardening, became layers of cherty dolomite and sandstone that are surmounted by beds of pure limestone, the whole totalling many hundreds of feet in thickness.

The oldest of these rocks brought to the surface in the Hardin and Brussels quadrangles is the Cotter (?) dolomite in its upper few feet. Above this formation lies a thick unit made up almost entirely of rounded sand grains that are nearly uniform in size: the well-known St. Peter sandstone. This sand probably was derived in large part from Cambrian sandstones that cropped out in the northern Mississippi Valley region, and it was swept southward and was deposited in a shallow sea. The deposition of the St. Peter sandstone was succeeded by that of the Joachim dolomite and the Plattin limestone. Near the close of Plattin deposition much organic matter was laid down along with the limy oozes, and this material gave rise to the brown, strongly petroliferous Decorah limestone. The seas that followed next were the home of a great many small animals, such as brachiopods, and these seas laid down deposits of a nearly pure lime ooze, which became the fossiliferous Kimmswick limestone. Near the close of the Ordovician period conditions changed and more clay and sand were swept from some uplifted land surface and began to be deposited within the region. In the Hardin and Brussels quadrangles these deposits make up the Maquoketa shale, but farther south they formed the Thebes sandstone.

Silurian period.—Uplift near the close of the Ordovician period seems to have established an upland similar in the position of at least its eastern margin to that of the present Ozark uplift. At any rate, the earliest Silurian seas seem to have advanced northward up a troughlike depression that was limited on its western side by the present Ozarks. The oldest deposits of these Silurian seas that are left in the Hardin and Brussels quadrangles are those of the Edgewood limestone. This formation thickens and thins irregularly within the area, and at least locally it includes several unconformities, so that it appears highly probable that local warping had started within the area by earliest Silurian time. The sea that laid down the Edgewood limestone withdrew, and there was an interval of pronounced erosion before it returned and deposited the Brassfield limestone. This sea again withdrew, or it at least became so shallow that deposition was prevented, until much later in Silurian time when the Joliet limestone was laid down.

In the northern part of the Hardin and Brussels quadrangles these Silurian formations consist largely of limestone, but in the southern part of the area they are almost entirely dolomite. It is possible that this dolomitization occurred at the time of deposition, but it seems somewhat more probable that it was the result of later changes brought about by waters carrying magnesium and iron that circulated through the rocks near the Cap au Grès faulted flexure.

Devonian period.—Some time after the deposition of the early and middle Silurian formations and before late Devonian time, the area of the Hardin and Brussels quadrangles was again subjected to warping and erosion. Then in late Devonian time, an arm of the sea that had lain to the northwest in what is now the state of Iowa spread into the area. Its deposits were chiefly impure limestone that contains a great many fossil brachiopods and corals. While these sediments were being deposited, the area underwent some further warping, and a narrow trough was formed across the Hardin quadrangle. When this trough had become filled with sediments, the sea began to spread southwestward up the slope, depositing a sand made up of grains that probably were derived from outcrops of the St. Peter and similar sandstones in the Ozark region.

Carboniferous (Mississippian) period.—During or not long after the late Devonian deposition, the warping of the area began to be localized along lines that eventually marked out the Lincoln anticline. The early Mississippian or Kinderhook sea came in gradually from the north and probably also from the south across an eroded surface of very low relief, and in doing so it deposited argillaceous and calcareous sediments. At first this sea was divided by the barrier of the early Lincoln anticline—the Louisiana limestone seems to have been laid down only on the northern side and the Glen Park formation on both sides but not across the anticline. Later, however, the Kinderhook sea encroached farther up the flanks, and during the deposition of the Hannibal shale the entire area seems to have become covered. There may have been other islands or peninsulas in this sea, for throughout this general region the Kinderhook sediments are very irregular in their distribution and character. The Hannibal shale, for instance, now grades northward into sandy beds and southward into an argillaceous limestone that is part of the overlying Chouteau limestone.

At the close of Kinderhook deposition, there was, at least locally, moderate folding along the axis that later became the Cap au Grès flexure, and some of the folded rocks were bevelled off by erosion. Then the sea returned again and laid down a thick series of limy muds. To the south and the east, red and green clays, perhaps derived from the Ozark uplift, were mixed with these muds and gave rise to the Fern Glen formation; but to the north and west of the flexure, the waters were much clearer, sea anemones grew in abundance, and relatively pure calcareous oozes were deposited. These sediments hardened into the Sedalia limestone, the crinoidal and cherty Burlington limestone, and the Keokuk limestone.

Again clayey material was swept into the entire area, and the argillaceous Warsaw formation and the somewhat dolomitic Spergen limestone were deposited. These were in turn succeeded by limy sediments that exhibit evidence of increasing local disturbance and shallow-water deposition: ripple marks, somewhat oolitic textures, limestone conglomerates, and finally cross-bedded sandstone. These, the youngest Mississippian sediments now exposed in the area of the Hardin and Brussels quadrangles, make up the St. Louis limestone. This formation thickens eastward down the trough of the Troy-Brussels syncline until near Alton it is overlain by the even more oolitic and sandy Ste. Genevieve limestone. Still farther southeastward, late Mississippian Chester formations, composed of limestone, shale, sandstone, and conglomerate, overlie this Ste. Genevieve limestone.

Whether or not the Ste. Genevieve limestone or any of the overlying Chester formations were ever deposited within the area of the Hardin and Brussels quadrangles, it appears probable that local uplift had started again by the close of St. Louis deposition. This movement continued and produced the major deformation of the region; the Lincoln anticline was uplifted several hundred feet and the Cap au Grès flexure was steeply folded. During and immediately after this uplift, streams cut deeply into the limestone uplands, stripping off at least several hundred feet of rocks from the crest of the anticline and whatever formations younger than the St. Louis limestone that may have been deposited south of the flexure.

Carboniferous (Pennsylvanian) period.—The uplift and erosion had produced a broken land surface with narrow valleys and sinkholes from 50 to 100 feet or more deep. However, in early Pennsylvanian time conditions changed, and the valleys began to fill up with the residual chert, sand, silt, and fine clay that today make up the Pottsville formation. Eventually, all depressions on the old land surface were filled, and the area became an extensive swamp in which accumulated a widespread deposit of peat that later was converted into coal. After the deposition of the peat the sea again spread across the area and laid down muds, clays, and fine-grained sands. Then began a peculiar rhythmic alternation of conditions, recognizable throughout much of the central interior region of the continent and expressed locally by the deposition of alternate thin layers of limestone and clay or shale. It is not known how long this alternation of conditions continued within the local area, for an unknown thickness of Pennsylvanian strata has been eroded away. However, it is improbable that a very great thickness of Pennsylvanian rocks was ever deposited within the area of the Hardin and Brussels quadrangles, for throughout this entire period much greater thicknesses had been accumulating in the central part of the coal basins of northwestern Missouri and south central Illinois.

The Pennsylvanian seas finally withdrew for the last time from the entire region, and with their retreat the long era of shallow seaways came to a close. Hence-forth the local record was one of erosion and deposition upon the land; the region had permanently become a part of the North American land area.

Permian period, Mesozoic era, and Tertiary period.—The long interval of time between the retreat of the Pennsylvanian seas and the advance of the Pleistocene glaciers left a very meager record in the central Mississippi Valley region, and only a few glimpses are revealed of the geologic history during this long interval. Perhaps frequent periods of deposition alternated with periods of erosion, but if so, nearly all the deposits were removed during the subsequent erosion. The evidence from which the geologic history must be read is very largely that of the land forms produced during the periods of erosion.

The Permian period and all the Mesozoic era are essentially a missing interval in this region. Some time after the Pennsylvanian and before the mid-Tertiary, the Lincoln anticline underwent a moderate uplift. This movement may possibly have taken place near the very beginning of the Mesozoic era when other parts of the region were being uplifted. It seems probable that some sort of a radial drainage system off the Ozark dome, with lateral tributaries along strike valleys, had developed before the Cretaceous period; but no evidence has been found that the Cretaceous seas of the Mississippi embayment and the western interior ever extended into this area.

For some reason, perhaps related to the first blocking out of the Mississippi embayment, the early radial drainage system seems to have ben dismembered by a southward-flowing drainage system that extended back headward along the strike valleys on the east side of the Ozark uplift. This system, which drained through the area of the Hardin and Brussels quadrangles, became the ancestor of the present Mississippi River. The region of the northern Mississippi Valley probably drained southward at that time along the line of the present Illinois River; and north of the Ozarks the principal river seems to have been joined by several large streams from the west. This entire group of streams continued to cut down the region until, by about the middle of the Tertiary period, they had produced a wide flat plain that is here called the Calhoun peneplain.

This process of peneplanation was interrupted, probably near the end of the Miocene epoch, by renewed warping, tilting, and uplift, and possibly by faulting of the Lincoln anticline, the northeastern slope of the Ozarks, and perhaps other areas. These earth movements disturbed the courses of some of the earlier streams. In places, as near the mouth of Missouri River, streams were diverted from their earlier courses and forced to flow along downwarped or downfaulted zones. Elsewhere the earlier streams were rejuvenated and swept large quantities of coarse gravel and sand (the Grover gravel) out over the flat plain and then began cutting deeply into the uplifted land surface.

This cutting proceeded, perhaps throughout the Pliocene epoch, until large parts of the new upland had been dissected and the land surface was reduced to smooth hill slopes. For the first time, the topographic and geographic relations became essentially those of the present day and the modern landscape was more or less established. Then, at about the close of the Pliocene or the beginning of the Pleistocene epoch, the streams were again sharply rejuvenated, this time by vertical uplift or lowering of sea level instead of by differential warping. The streams cut down vertically and made narrow trenches below the postmature Pliocene land surface.

Pleistocene epoch.—Climatic changes which affected the entire northern hemisphere brought about heavy accumulations of snow and the spread of continental glaciers across a large part of North America. The first of these ice sheets, the Nebraskan, left only an obscure record of its advance into the central Mississippi Valley region. Deposits laid down by this ice sheet have been recognized a short distance north of the Hardin quadrangle, but it seems fairly certain that the uplands of Calhoun County were never overspread by the ice.

With a change of climatic conditions the Nebraskan ice sheet disappeared, and the first or Aftonian interglacial stage set in. This interglacial, like the preceding glacial, stage left very little record in the region. Then the ice advanced for a second time and spread southward across all of northern Missouri. The eastward-flowing tributaries of the ancestral Mississippi River were forced southward and westward into a marginal stream that persists today as the Missouri River. Directly opposite the Hardin quadrangle, the Missouri lobe of this glacier was stopped at the uplands developed on the Lincoln anticline, but a subordinate lobe or tongue of the ice extended around the southern margin of these uplands eastward into the river valley and banked high against the west side of the Calhoun County upland. The ice dam thus formed ponded the waters for many miles along the valley of what is now the Mississippi River, and a temporary spillway, the Batchtown channel, was formed across a series of cols made by the outcrop of the Maquoketa shale. The Kansan glacier also advanced from the north and east until it came close to the area of the Hardin and Brussels quadrangles, but from this direction, as from the north and west, it failed to reach the uplands of Calhoun County.

Climatic conditions changed again, and the Kansan ice sheet withdrew from the region. During the second or Yarmouth interglacial stage the topography of the area seems to have been very similar to that of the present day, not only in the position of the valleys, but also in their depth below the uplands.

Then again the ice readvanced, this time from the northeast, and the Mississippi River, which had long drained southward through the valley of the present Illinois River, was forced westward into tributary valleys, developing essentially the course that it now follows. Near the mouth of the Illinois River, the glacial advance was halted by the uplands along the Cap au Grès flexure and by the trenchlike valley; thus, only the northeastern part of the Hardin quadrangle was overridden by this Illinoian ice sheet. Valleys that drained northeastward off the small unglaciated area in the highest uplands of Jersey County were dammed by the ice and formed lakes or ponds. Erosion by the slowly moving ice was negligible within the area of the Hardin quadrangle. The chief effect was depositional; the pre-Illinoian valleys were filled with till, and a wide flat till plain was built up. On this till plain were deposited a few drumloidal mounds, but the glacier left no terminal moraines in this area.

The Illinoian ice sheet did not reach its maximum extent at the same time everywhere. Shortly after it had begun to melt back from the Hardin quadrangle, the ice pushed westward across the Mississippi River at the site of the city of St. Louis and so obstructed the swollen stream that the valley slowly filled up with thick deposits of silt, sand, clay, and gravel. This aggradation built an extensive alluvial plain, here called the Brussels terrace, about 100 feet above the present river level, and this plain extended up the valley from St. Louis to and beyond the Hardin and Brussels quadrangles.

Again the ice retreated and during the Sangamon interglacial stage great quantities of finely ground rock flour, dumped by the melting glaciers, were washed down the rivers and spread out in wide mud flats. During low-water stages of the streams, the wind whipped the dried mud into the air and deposited it as great thicknesses of dust or loess upon the wooded uplands alongside the streams.

There is no local record of the succeeding Iowan stage of glaciation. In the fourth or Peorian interglacial stage, conditions were similar to those in the Sangamon. Loess again accumulated on the uplands but not in such great thicknesses as before.

The Wisconsin or final stage of glaciation was in itself made up of several minor advances and retreats of the ice. However, none of its ice advances came nearer than about 100 miles to the northeast of the Hardin and Brussels quadrangles. With the final retreat of the Wisconsin glaciers, the present Great Lakes began to come into existence and at successive stages in their formation, several of these lakes discharged water southward down the Illinois River. One of these flood outlets may possibly have cut the Metz Creek terrace and left the scattered pebbles that are found alongside the lower Illinois River. However, the most conspicuous Wisconsin record within the area is the Deer Plain terrace. This is an alluvial plain built up of coarse gravels by the Mississippi River to an elevation about 40 feet above the present river level. Similar coarse materials were not then being carried by the Illinois River, and the Mississippi flood plain virtually dammed the mouth of the smaller river so as to cause the deposition of much finer grained materials there. The exact source of these Deer Plain deposits is not known, but it seems probable that the flood waters which washed them down the Mississippi River may have come from the drainage of glacial Lake Agassiz—the Red River valley—in very late Wisconsin time.

During all of the Pleistocene epoch the unglaciated uplands were undergoing almost continuous erosion and, immediately after the disappearance of the Kansan and Illinoian ice sheets, streams also began to dissect the till plains that had been left. Meanwhile the valleys of the Mississippi and Illinois Rivers, which had been trenched to approximately their present depth before the first stage of glaciation, were progressively widened by lateral planation each time the rivers impinged against the base of the bordering bluffs.

Recent epoch.—After the climate ameliorated and the last of the Pleistocene glaciers had completely disappeared, the work of running water became the dominant geologic process operating within the region. Yet even within an epoch of such relative briefness as the Recent, there has been time for geologic processes and conditions to change more than once. For a time after the building of the Deer Plain terrace, the Illinois and Mississippi Rivers cut vertically below and laterally into their flood plains.

This degradation finally ceased and, long before the earliest historic record, the Illinois and perhaps the Mississippi began very slowly to deposit or else just about maintained their flood-plain levels. With this change Illinois River abandoned the meandering habit by which it had cut laterally into the Deer Plain terrace and made for itself a very stable course by building up natural levees along its banks and alluvial islands within its channel.

These conditions of essential adjustment were again unbalanced when civilized man came into the region. Deforestation and cultivation of the soil, artificial improvement of the rivers for purposes of navigation, and diversion of waters from Lake Michigan into the Illinois River have within recent decades somewhat disturbed the regimen of the major streams.

Similar but less pronounced changes also took place on the uplands. The washing away of the thick deposits of loess and the dissection of the glacial till plains continued without important interruption. But these processes have been quickened since the region was settled and sharp gullying of the old slopes has started in many places.

ECONOMIC GEOLOGY

The various mineral resources of the Hardin and Brussels quadrangles have been described in more or less detail in an earlier report by Lamar [76a] and in the lithologic descriptions of the different rock formations in the present report. The descriptions of those materials that have present or potential economic value are brought together and summarized briefly in the following pages.

LIMESTONE

DISTRIBUTION AND USE OF LIMESTONE

Few if any parts of Illinois have as great a variety and quantity of easily quarried limestone and dolomite as the Hardin and Brussels quadrangles, yet the quarrying industry has made very little progress in the area. This failure to develop the limestone resources is largely the result of inadequate railroad facilities. The local demand for stone is very limited and inasmuch as barges afford the only economical means of transportation of stone, the area is dependent upon markets on or near the rivers. This situation is disadvantageous because limestone crops out extensively along all the rivers of the region, and potential river markets such as St. Louis, Mo., are supplied in large part by nearby quarries. However, it seems possible that, even with the present transportation facilities, markets might be developed for certain types of limestone that are not so widely exposed.

The two principal uses for which limestone is now being quarried in the area are for agricultural purposes and for riprap in river control work. Many small quarries, chiefly in the Burlington limestone, have been opened and operated intermittently by local residents to obtain lime for fertilizer, but no effort has been made to compete with the local supplies at more distant markets. The calcareous tufa (pp. 97–98) is locally reputed to be very well adapted, in its ease of grinding and chemical composition, to use as fertilizer. In 1928 and 1929, two large quarries were being operated along the Mississippi River in southern Calhoun County—Seifermann's in the NW¼NW¼ sec. 27, T. 13 S., R. 2 W., and Keller's, in the NE¼SW¼ sec. 6, T. 14 S., R. 1 W. These quarries were furnishing rock from the St. Louis limestone for use as riprap and shipping it by river barges. Other quarries in the St. Louis limestone and one in the Joachim dolomite, in the NE¼SE¼ sec. 19, T. 12 S., R. 2 W., formerly furnished rock for this same purpose, but are now abandoned. The bluff line or river front from Dogtown Landing to Calhoun Landing affords many quarry sites in the St. Louis limestone and the overburden of loess is no thicker than it is at similar quarry sites along the Mississippi and Missouri rivers near Alton, Ill.

Undeveloped uses to which many of the different beds of limestone in the Hardin and Brussels quadrangles might be put are as building stone, road materials, and ornamental stone, and for fluxes, burning, and cement. The Joachim and Edgewood dolomites and all the more massive limestones of the area can probably be worked into dimension stone suitable for construction. The dolomitized Edgewood has been quarried at Meppen and used locally for building. The Brassfield and Joliet limestones and the denser, less cherty parts of the Plattin, Chouteau, Burlington, St. Louis, and Pennsylvanian limestones would probably be satisfactory for road materials and concrete aggregate. (See Physical tests, below.)[76b] Specimens prepared for the writer show that the "fucoidal" beds of the Plattin limestone (pl. 4*B*), the coarsely crystalline "marble" of the Kimmswick and Burlington limestones, the Noix oolite, the green-flecked Brassfield limestone, the brecciated beds in the St. Louis limestone, and the dark, dense, fossiliferous Pennsylvanian limestone take a high polish and have a pleasing, unusual appearance; perhaps these rocks might make valuable ornamental stones for interior decoration. Limestones for fluxes and for making lime need to be nearly pure; hence the Kimmswick, Pennsylvanian, Burlington, Brassfield—in northern part of area where it is not dolomitized—Joliet, and St. Louis limestones, which contain more than 95 percent calcium carbonate (see Chemical Analyses, below), would be the most suitable. The Louisiana limestone has a dense, fine-grained texture similar to that of lithographic stone. Tests of samples collected in Missouri [77] have shown that some parts of the formation make "excellent slabs, large enough for small engravings," but the jointed structure of the rock makes it difficult to obtain large slabs.

TESTS OF LIMESTONES [78]

A sample of Joachim dolomite was collected from the 50-foot face of the abandoned quarry in the NE¼SE¼ sec. 19, T. 12 S., R. 2 W., Calhoun County, near the West Point Ferry landing, by J. E. Lamar, T. B. Root, Robert Gillson, and the writer.

[76a] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. Inv. no. 8, 1926.

[76b] For a discussion of the requirements and resources of stone in this general region see Buckley, E. R., and Buehler, H. A., The quarrying industry of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 2, 1904; and Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, 1925.

[77] Swallow, G. C., Lithographic limestone: Missouri Geol. Survey 2d Ann. Rept., pp. 169–170, 1855.

[78] Tests conducted at the Testing Laboratory of the State Highway Department of Illinois. For an explanation of the significance of the physical tests see Krey, Frank, and Lamar, J. E., Limestone resources of Illinois: Illinois Geol. Survey Bull. 46, p. 31, 1925.

Chemical analysis

Calcium oxide (CaO)	34.28
Magnesia (MgO)	16.39
Silica (SiO_2)	3.54
Alumina (Al_2O_3)	.60
Iron oxide (Fe_2O_3)	.94
Sulfuric anhydride (SO_3)	.14
Ignition loss	43.83
	99.72

A sample was collected from the basal half of the Plattin limestone near the abandoned quarry in the NE¼SE¼ sec. 19, T. 12 S., R. 2 W., Calhoun County.

Chemical analysis

Calcium oxide (CaO)	48.41
Magnesia (MgO)	5.35
Silica (SiO_2)	2.19
Alumina (Al_2O_3)	.72
Iron oxide (Fe_2O_3)	.46
Sulfuric anhydride (SO_3)	.26
Loss on ignition	43.01
	100.40

Physical tests

[Classification: Limestone, gray, argillaceous, hardness 4 (Moh's scale), crystalline, fine-grained, compact, hackly fracture]

Specific gravity	2.67
Weight (lbs. per cu. ft.)	167
Absorption:	
(Percent)	.8
(Lbs. per cu. ft.)	1.3
Wear (percent)	3.6

A sample was collected from 37 feet in the middle part of the Kimmswick limestone in the NW¼SE¼ sec. 17, T. 12 S., R. 2 W., Calhoun County.

Chemical analysis

Calcium oxide (CaO)	55.52
Magnesia (MgO)	.42
Silica (SiO_2)	.74
Alumina (Al_2O_3)	.28
Iron oxide (Fe_2O_3)	.62
Sulfuric anhydride (SO_3)	.10
Loss on ignition	42.67
	100.35

Physical tests

[Classification: Limetone, gray, hardness 3, crystalline and fossiliferous, medium-grained, compact, hackly fracture]

Specific gravity	2.53
Weight (lbs. per cu. ft.)	158
Absorption:	
Percent	1.3
Lbs. per cu. ft	2.1
Wear (percent)	6.8

A sample was collected from 12 feet of the Edgewood and 7 feet of the overlying Brassfield formation—at this locality lithologically indistinguishable from the Edgewood—from the abandoned quarry just north of Meppen, SE¼ sec. 23, T. 12 S., R. 2 W., Calhoun County, by T. B. Root and assistant.

Chemical analysis

Calcium oxide (CaO)	29.13
Magnesia (MgO)	19.27
Silica (SiO_2)	4.82
Alumina (Al_2O_3)	1.15
Iron oxide (Fe_2O_3)	1.71
Sulfuric anhydride (SO_3)	.10
Loss on ignition	43.99
	100.17

Physical tests

[Classification: Dolomitic limestone, yellow, argillaceous, hardness 3, noncrystalline, fine-grained, porous, hackly fracture]

Specific gravity	2.49
Weight (lbs. per cu. ft.)	155
Absorption:	
Percent	3.3
Lbs per cu. ft	5.1
Wear (percent)	4.3

A sample of Brassfield limestone was collected from SE¼NE¼ sec. 29, T. 8 N., R. 13 W., Jersey County.

Chemical analysis

Calcium oxide (CaO)	53.93
Magnesia (MgO)	.60
Silica (SiO_2)	2.10
Alumina (Al_2O_3)	.48
Iron oxide (Fe_2O_3)	.32
Sulfuric anhydride (SO_3)	.14
Ignition loss	42.70
	100.27

A sample was collected from the 16 feet of Joliet limestone and 6 feet of the immediately underlying Brassfield limestone in the creek bed in the southern part of Hamburg, in the NW¼SE¼ sec. 35, T. 9 S., R. 3 W., Calhoun County.

Chemical analysis

Calcium oxide (CaO)	53.36
Magnesia (MgO)	.42
Silica (SiO_2)	2.71
Alumina (Al_2O_3)	.38
Iron oxide (Fe_2O_3)	.62
Sulfuric anhydride (SO_3)	.15
Loss on ignition	41.82
	99.46

Physical tests

[Classification: Limestone, greenish-gray, argillaceous, hardness 4, crystalline, medium-grained, compact, hackly fracture]

Specific gravity	2.68
Weight (lbs. per cu. ft.)	167
Absorption:	
Percent	.7
Lbs. per cu. ft	1.2

A sample was collected from the upper 13 feet of the Cedar Valley limestone exposed along highways in the NE¼NE¼ sec. 29, T. 8 N., R. 13 W., Jersey County.

Chemical analysis

Calcium oxide (CaO)	49.57
Magnesia (MgO)	.50
Silica (SiO_2)	9.92
Alumina (Al_2O_3)	.54
Iron oxide (Fe_2O_3)	.46
Sulfuric anhydride (SO_3)	.12
Loss on ignition	39.23
	100.34

A sample was collected from the upper 15 feet of the Chouteau limestone in an abandoned quarry in the town of Hardin, center E½ sec. 27, T. 10 S., R. 2 W., Calhoun County.

Chemical analysis

Calcium oxide (CaO)	44.23
Magnesia (MgO)	1.31
Silica (SiO_2)	14.90
Alumina (Al_2O_3)	2.02
Iron oxide (Fe_2O_3)	1.24
Sulfuric anhydride (SO_3)	.12
Loss on ignition	36.28
	100.10

Physical tests

[Classification: Limestone, dark gray, hardness 3, crystalline, medium-grained, compact, hackly fracture]

Specific gravity	2.61
Weight (lbs. per cu. ft.)	163
Absorption:	
Percent	1.11
Lbs. per cu. ft	1.8
Wear (percent)	3.5

A sample was collected from lower 70 feet of the Burlington limestone exposed along road on Rocky Hill in SE¼SE¼ sec. 28, T. 10 S., R. 2 W., Calhoun County.

Chemical analysis

Calcium oxide (CaO)	53.79
Magnesia (MgO)	.73
Silica (SiO_2)	2.64
Alumina (Al_2O_3)	.14
Iron oxide (Fe_2O_3)	.46
Sulfuric anhydride (SO_3)	.19
Loss on ignition	42.17
	100.12

A sample of St. Louis limestone was collected from the 39 feet of rocks that underlie the hard massive bed in the quarry face in the NE¼SW¼ sec. 6, T. 14 S., R. 1 W., Calhoun County, by T. B. Root and assistant.

Chemical analysis

Calcium oxide (CaO)	53.21
Magnesia (MgO)	.59
Silica (SiO_2)	3.23
Alumina (Al_2O_3)	.44
Iron oxide (Fe_2O_3)	.62
Sulfuric anhydride (SO_3)	.10
Loss on ignition	41.98
	100.17

Physical tests

[Classification: Limestone, dark gray, hardness 4, crystalline, fine-grained, compact, hackly fracture]

Specific gravity	2.68
Weight (lbs. per cu. ft.)	167
Absorption:	
Percent	.6
Lbs. per cu. ft	1.0
Wear (percent)	3.4

A sample was collected to represent the 5½ feet of limestone in Carbondale formation and lower 2¼ feet of limestone at base of McLeansboro formation in the SW¼SW¼ sec. 14, T. 13 S., R. 2 W., Calhoun County.

Chemical analysis

Calcium oxide (CaO)	54.29
Magnesia (MgO)	.63
Silica (SiO_2)	1.53
Alumina (Al_2O_3)	.22
Iron oxide (Fe_2O_3)	.62
Sulfuric anhydride (SO_3)	.05
Loss on ignition	42.80
	100.14

Physical tests

[Classification: Limestone, dark gray, hardness 4, crystalline, medium-grained, compact, hackly fracture]

Specific gravity	2.71
Weight (lbs. per cu. ft.)	169
Absorption:	
Percent	.2
Lbs. per cu. ft	.3
Wear (percent)	3.3

A sample was collected from a tufa cone in the NW¼SE¼ sec. 28, T. 8 N., R. 13 W., Jersey County.

Chemical analysis

Calcium oxide (CaO)	48.04
Magnesia (MgO)	1.00
Silica (SiO_2)	8.64
Alumnia (Al_2O_3)	1.47
Iron oxide (Fe_2O_3)	1.24
Sulfuric anhydride (SO_3)	.12
Loss on ignition	39.32
	99.83

CEMENT MATERIALS

Raw portland cement is produced by burning and grinding a mixture of limestone and clay or shale in proportions so chosen that the mixture contains about 75 percent of calcium carbonate and the remainder is of claylike substances. Unless the exact proportions happen to be found together in one rock or at one quarry site, two or more different rocks must be chosen and mixed according to a formula. That is to say, the range of composition allowable in each rock constituent is very wide, provided that a suitable complementary constituent is available. For this reason, it is impossible to specify exactly which individual rocks are best suited for making cement. However, magnesia, sulfur, sand,

and chert are undesirable, and rocks that contain more than a very small amount of these impurities must be avoided.[79]

Many of the limestones in the Hardin and Brussels quadrangles—in particular, the Kimmswick, Brassfield, Joliet, Cedar Valley, St. Louis, and Pennsylvanian limestones, and possibly the Chouteau and Burlington limestones—are sufficiently free from impurities to furnish the calcium carbonate part of the cement. Similarly, analyses show that the Hannibal shale and parts of the Maquoketa and Carbondale shales are sufficiently pure to furnish the required aluminum silicate, and much of the loess and Pleistocene silts probably could be used also. There are thus adequate supplies of cement materials in the Hardin and Brussels quadrangles, and it is probable that these materials might be found available in the proper proportions in single quarries. However, no effort has yet been made to develop the cement industry in this area because these materials are also available nearer to the markets and at localities where transportation facilities are much better.[80]

CHEMICAL ANALYSIS OF SHALES[81]

A sample taken to represent the upper third of the Maquoketa shale in the NE¼SW¼ sec. 17, T. 11 S., R. 2 W., Calhoun County, was analyzed as follows:

Calcium oxide (CaO)	1.80
Magnesia (MgO)	2.81
Silica (SiO_2)	56.69
Alumina (Al_2O_3)	23.31
Iron oxide (Fe_2O_3)	6.05
Sulfuric anhydride (SO_3)	.14
Loss on ignition	7.92
	98.72

A sample was collected from upper 40 feet of Hannibal shale in the SW¼NW¼ sec. 31, T. 9 S., R. 2 W., and the SW¼NE¼ sec. 36, T. 9 S., R. 3 W., Calhoun County. Ceramic tests of this sample are given on page 160.

Calcium oxide (CaO)	1.35
Magnesia (MgO)	2.50
Silica (SiO_2)	69.20
Alumina (Al_2O_3)	15.38
Iron oxide (Fe_2O_3)	4.18
Sulfuric anhydride (SO_3)	.15
Loss on ignition	5.90
	98.66

A sample was collected from upper 30 feet of shale member of Carbondale formation in open pit at abandoned Golden Eagle or Winneberger brick plant in sec. 1, T. 14 S., R. 2 W., Calhoun County. Ceramic tests of this sample are given on page 161.

Calcium oxide (CaO)	1.05
Magnesia (MgO)	2.04
Silica (SiO_2)	58.04
Alumina (Al_2O_3)	24.40
Iron oxide (Fe_2O_3)	6.66
Sulfuric anhydride (SO_3)	.86
Loss on ignition	7.61
	100.66

CLAY AND SHALE

The beds of white Pennsylvanian fire clay in the Hardin and Brussels quadrangles were not being utilized at the time when field work for this report was done. Years ago, however, at one locality, a part of the extensive beds of southern Calhoun County were mined along with the coal and made into fire brick at the old brick plant at Winnberger or Golden Eagle.[82] The recent development of deposits of flint clay on the uplands near Belleview in northern Calhoun County and the discovery of small pockets of similar materials on the uplands in the Hardin quadrangle have again stimulated interest in the clay resources of the area.[83]

Tests made on samples of clay collected in the Hardin and Brussels quadrangles show that the flint clay and much of the fire clay are of an excellent quality for the manufacture of refractory ware and, with better transportation facilities, these clays could undoubtedly compete with the clays of similar age now being mined in St. Louis County, Mo., and near Carrollton and Whitehall, Ill.

CERAMIC TESTS[84]

A sample of fire clay from the Pottsville formation was collected from the SW¼SW¼ sec. 34, T. 12 S., R. 2 W., and was tested by the Department of Ceramic Engineering of the University of Illinois, as follows:

Raw clay

Reaction for carbonates		Small amount present
Color		Light buff
Working property		Fair; sticky
Drying conduct		Good
Shrinkage:		
Volume	percent	29.4
Linear	do	8.9
Water of plasticity	do	27.7
Shrinkage water	do	15.4
Pore water	do	12.3
Transverse strength tests of unburned clay:		
With 50 percent standard sand:		
Modulus of rupture	lbs. per sq. in.	312
Number of briquettes		9
Without sand:		
Modulus of rupture	lbs. per sq. in.	487

[79] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. Inv. no. 8, pp. 13–14, 1926.

[80] Buehler, H. A., The lime and cement resources of Missouri: Missouri Bur. Geology and Mines, 2d ser., vol. 6 [1908].

[81] Tests conducted at the Testing Laboratory of the State Highway Department.

[82] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 232, 1907.

[83] Lamar, J. E., Refractory clays in Calhoun and Pike Counties: Ill. Geol. Survey Rept. Inv. No. 22, pp. 7–43, 1931.

[84] For discussion of the significance of these types of tests see Parmalee, C. W., and Schroyer, C. R., Further investigations of Illinois fire clays: Illinois Geol. Survey Bull. 38, pp. 287–298, 1922.

Fineness test:

Mesh	Residue	
	Percent	Character
On:		
10	Trace	Small lime pebbles.
20	0.1	Do.
48	.1	Sandy.
100	.3	Do.
200	1.1	Do.

Through 200-mesh .... percent.. 98.4

Burning test:

Fired clay

Cone	Shrinkage			Porosity (percent)	Color after burning	Hardness
	Burning		Total linear (percent)			
	Linear (percent)	Volume (percent)				
2	7.6	21.0	16.5	19.5	Cream	Steel hard.
4	7.9	21.8	16.8	17.4	do	Do.
6	8.0	22.0	16.9	16.5	do	Do.
8	8.4	23.2	17.3	14.2	Slightly darker.	Do.
10	9.1	24.8	18.0	11.4	do	Do.
12	10.0	27.0	18.9	5.9	Gray	Do.
13	10.4	28.0	19.3	1.2	Rusty	Steel hard (fused lime spots).

Oxidation conduct .... Easily oxidized
Total soluble salts .... Vanadium
Fusion (deformation) test—pyrometric cone equivalent (P. C. E.) .... Cone 30
Warpage .... None.
Suggested uses: Light-colored face brick; conduit, refractories, refractory bond clay; terra cotta; quarry tile; roofing tile.
Remarks: Good burning range: cones 4–8, inclusive for light color.

Similar tests were made earlier [84a] on the fire clay formerly mined from below the coal at the old brick plant at Golden Eagle or Winneberger in sec. 1, T. 14 S., R. 2 W.

A sample of fire clay from the Pottsville formation on the uplands in the northern part of the Hardin quadrangle, SE¼SE¼ sec. 8, T. 10 S., R. 2 W., is of similar character, as shown below. Test was conducted by the Department of Ceramic Engineering of the University of Illinois.

Raw clay

Reaction for carbonates .... Present
Color .... Almost white
Working property .... Fair; sticky
Drying conduct .... Good
Shrinkage:
Volume .... percent.. 32.3
Linear .... do.... 9.8
Water of plasticity .... do.... 33.5
Shrinkage water .... do.... 17.8
Pore water .... do.... 15.7
Transverse strength tests of unburned clay:
With 50 percent standard sand:
Modulus of rupture .... lbs. per sq. in.. 406
Number of briquettes 10
Without sand: Modulus of rupture..lbs. per sq. in.. 694

[84a] Parmalee and Schroyer, op. cit., pp. 349–350. Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Ill. Geol. Survey Rept. 8 ,p. 18, 1926.

Fineness test:

Mesh	Residue	
	Percent	Character
On:		
10	0.5	Small lime pebbles.
20	.6	Do.
48	.8	Do.
100	.5	Sand and lime pebbles.
200	.5	Do.

Through 200-mesh 97.1

Burning test:

Fired clay

Cone	Shrinkage			Porosity (percent)	Color after burning	Hardness
	Burning		Total linear (percent)			
	Linear (percent)	Volume (percent)				
2	10.0	27.1	19.8	8.8	Light buff	
4	11.1	29.7	20.9	3.7	do	
6	11.9	31.1	21.7	.6	Buff	
10	12.0	31.8	21.8	.0	Gray	
12	10.9	29.3	20.7	.5	do	Fused lime spots.
13	9.3	25.4	19.1	3.8	do	Do.

Oxidation conduct .... Easily oxidized
Soluble sulfates .... None
Fusion (deformation) test—Pyrometric cone equivalent (P. C. E.) .... Cone 29
Warpage .... Warps a little; high shrinkage
Suggested uses: Aside from disadvantage of high shrinkage the clay should be an excellent stoneware material, refractory bond clay for terra-cotta face brick. Firing range for zero absorption and constant shrinkage, cones 6 to 10 or 12, inclusive. There is a change of color between 8 and 10, to gray.

A sample of flint clay from this same locality on the uplands, SE¼SE¼ sec. 8, T. 10 S., R. 2 W., was found to be a high-grade refractory clay. It was tested by the Department of Ceramic Engineering of the University of Illinois, as follows:

Raw clay

Reaction for carbonates .... None
Reaction for pyrite .... None
Color .... Silver gray
Hardness: Very hard for raw clay. Can be scratched with fingernail with some difficulty.
Working property: Works very well and easily after the first few minutes of wedging.
Drying conduct.... Can be dried very quickly without warping or cracking.
Shrinkage:
Volume .... percent.. 10.1
Linear .... do.... 2.5
Water of plasticity .... do.... 22.0
Shrinkage water .... do.... 5.5
Pore water .... do.... 16.5
Transverse strength tests of unburned clay:
Without sand:
Modulus of rupture .... lbs. per sq. in.. 78
Number of briquettes 15
Fineness test: Impossible to slake all the clay to obtain screen analysis. The clay is very fine grained; all clay that slakes passes the 200-mesh sieve.
Slaking test .... 6 minutes

Fired clay

Burning test:

Cone	Shrinkage—Burning		Porosity (percent)	Color after burning	Hardness
	Linear (percent)	Volume (percent)			
01	6.1	12.1	31.4	White	Not steel hard.
2	6.6	18.6	30.4	Cream	Do.
3					Do.
4	8.5	23.5	26.1	Cream	Steel hard.
6	9.3	25.3	23.9	do	Do.
8	9.7	26.4	22.1	do	Do.
10	11.0	29.5	18.8	do	Do.
12	11.8	31.3	16.8	Gray	Do.
14	13.0	34.2	14.2	do	Do.
16	13.6	35.5	12.3	do	Do.

Soluble sulfates — None
Warpage — None
Fusion (deformation) test—pyrometric cone equivalent (P. C. E.) — Cone 33–34
Suggested uses: The clay should be a valuable raw material for use in the manufacture of high-grade flint fire clay refractories. In refractoriness the clay is equal to the best of the Missouri smooth flints. The firing shrinkage of the clay is somewhat excessive, and this would probably necessitate the use of a large amount of calcined clay.

A sample of the fire-clay member of the Carbondale formation from an open pit at abandoned brick plant in sec. 1, T. 14 S., R. 2 W. was tested by the Department of Ceramic Engineering of the University of Illinois, as follows:

Raw clay

Reaction for pyrite — None
Color — Cream
Working property — Good
Drying conduct — Satisfactory
Shrinkage:
Volume — percent — 27.4
Linear — do — 9.3
Water of plasticity — do — 27.4
Shrinkage water — do — 15.8
Pore water — do — 11.6
Transverse strength tests of unburned clay — Not enough clay to test.

Fineness test:

Mesh	Residue	
	Percent	Character
On:		
10	0.0	
20	.0	
48	.1	Sandy.
100	Trace	
200	3.6	Sandy, micaceous.

Through 200-mesh — percent — 96.3

Fired clay

Burning test:

Cone	Shrinkage			Porosity (percent)	Color after burning	Hardness
	Burning		Total linear (percent)			
	Linear (percent)	Volume (percent)				
03	6.4	17.9	15.7	2.0	Light tan	Steel hard.
01	6.4	18.1	15.7	.6	Tan	Do.
2	6.6	18.4	15.9	.5	do	Do.
4	6.6	18.5	15.9	.8	Grayish tan	Do.
8	6.2	17.4	15.5	1.7	do	Do.
10				Flat		

Oxidation conduct — Easily oxidized
Soluble sulfates — None
Fusion (deformation) test—pyrometric cone equivalent (P. C. E.) — Cone 15
Warpage — None
Suggested uses: The clay has a long firing range and could be used for light-colored brick, terra cotta, quarry tile, and roofing tile. Overburned at cone 8.

The large quantities of the Maquoketa, Carbondale, and Hannibal shales available in the area are suitable for the manufacture of brick and tile, but their potential value is probably much less than that of the Pennsylvanian clays. Worthen[85] reports that clays were once quarried from the till and loess near Fieldon and made into coarse pottery.

A sample from the upper 40 feet of the Hannibal shale was collected in the SW¼NW¼ sec. 31, T. 9 S., R. 2 W., and was tested by the Department of Ceramic Engineering of the University of Illinois. (For a chemical analysis of this sample see p. 158.)

Raw clay

Reaction for carbonates — Present
Color — Green
Working property — Good
Conduct when flowing through a die — Satisfactory
Drying conduct — Very large amount of scum. No warping
Shrinkage:
Volume — percent — 21.1
Linear — do — 6.6
Water of plasticity — do — 23.5
Shrinkage water — do — 10.9
Pore water — do — 12.6
Transverse strength tests of unburned clay:
With 50 percent standard sand:
Modulus of rupture — lbs. per sq. in. — 357
Number of briquettes — 15

Fired clay

Burning test:

Cone	Shrinkage			Porosity (percent)	Color after burning	Hardness
	Burning		Total linear (percent)			
	Linear (percent)	Volume (percent)				
05	2.7	7.8	9.3	22.0	Light red	Nearly steel hard.
03	6.1	17.2	12.7	5.8	Reddish brown.	Steel hard.
01	4.9	14.0	11.5	1.2	Darker brown.	Do.
2	2.9	8.5	9.5	.3	Brown	Do.
4	(1)	(1)	(1)	(1)	(1)	(2).

1 Bloated very large: stuck in kiln.
2 Overfired.

Oxidation conduct — Oxidizes easily at low temperature
Soluble sulfates — Present
Warpage — None
Suggested uses: Face brick, paving tile, drain tile, quarry tile, and similar products. Overburned at cone 2.

A sample from the upper 30 feet of the shale member of the Carbondale formation was collected from an open

85 Worthen, A. H., Geology of Illinois; Jersey County: Illinois Geol. Survey, vol. 3, pp. 106–107, 119, 1868.

pit at abandoned brick plant sec. 1, T. 14 S., R 2 W., and was tested by the Department of Ceramic Engineering of the University of Illinois. (For a chemical analysis of this sample see p. 158.)

Raw clay

Reaction for carbonates — Present
Reaction for pyrite — None
Color — Light chocolate
Working property — Not very plastic
Conduct when flowing through a die — Satisfactory
Drying conduct — Small amount of scum. No warping
Shrinkage:
Volume — percent — 20.1
Linear — do — 6.3
Water of plasticity — do — 26.2
Shrinkage water — do — 10.8
Pore water — do — 15.4
Transverse strength tests of unburned clay:
With 50 percent standard sand:
Modulus of rupture — lbs. per sq. in. — 289
Number of briquettes — 12

Fired clay

Burning test:

Cone	Shrinkage			Porosity (percent)	Color after burning	Hardness
	Burning		Total linear (percent)			
	Linear (percent)	Volume (percent)				
05	8.3	22.8	14.6	12.3	Light red	Steel hard.
03	10.7	28.7	17.0	1.1	Reddish brown	Do.
01	10.6	28.5	16.9	.8	Good dark red	Do.
2	10.4	28.1	16.7	.4	do	Do.
4	9.6	23.6	15.9	.5	Very dark red	Do.

Oxidation conduct — Oxidizes easily at low temperature
Warpage — None
Soluble sulfates — Trace
Suggested uses: The shale burns to a good color and has an excellent firing range—cones 03 to 2, inclusive—and should be valuable for brick manufacture, paving brick, quarry tile, and roofing tile.

Preliminary burning tests by the Department of Ceramic Engineering indicate that the material represented by a sample of the upper third of the Maquoketa shale in the NE¼SW¼ sec. 17, T. 11 S., R. 2 W., could be used only for the manufacture of brick and tile.

COAL

Only one bed of workable coal is found within the Hardin and Brussels quadrangles, and it is somewhat thinner than most of the coal beds being mined in adjacent parts of Illinois and Missouri. This bed is the one that marks the contact between the Pottsville and Carbondale formations, and it is restricted to the area south of the Cap au Grés flexure. It appears to thicken southwestward and reaches its maximum thickness of 30 inches or slightly more near the Mississippi River in secs. 15, 22, and 27, T. 13 S., R. 2 W. Northward and eastward the coal bed thins and becomes interlaminated with partings of shale, and a short distance northeast of the divide between the Mississippi and Illinois Rivers it seems to consist of less than 1 foot of pure coal.

This coal bed has been prospected and actually mined from time to time at many places throughout that part of the area in which its thickness exceeds about 20 inches. But, although the coal is of good quality, the thinness of the bed and the inaccessibility of other than strictly local markets have discouraged any attempts at large-scale production. Many years ago [86] this coal was mined in sec. 1, T. 14 S., R. 2 W., and shipped by boat. Then for a time it was taken out along with the fire clay and shale at the same locality and used in the firing of bricks that were ferried or shipped by river. At the present time, however, neither brick plant nor coal mine is running. Despite the apparent failure of this attempt to mine the fire clay and coal together, it still appears that the best opportunity for commercial development of these two resources lies in working them jointly.

The coal bed doubtless continues eastward across the uplands of southern Calhoun County, and remnants of it may be expected here and there below the Brussels formation where it has not been removed by erosion. However, it is probably too thin to be of any commercial value in this eastern part of the area.

Analysis of coal sample

[Collected from an old prospect pit in the center SW¼NW¼ sec. 26, T. 13 S., R. 2 W. Analyzed in the chemical laboratory of the Illinois Geological Survey by A. K. Joshi]

	Air-dried sample	Sample as received	Moisture free	Moisture, ash, and sulfur free
Moisture	6.53	9.51		
Volatile matter	38.97	37.73	41.69	47.63
Fixed carbon	42.85	41.48	45.84	52.37
Ash	11.65	11.28	12.47	
Sulfur	7.52	7.28	8.05	
B. t. u.	11,766	11,391	12,588	14,841

Analyses published by earlier writers [87] show that the coal formerly mined in sec. 1, T. 14 S., R. 2 W., is of similar character. This mine, now abandoned, is the only large-scale development of the coal ever attempted in the region.

It is possible that small pockets of coal, similar to those in Lincoln County, Mo.,[88] may be found north of the Cap au Grès flexure on the uplands east and west of the Illinois River. Coal has in fact been reported from "somewhere along St. Andrew Ridge" in western Jersey County, but the writer was unable to verify this report.

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[86] Worthen, A. H., Geology and paleontology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, pp. 21–22, 1870.

[87] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, p. 21, 1870. Culver, H. E., Coal resources of District III: Illinois Geol. Survey, Coop. Min. Ser. Bull. 29, p. 23, 1925. Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Survey Rept. of Inv. no. 8, p. 19, 1926.

[88] Potter, W. B., Geology of Lincoln County: Missouri Geol. Survey, Prelim. Rept. Iron Ores and Coal Fields, pt. 2, pp. 263–281, 1873.

SAND AND GRAVEL

Deposits of sand and gravel occur at many places in the Hardin and Brussels quadrangles, but at only a few localities have these deposits been worked.

The St. Peter sandstone cropping out at Cap au Grès has at times been quarried and, according to local reports, shipped by barges to Alton for making glass and to Keokuk for use as a molding sand. At present this sandstone is not being utilized. Mechanical analyses of samples from this outcrop have been published by Lamar [89] and chemical analyses of samples from the St. Peter sandstone of Lincoln County, Mo., have been published by Potter.[90]

Other deposits of sand occur in the Pleistocene and Recent alluvium. The abandoned stream channel in secs. 21, 22, 27, and 28, T. 9 N., R. 13 W., Greene County, contains an immense volume of well-sorted sand (p. 121) that may some day be useful. In several valleys in southern Calhoun County, as in secs. 5, 16, and 21, T. 13 S., R. 2 W., the Brussels formation is made up largely of well-sorted sand (p. 83). For 6 or 7 miles northwest of Deer Plain, the Deer Plain terrace or, as it is known locally, the "Sand Ridge" consists of coarse, medium, and fine-grained sand (pp. 91–92 and fig. 6) which could very easily be dug for use.

TESTS OF MOLDING SAND [91]

Sample 1, from the Brussels formation, was collected in the NW¼SW¼NE¼ sec. 28, T. 9 N., R. 13 W. Sieve, particle, and heavy-mineral analyses of this sample are given on page 163.

	First trial	Second trial
Moisture ... percent	6	8
Cohesiveness ... grams per break	105	103
Permeability	107	90
Saeger compression ... pounds	1.4	1.0

This sand is relatively high in silica and appears to be a good quality core sand. If mixed with a sand having a higher cohesiveness, it would be a good quality for gray-iron casting.

Sample 16, from the Brussels formation, was collected in the NE¼NE¼SE¼ sec. 21, T. 13 S., R. 2 W. Sieve, particle, and heavy-mineral analyses of this sample are given on page 163.

	First trial	Second trial
Moisture ... percent	6	8
Cohesiveness ... grams per break	80	82
Permeability	212	154
Saeger compression ... pounds	1.0	1.0

This sand is relatively high in silica and appears to be a good quality core sand. If mixed with a sand having a higher cohesiveness, it would be a good quality for gray-iron casting.

Sample 9, from the Deer Plain formation, was collected in the NE¼NE¼ sec. 21, T. 13 S., R. 1 W. Sieve particle, and heavy-mineral analyses of this sample are given on pages 164–165.

	First trial	Second trial
Moisture ... percent	6	8
Cohesiveness ... grams per break	130	142
Permeability	13.0	11.6
Saeger compression ... pounds	3.5	3.0

This is an extremely fine sand that appears to be well suited to casting brass and aluminum.

In a few places along the bluffs immediately east of the Mississippi and Illinois Rivers the loess contains much fine-grained sand instead of the usual silt. At many places the Recent alluvium of the Mississippi flood plain and the bed of the river itself are made of sand (pp. 99–100), which might be obtained by dredging.

Large deposits of gravel are relatively uncommon within the area. The small remnants of Deer Plain gravel along the Mississippi River and the lower part of this formation near Deer Plain have been worked at intervals to supply local demands. (For sieve analysis and physical tests of a sample see p. 165.) Some of the gravel that has been concentrated in nearly every one of the small valleys of the area by the erosion of residual chert and glacial till have likewise been utilized from time to time. (For sieve analysis and physical tests of a sample see p. 165.) The remnant of the Brussels terrace in the NE¼ sec. 11, T. 7 N., R. 13 W., is made up largely of gravel and is readily accessible by road, but it seems never to have been worked. Small lenses of water-laid gravel that occur here and there within the Illinoian till may possibly be found useful for strictly local purposes. The gravel in the Batchtown channel is so deeply weathered at all its exposures and covered by so thick an overburden of loess everywhere that it seems unlikely it will ever be of any commercial value. Similarly, the Grover gravel occurs in remnants too thin and scattered and too much mixed with fine clay to be of use.

[89] Lamar, J. E., Preliminary report on the economic mineral resources of Calhoun County: Illinois Geol. Rept. Inv. no. 8, p. 20, 1926; Geology and economic resources of the St. Peter sandstone of Illinois: Illinois Geol. Survey Bull. 53, pp. 44–45, 166, 1928.

[90] Potter, W. B., Geology of Lincoln County: Mo. Geol. Survey, Prelim. Rept. Iron Ores and Coal Fields, pt. 2, p. 289, 1873.

[91] Tests conducted at the Laboratory of the Illinois State Geological Survey. For interpretation of molding sand tests, see American Foundryman's Association, Standard—methods of testing—foundry sands, pp. 5–26, July, 1928.

MECHANICAL ANALYSES, MINERAL CONSTITUENTS, AND PHYSICAL TESTS OF SAND AND GRAVEL

Sample 1 from the Brussels formation, was collected in the NW¼SW¼NE¼ sec. 28, T. 9 N., R. 13 W. Tests were conducted in the laboratory of the State Geological Survey by H. B. Willman. (For molding-sand test of this sample see p. 162.)

Sieve analysis [92]

[See fig. 6]

Diameter in millimeters	Percentage by weight between given diameters	Total percentage larger than each diameter
	0. 17	
0. 589		0. 17
	1. 63	
. 417		1. 80
	17. 12	
. 295		18. 92
	29. 78	
. 208		48. 70
	29. 92	
. 147		78. 62
	8. 10	
. 104		86. 72
	3. 22	
. 074		89. 94
	3. 12	
. 0039		93. 06
	6. 94	
	100. 00	

[92] Tyler standard screen scale sieves.

Particle analysis

[This test indicates the dominant types of rock or mineral particles composing the sand]

Constituents	Percentage of constituents between particle diameters (in millimeters) of—							
	0.589	0.417	0.295	0.208	0.147	0.104	0.074	0.0039
Quartz	60	65	92	93	95	93	92	100
Chert	21	21	6	4	1	1		
Quartzitic sandstone	16	13	2	3	4	3	1	
Muscovite	1							
Granite	2	1					6	
Black opaque grains				(1)	(1)	2	1	
Garnet						1	(1)	
	100	100	100	100	100	100	100	100

[1] Less than 1 percent.

Heavy-mineral analysis

[Grains between 0.833 and 0.0039 mm. in diameter]

	Milner's frequency [1] No.	Milner's descriptive term
Magnetite	8	Very abundant.
Garnet	7	Abundant.
Hornblende	6	Very common.
Ilmenite	6	Do.
Epidote	5	Common.
Kyanite	3	Very scarce.
Andalusite	3	Do.
Leucoxene	3	Do.
Tourmaline	2	Rare.
Rutile	1	Very rare.
Zircon	1	Do.

[1] Milner, H. B., An introduction to sedimentary petrography, p. 99, errata p. 9, 1922; Sedimentary petrography, p. 386, 1929.

Sample 16, from the Brussels formation, was collected in the NE¼NE¼SE¼ sec. 21, T. 13 S., R. 2 W. Tests were conducted in the laboratory of the State Geological Survey. (For molding-sand test of this sample, see p. 162.)

Sieve analysis

[See fig. 6]

Diameter in millimeters	Percentage by weight between given diameters	Total percentage larger than each diameter
	0. 62	
0. 589		0. 62
	5. 06	
. 417		5. 68
	30. 67	
. 295		36. 35
	43. 00	
. 208		79. 35
	16. 66	
. 147		96. 01
	. 83	
. 104		96. 84
	. 17	
. 074		97. 01
	. 20	
. 0039		97. 21
	2. 79	
	100. 00	

Particle analysis

Constituents	Percentage of constituents between particle diameters (in millimeters) of—							
	0.589	0.417	0.295	0.208	0.147	0.104	0.074	0.0039
Quartz	89	95	96	96	96	93	58	25?
Chert	9	5	4	4	4	3	9?	15?
Chalcedony	2	(1)	(1)	(1)	(1)			
Brown aggregates							30	60?
Black opaque grains						4	3	
	100	100	100	100	100	100	100	100

[1] Less than 1 percent.

Heavy-mineral analysis

[Grains between 0.833 mm. and 0.0039 mm. in diameter]

	Milner's frequency No.	Milner's descriptive term
Magnetite	6	Very common.
Garnet	6	Do.
Epidote	6	Do.
Hornblende	5	Common.
Kyanite	4	Scarce.
Tourmaline	4	Do.
Ilmenite	3	Very scarce.
Andalusite	3	Do.
Rutile	3	Do.
Zircon	1	Very rare.

Sample 8, from the Deer Plain formation, was collected in the NE¼SE¼ sec. 16, T. 13 S., R. 1 W. Tests were conducted in the laboratory of the State Geological Survey.

Sieve analysis

[See fig. 6]

Diameter in millimeters	Percentage by weight between given diameters	Total percentage larger than each diameter
	1.33	
53.3±		1.33
	1.93	
26.7±		3.26
	1.48	
18.8±		4.74
	2.32	
13.3±		7.06
	4.66	
6.68±		11.72
	4.80	
3.33		16.52
	10.00	
1.65		26.52
	21.85	
.833		48.37
	24.19	
.589		72.56
	16.28	
.417		88.84
	3.78	
.295		92.62
	4.20	
.208		96.82
	2.88	
.147		99.70
	.19	
.104		99.89
	.04	
.074		99.93
	.01	
.053		99.94
	.06	
	100.00	

Particle analysis

Constituents	Percentage of constituents between particle diameters (in millimeters) of—													
	53.3±	26.7±	18.8±	13.3±	6.68±	3.33	1.65	0.833	0.589	0.417	0.295	0.208	0.147	0.104
Greenstone	----	10	----	----	----	----	----	----	----	----	----	----	----	----
Igneous (dark)	----	----	----	8	18	9	5	15	10	8	4	3	2	----
Igneous (light)	----	----	13	11	15	20	26	11	9	2	2	0	----	----
Feldspar	----	----	----	----	----	2	2	----	----	----	----	----	----	----
Quartzite	----	10	4	2	----	----	1	----	----	----	----	----	----	----
Quartz	----	----	----	5	10	23	52	67	75	88	90	91	96	95
Chert (light)	----	40	27	34	23	25	8	6	4	1	2	4	1	----
Chert (dark)	100	40	48	32	30	21	6	1	2	1	2	2	1	----
Chalcedony	----	----	4	7	1	----	----	----	----	----	----	----	----	----
Geode	----	----	4	----	----	----	----	----	----	----	----	----	----	----
Shale	----	----	----	1	1	----	----	----	----	----	----	----	----	----
Limonite	----	----	----	----	2	----	----	----	----	----	----	----	----	----
Coal	----	----	----	----	(1)	----	----	----	----	----	----	----	----	----
Black opaque	----	----	----	----	----	----	----	----	----	----	----	----	----	3
Others	----	----	----	----	----	----	----	----	----	----	----	----	----	2
	100	100	100	100	100	100	100	100	100	100	100	100	100	100

[1] Less than 1 percent.

Heavy-mineral analysis

Grains between 0.833 mm. and 0.0039 mm. in diameter]

	Milner's frequency No.	Milner's descriptive term
Hornblende	9	"Flood."
Garnet	6	Very common.
Epidote	6	Do.
Leucoxene	5	Common.
Tourmaline	5	Do.
Hypersthene	5	Do.
Magnetite	4	Scarce.
Kyanite	4	Do.
Rutile	3	Very scarce.
Andalusite	3	Do.
Corundum	2	Rare.

Sample 9, from the Deer Plain formation, was collected in the NE¼NE¼ sec. 21, T. 13 S., R. 1 W. Tests were conducted in the laboratory of the State Geological Survey. (For molding sand tests of this sample, see p. 162.)

Sieve analysis

[See fig. 6]

Diameter in millimeters	Percentage by weight between given diameters	Total percentage larger than each diameter
	0.04	
0.417		0.04
	.05	
.295		.09
	.18	
.208		.27
	4.96	
.147		5.23
	12.61	
.104		17.84
	17.52	
.074		35.36
	56.05	
.0039		91.41
	8.59	
	100.00	

Particle analysis

Constituents	Percentage of constituents between particle diameters (in millimeters) of—					
	0.417	0.295	0.208	0.147	0.104	0.074
Quartz	80	69	35	78	80	85
Chert	3	10	47	18	2	------
Black, crystalline aggregates	11	14	14	3	5	------
White mica	2	2	1	------	------	(1)
Brown mica	------	3	3	1	2	1
Siltstone	2	1	------	------	------	------
Brown chalcedony	2	1	------	------	(1)	------
Black opaque	------	(1)	------	------	(1)	------
Yellow aggregates	------	------	------	------	11	14
	100	100	100	100	100	100

[1] Less than 1 percent.

Heavy-mineral analysis

[Grains between 0.833 mm. and 0.0039 mm. in diameter]

	Milner's frequency No.	Milner's descriptive term
Hornblende	9	"Flood."
Magnetite	8	Very abundant.
Garnet	6	Very common.
Ilmenite	5	Common.
Leucoxene	4	Scarce.
Tourmaline	4	Do.
Corundum	3	Very scarce.
Zircon	3	Do.
Kyanite	2	Rare.
Epidote	2	Do.
Muscovite	2	Do.
Biotite	2	Do.

Sample 10, from the Deer Plain formation, was collected in the SW¼NW¼ sec. 27, T. 13 S., R. 1 W. Tests were conducted in the Testing Laboratory of the State Highway Department.

Sieve analysis

[See fig. 6]

Diameter in millimeters	Percentage by weight between given diameters	Total percentage larger than each diameter
53. 3±		0
	4	
37. 7±		4
	17	
26. 7±		21
	11	
18. 8±		32
	8	
13. 3±		40
	7	
9. 42±		47
	9	
4. 76±		56
	7	
2. 38±		63
	8	
1. 19±		71
	5	
. 84±		76
	22	
. 297±		98
	1	
. 149±		99
	1	
	100	

Physical tests

Sand:
- Specific gravity — 2. 66
- Wear — percent — . 7

Gravel:
- Specific gravity — 2. 47
- Weight — lbs. per cu. ft — 154
- Wear — percent — 8. 2
- Absorption — do — 1. 6

Clay present in sand and gravel — do — 4. 9

Aggregate, pit-run sample: Weight — lbs. per cu. ft — 114. 0

Lithologic description.—The gravel is of mixed siliceous materials, some of it cemented, with small percentages of limonite and soft material, and traces of limestone and chert. The sand is mainly of mixed siliceous materials with a large percentage of quartz, some limestone, and traces of limonite ochre, chert, and soft material.

Sample 25, of Recent chert gravel from bed of North Prong of Michael Hollow, was collected in the SW¼ SE¼ sec. 28, T. 9 S., R. 2 W., by T. B. Root and assistant. Tests were conducted in the testing laboratory of the State Highway Department.

Sieve analysis

[See figure 6]

Diameter in millimeters	Percentage by weight between given diameters	Total percentage larger than each diameter
53. 3±		0
	18	
37. 7±		18
	15	
26. 7±		33
	20	
18. 8±		53
	16	
13. 3±		69
	12	
9. 42±		81
	12	
4. 76±		93
	4	
2. 38±		97
	1	
1. 19±		98
	1	
. 84±		99
	1	
. 297±		100
	100	

NOTE.—Two 3-inch rocks not included in sieve analysis.

Physical tests

Sand (not enough for testing).

Gravel:
- Specific gravity — 2. 18
- Weight — lbs. per cu. ft — 136
- Wear — percent — 13. 4
- Absorption — do — 5. 7

Clay present in gravel — do — 6. 3

Aggregate, pit-run sample: weight — lbs. per cu. ft — 88. 2

Lithologic description.—The gravel consists mainly of chert, with a small percent of soft sandstone and a trace of limestone. The sand consists of chert.

SOILS

No doubt the most valuable mineral resource of the area is its soil. Soil is made up largely of decayed rock; hence its composition and texture are greatly influenced by the character of the underlying rock, although other factors, such as the extent of weathering, percentage of admixed humus, and the ease of drainage, are equally important.

Broadly speaking, the important soils of the Hardin and Brussels quadrangles are of only two types: the wind-blown soils of the uplands and slopes and the alluvial soils of the lowlands and minor valleys. There are, it is true, small areas of purely residual and glacial soils and of bare-rock exposures, but compared with the two principal types these areas are quantitatively insignificant. The wind-blown soils derived from the weathering of the loess constitute the chief agricultural asset of the area. On hill slopes their open texture gives good drainage and this, together with their natural fertility, makes them excellently adapted to orchard husbandry. On flatter surfaces, such as the Brussels terrace, they have been found less satisfactory for this purpose, and they are used chiefly for the growing of cereals or grain. The alluvial soils developed from the weathering of Recent and late Pleistocene alluvial materials are for the most part very fertile, but much of the area in which they occur is poorly drained and subject to occasional overflow. The soils of the southern part of the area have been mapped by the Bureau of Soils, Department of Agriculture.[93]

OTHER MINERAL RESOURCES

Ground water.—Although some might question whether ground waters can properly be considered as part of the mineral resources of a region, there is little doubt that their study and search appropriately fall under Economic Geology. The question of water supply has thus far not been an important one in the Hardin and Brussels quadrangles. The area is not densely populated, springs are abundant in the limestone uplands, and in many of the towns cisterns have been adequate to supply domestic needs. On the Illinoian till plain near Fieldon, water is struck at the base of the till at depths of 25 to 50 feet.[94] Near Batchtown, water is found in the Kansan gravel at depths of 35 to 65 feet. On the Brussels terrace, small supplies of of water are found at the base of the Brussels formation at depths of 30 to 80 feet. Near Deer Plain, adequate supplies of water are found at shallow depths in the Deer Plain formation. Elsewhere, wells have obtained water from alluvial deposits and from sandy portions of the loess.

Throughout nearly all the region, a much larger supply of water is available in the St. Peter sandstone. This water may be obtained by drilling deep wells to this bed. In this general region water from this source commonly contains small amounts of dissolved salts, and the water might therefore be unsatisfactory for certain industrial purposes. The probable altitude of the top of the St. Peter sandstone in different parts of the area may be estimated from the structure-contour map (pl. 2) by subtracting from the altitude of the top of the Kinderhook group the interval 550 feet in the southern part of the area and 700 feet in the northern part.

In Salt Spring Hollow, in the SE¼SE¼ sec. 8, T. 11 S., R. 2 W., there is a flowing mineral spring. The water is strongly "sulfo-saline" and contains much gas that escapes in bubbles. The composition of the water and the gas is not known. According to local reports, salt was once prepared from this water. The spring rises through alluvial deposits, but its position is near the axis of the Gilead anticline and only a short distance above the Kimmswick limestone. It may possibly mark the position of a fault or a joint surface along which water escapes from the underlying St. Peter sandstone.

Oil and gas.—Prospects for oil and gas in the Hardin and Brussels quadrangles seem to be very poor. It is true that some oil and gas have been found relatively nearby to the north, northeast, east, and southeast—at the Colmar and Pittsfield-Hadley fields in Hancock and Pike Counties, at Carlinville and Staunton in Macoupin County, and at Waterloo and Dupo in Monroe and St. Clair Counties [95]—and that showings of oil and gas have been reported at a number of other places in west-central Illinois and in the city of St. Louis, Mo.[96] Nevertheless, all the horizons at which petroleum has been found in these adjacent regions come to the surface at one place or another within the Hardin and Brussels quadrangles, and at these exposures they do not contain oil or its weathered residuum, asphalt. Hence, it seems very improbable that in the parts of the area where these horizons happen not to be exposed they should contain commercial quantities of oil.

At a few places within the area, however, the structure of the rocks appears to be favorable for accumulation, were there any oil or gas to be trapped. The Gilead and Nutwood anticlines (pl. 2) seem to be the most promising of these structures but, because both extend into the alluvium-filled valleys of the rivers, their exact limits are difficult to determine.

A few unsuccessful attempts have been made to find oil within the area. About 1905, two wells were drilled in the SE¼ sec. 9, T. 6 N., R. 13 W., to a depth of approximately 1,100 feet. In 1907, a well was drilled in the NW¼ sec. 25, T. 7 N., R. 13 W., to a depth of about 1,000 feet. Other wells have been drilled near Grafton, Ill., and near Orchard Farm and St. Peters, Mo., without finding oil. A well drilled in 1922, to a depth of 300 feet at the Gilead Gun Club in sec. 36, T. 10 S., R. 3 W., was probably located near the axis of the Gilead anticline, but no traces of oil were reported.

[93] Fippin, E. O., and Drake, J. A., Soil survey of the O'Fallon area, Missouri-Illinois: U. S. Dept. Agr., Field operations of the Bur. Soils, 1904, pp. 815–843.

[94] Leverett, Frank, The Illinois glacial lobe: U. S. Geol. Survey Mon. 38, p. 747, 1899.

[95] Krey, Frank, Structural reconnaissance of the Mississippi Valley area from Old Monroe, Mo., to Nauvoo, Ill.: Illinois Geol. Survey Bull. 45, p. 54, 1924. Bell, A. H., The Dupo oil field: Illinois Geol. Survey, Press Bull. ser., Illinois Petrol. 17, pp. 1–14, 1929.

[96] Fenneman, N. M., Geology and mineral resources of the St. Louis quadrangle, Missouri-Illinois: U. S. Geol. Survey Bull. 438, pp. 58–63, 1911.

Oil shale.—The Decorah limestone is a chocolate-brown oil shale from 5 to 10 feet thick. Qualitative tests of one sample indicate that the rock carries from 15 to 25 gallons of crude oil to the ton (p. 18). Many more samples, systematically collected and tested, are needed before it will be possible to decide whether this oil shale has any commercial value.

Phosphate.—Weller [97] called attention to a thin bed of somewhat phosphatic rock at the base of the Edgewood limestone and suggested that it might possibly prove to be of economic importance. However, this bed is thin and apparently very limited in its distribution, and, although no sampling was done, its value appears rather doubtful. Small amounts of phosphatic rock were also noted at the base of the Maquoketa shale, in the Noix and "Hamburg" oolites, and in the Pennsylvanian limestones.

Metals.—The belief still persists from early times that important deposits of lead, zinc, and copper occur within the region and local names, such as Lead Hollow in Calhoun County and Cuivre River in Missouri, are permanent records of these traditions that have come down from the early settlers. The work on which this report is based found little to encourage such beliefs. It is true that the dolomitization of the Silurian limestones in the southern part of the area suggests a period of possible mineralization, but the exceedingly small quantities of sulfides actually found since the area was first settled and the disseminated mode of occurrence and apparently sedimentary origin seem to show clearly that no commercial ore deposits are to be expected.

Several different minerals have certainly been found in small quantities in and near the Hardin and Brussels quadrangles and several others have been reported. The writer found a few small crystals of sphalerite (pp. 31, 35–37) and nodules of pyrite in several of the formations and some beds of ferruginous material much too impure to be considered iron ore in the Maquoketa, Hannibal, and Carbondale shales. Worthen [98] and Potter [99] reported small crystals of galena within the region and Potter [1] found some barite in a sinkhole in central Lincoln County, Mo. According to local reports, copper has been found in two forms—as native copper in the Illinoian till and as the sulfide, chalcopyrite, in the Noix oolite—but these reports could not be confirmed.

COLLECTIONS OF FOSSILS

In the following pages are listed, by number, collections of fossils from the Hardin and Brussels quadrangles. These collections were made during the field work on which this report is based. The arrangement of the lists is approximately stratigraphic, from oldest to youngest.

[97] Weller, Stuart, Notes on the geology of southern Calhoun County: Illinois Geol. Survey Bull. 4, p. 233, 1907.

[98] Worthen, A. H., Geology of Illinois; Calhoun County: Illinois Geol. Survey, vol. 4, pp. 20–21, 1870.

[99] Potter, W. B., Geology of Lincoln County: Missouri Geol. Survey, Prelim. Rept. Iron Ores and Coal Fields, pt. 2, p. 285, 1873.

[1] Potter, W. B., op. cit., p. 282.

ORDOVICIAN SYSTEM

Collecting localities of Ordovician fossils

[Fossils identified by Dr. Edwin Kirk. Collections arranged approximately in stratigraphic order. Species arranged alphabetically in taxonomic groups]

Species	Plattin										Decorah			Kimmswick												Fern-vale		Maquoketa					
	4	5	I 3	26a	8a	86	26	I 39	89	174	173	2	8	88 and 175	3a	41	82	40	43	81	167 a and b	168	172	7 and 165	170k	170f	171f	171m	166 and I 71	38	25b	25a	25
Batostoma sp																								X									
Escharopora subrecta (Ulrich)																									cf.								
Hemiphragma sp										X																							
Homotrypa sp										X																							
Pachydictya aff. *fimbriata* Ulrich																X																	
Pachydictya occidentalis Ulrich																cf.																	
Prasopora sp											X																						
Pseudohornera (*Drymotrypa*) sp																X																	
Rhinidictya aff. *fidelis* (Ulrich)																X																	
Rhinidictya nicholsoni Ulrich										X																							
Rhinidictya aff. *pediculata* Ulrich										X																							
Receptaculites oweni Hall																			X														
Receptaculites sp																						X											
Columnaria sp														X																			
Streptelasma sp														X				X	X				X	X									
Tetradium syringoporoides			X																														
Crania setigera Hall																								cf.									
"*Dalmanella*" sp																											X			X			
Dinorthis pectinella (Emmons)										X																							
Dinorthis sp													X																				
Glyptorthis insculpta (Hall)																										X							
Leptobolus occidentalis Hall																														X			
Lingula changi Hussey																														cf.			
Lingula whitfieldi Ulrich																															cf.	cf.	cf.
Parastrophia scofieldi (Winchell and Schuchert)																						cf.											
Pionodema subaequata (Conrad)									X	X		X	X																				
Platystrophia trentonensis McEwen																			X			X	X	X									
Platystrophia sp																									X								
Platystrophia (fragment)																																	X
Plaesiomys subquadrata (Hall)																										cf.							
Rafinesquina deltoidea (Conrad)																	X		X			X	X	X	X								

Collecting localities of Ordovician fossils—Continued

Species	Plattin										Decorah			Kimmswick												Fern-vale		Maquoketa					
	4	5	I 3	26a	8a	86	26	I 39	89	174	173	2	8	88 and 175	3a	41	82	40	43	81	167 a and b	168	172	7 and 165	170k	170f	171f	171m	166 and I 71	38	25b	25a	25
Rafinesquina jeffersonensis Bradley																	X	X			X			X									
Rafinesquina sp		X					X		X	X	X			X																			
Resserella rogata (Sardeson)														cf.	cf.				cf.			cf.	cf.		cf.								
Rhynchotrema increbescens Hall																				cf.	cf.	cf.	cf.										
Rhynchotrema sp											X																						
Sowerbyella sericea (Sowerby)														X	X		X			X	X	X	X	X	X								
Sowerbyella sp																											X						
Strophomena incurvata (Shepard)																	cf.	cf.					cf.	cf.	cf.								
Strophomena sp	X	X					X			X		X	X														X						
Zygospira deflecta										cf.																							
Zygospira nicolleti Winchell and Schuchert													X																				
Zygospira recurvirostra (Hall)		cf.					cf.		cf.		cf.																						
Bellerophon sp																			X					X					X			X	
Coleolus iowensis James																													X				
Conularia sp																														X			
Cyrtolites conradi Hall																													X				
Cyrtolites sp										X			X																				
Gastropods, indeterminable					X	X																											
Helicotoma sp				?									X																				
Hormotoma gracilis (Hall)																																	X
Hormotoma gracilis var. *angustata* Hall										X	X																						
Hormotoma? major Hall																								X									
Hormotoma sp													X																X				
Liospira micula (Hall)																																	X
Liospira sp	X								X		X													X									
Lophospira sp											X		X															X					
Maclurites sp																								X									
"*Pleurotomaria*" sp																													X				
Pterotheca triangularis Bradley																					X												
Sinuites sp																					X												
Tetranota obsoleta Ulrich and Schofield																					X												
Trochonema sp																					X												
Cleidophorus neglectus Hall																													X				X
Ctenodonta fecunda Hall																																cf.	X
Ctenodonta obliqua (Hall)																																	cf.
Ctenodonta sp																												X	X		X		
Cyrtodonta sp						X															X												
Endodesma sp												X																					
Modiodesma sp																												X					
Rhytimya sp																																	X
Vanuxemia sp																					X												
Cyrtocerina sp																												X					
Kionoceras sp																																	X
Michelinoceras? sociale Hall																												X	X	X			X
Spyroceras sp					X																												
Aparchites sp																X																	
Beyrichia sp																																X	
Ceratopsis robusta (Ulrich)																														X			
Leperditia sp	X	X				X																											
Acrolichas sp																								X									
Ampyxina bellulata Savage																														X			
Bathyurus aff. *spiniger* (Hall)												X																					
Bathyurus sp	X									X																							
Brachyaspis susae (Whitfield)																																cf.	cf.
Calliops callicephala (Hall)																			cf.		cf.												
Calymene sp																								X								X	
Ceraurinus platycanthus Bradley																						X											
Ceraurinus tenisculptus Bradley																							X										
Ceraurus globulobatus Bradley																									cf.								
Ceraurus plattinensis Foerste													X																				
Ceraurus sp														X																			
Encrinurus trentonensis Walcott																								cf.									
Illaenus americanus (Billings)																	X	X	X	X	cf.	X	X	X	X								
Illaenus sp								X			X																						
Isoteloides sp																				X													
Isotelus sp												X													X								
Pterygometopus sp										X																							
Remopleurides sp																								X									
Thaleops ovata Conrad																								X									
Vogdesia sp																														X			

Plattin limestone:

4. From 3 to 7 feet above base of formation, near east quarter corner sec. 19, T. 12 S., R. 2 W.

5. 4 feet above base of formation, in center NW¼ sec. 29, T. 12 S., R. 2 W.

I 3. Lower part of formation, in north center NW¼ sec. 29, T. 12 S., R. 2 W. (See pl. 4*B*.)

26a. Exact horizon unknown. In NW¼SW¼ sec. 17, T. 12 S., R. 2 W.

8a. Exact horizon unknown. In SE¼SE¼ sec. 7, T. 12 S., R. 2 W.

86. Probably about middle of formation, in NE¼NW¼ sec. 32, T. 12 S., R. 2 W.

26. About 40 feet below top of the formation, in SE¼NE¼ sec. 7, T. 12 S., R. 2 W.

Plattin limestone—Continued

I 39. Thin limestone conglomerate about 40 feet below top of formation, in NE¼SW¼ sec. 20, T. 12 S., R. 2 W.

89. About 10 feet below top of formation, in NW¼NE¼ sec. 32, T. 12 S., R. 2 W.

174. 5 feet below top of formation, in center NE¼ sec. 32, T. 12 S., R. 2 W.

Decorah limestone:

173. From basal foot of formation, 5 feet above Coll. 174, in center NE¼ sec. 32, T. 12 S., R. 2 W.

2. 4 feet below top of formation, in SE¼NE¼ sec. 19, T. 12 S., R. 2 W.

8. 1 foot below top of formation, in SE¼NE¼ sec. 6, T. 12 S., R. 2 W.

Kimmswick limestone:

88 and 175. From basal foot of formation, in NE¼NE¼ sec. 32, T. 12 S., R. 2 W.

3a. Lower or middle part of formation, in NE¼SW¼ sec. 17, T. 12 S., R. 2 W.

41. Probably from near middle of formation, in SE¼SE¼ sec. 31, T. 11 S., R. 2 W.

82. 20 to 25 feet below top of formation, in NW¼SE¼ sec. 5, T. 12 S., R. 2 W.

40. Probably about 10 or 20 feet below top of formation, in center NW¼ sec. 32, T. 11 S., R. 2 W.

43. Probably from uppermost 20 feet of formation, in south center SE¼ sec. 32, T. 11 S., R 2 W.

81. From 1 to 2 feet below top of formation, in NE¼NE¼ sec. 5, T. 12 S., R. 2 W.

167a and 167b. ½ foot and 3 feet below top of formation. Faunas alike and therefore combined. In north center SE¼ sec. 5, T. 12 S., R. 2 W.

168. From ½ to 1 foot below top of formation, in SE¼SE¼ sec. 8, T. 12 S., R. 2 W.

172. Uppermost 6 inches of formation, in NW¼SW¼ sec. 28, T. 12 S., R. 2 W.

7 and 165. Uppermost 4 inches of formation, in NW¼ NW¼ sec. 32, T. 11 S., R. 2 W.

170k. Uppermost 8 inches of formation, in SE¼NE¼SE¼ sec. 17, T. 12 S., R. 2 W.

Fernvale limestone (possible remnants):

170f. Two species on or in the eroded upper surface of the limestone at the exact locality and bed where Coll. 170k was made.

171f. Same locality and bed as Coll. 171m. These genera were found in fragments of weathered chert in same bed with forms characteristic of the Maquoketa shale, Coll. 171m.

Maquoketa shale:

171m. Basal few inches of formation. A zone of weathered chert from 2 to 6 inches thick that lies unconformably upon Kimmswick limestone, Coll. 170k, and is separated from overlying shale by a sharp contact. Forms listed here were found in fragments of weathered chert along with genera not characteristic of the Maquoketa shale, Coll. 171f. In SE¼NE¼-SE¼ sec. 17, T. 12 S., R. 2 W.

166 and I 71. Granular phosphatic bed, 4 feet above base of formation, in NE¼NE¼ sec. 5, T. 12 S., R. 2 W.

38. 6 feet above base of formation, in SW¼SW¼ sec. 29, T. 11 S., R. 2 W.

25b. Probably 25 to 35 feet above base of formation, in NE¼NW¼ sec. 8, T. 11 S., R. 2 W.

25a. About 60 or 75 feet above base of formation, in same locality as Coll. 25.

25. About 85 or 100 feet above base of formation, in NE¼-SW¼ sec. 20, T. 11 S., R. 2 W.

SILURIAN SYSTEM

Collecting localities of Silurian fossils

[Fossils identified by T. E. Savage. Names revised, without review of identifications, by J. M. Berdan in consultation with G. A. Cooper, J. B. Knight, and Helen Duncan. Collections arranged in approximate stratigraphic order]

	Edgewood															Brassfield												Joliet	
	Noix oolite member				Bowling Green(?) limestone member																								
	71	72	18a	19	70	83	182	159	154	33	152	69	6	46 and 155	108	160	156	158	146	147a and b	148	149	151	157	153	52	68 and 163	161	162
Lyellia thebensis							X						X									cf.							
Zaphrentis sp				X	X					X				X															
Zaphrentis sp. small									X		X			X			X		X	X				X					
Cornulites sp					X																								
Crinoid segments																				X									
Rhinopora near *R. verrucosa* Hall																							X						
Bryzoa impressions								X	X												X								X
Atrypa sp																	X		X		X						X		
Atrypa? putilla (Hall and Clarke)						X																							
Atrypa recticularis (Linnaeus)																													X
Cliftonia tubulistriata (Savage)	X																												
Clorinda transversa																											X		
Dalmanella edgewoodensis (Savage)					X			X	cf.		X			cf.															
Dalmanella sp					X																				X				
Dolerorthis flabellites (Foerste) var			X		X																								
Dolerorthis flabellites (Foerste)				X				X	X	X				X	cf.		X				X			X					
Eospirifer radiatus (Sowerby)																													X
Fardenia curvistriata (Savage)					cf.																								
Hebertella sp. small									X					X			X		X	X				X	X				
Hebertella sp					X						X			X															
Leptaena rhomboidalis					X						X																		
Parmorthis elegantula (Dalman)																	X	X			cf.								
Pentamerus laevis Sowerby																											X		
Platymerella manniensis Foerste																X	X	X	X	X									
Playstrophia daytonensis				cf.	X				X					X							X		X						
Plectodonta transversalis (Wahlenberg)					cf.			cf.	cf.					cf.			cf.	cf.	cf.	cf.	cf.			cf.					
Plectambonites sp					X					X		X														X	X		
Plectatrypa cf. *P. praemarginalis* (Savage)					X				X					X															
Plectatrypa praemarginalis (Savage)					X			X						X															
Rhynchotreta sp					X	X																							
Schuchertella sp	X	X							X		X					X													
Stricklandinia pyriformis																											X		
Stricklandinia sp																											X		
Whitfieldella sp																				X									
Pterinea sp					X																	cf.							
Cyclonema sp																											X		
Hormotoma tenera					X	cf.																							
Platyceras (Platyostoma) cornutum (Kindle and Breger)											X												X						
Tentaculites sp								X																					
"*Orthoceras*" sp																													X
"*Orthoceras*" sp																											X		X
Calymene niagarensis Hall																			X		X								
Calymene sp					X				X																				
Cyphaspis intermedia Weller					cf.																								
Cyphaspis sp																										X			
Dalmanites sp																													X
Encrinurus sp					X				X		X														X				
Illaenus sp																							X					X	X
Proetus sp									X					X						X									

Noix oolite member of Edgewood limestone:

71. Lower 2 feet of formation, in SW¼NE¼ sec. 13, T. 10 S., R. 3 W.
72. Lower 2 feet of formation, in NW¼NE¼ sec. 13, T. 10 S., R. 3 W.
18a. Lower 2 feet of formation, in NW¼SW¼ sec. 18, T. 10 S., R. 2 W.
19. Lower foot of formation, SW¼NE¼ sec. 32, T. 10 S., R. 2 W.

Bowling Green(?) limestone member of Edgewood limestone:

70. Lower few feet of formation, about 40 feet below top, in north center SW¼ sec. 21, T. 7 N., R. 13 W.
83. Lower foot of formation, 35 to 40 feet below top, in NW¼SE¼ sec. 9, T. 12 S., R. 2 W.
182. About 10 feet below top of formation—11 feet below Coll. 158—in center SE¼ sec. 23, T. 12 S., R. 2 W.
159. Float. Center SE¼ sec. 23, T. 12 S., R. 2 W.
154. 12 feet below top of formation, in NE¼SW¼ sec. 35, T. 11 S., R. 2 W.
33. About 10 feet below top of formation, in NW¼NE¼ sec. 26, T. 12 S., R. 2 W.
152. 6 feet above upper of two unconformities within formation and about 13 feet below top of formation, in south center sec. 28, T. 7 N., R. 13 W.

Bowling Green(?) limestone member of Edgewood limestone—Continued

69. In upper 15 feet of formation, in NW¼SW¼ sec. 33, T. 8 N., R. 13 W.
6. About 3 feet below top of formation, in NE¼ sec. 13, T. 10 S., R. 3 W.
46 and 155. 1 foot below top of formation and 11 feet above Coll. 154. In NE¼SW¼ sec. 35, T. 11 S., R. 2 W.
108. Probably from uppermost part of formation, in NW¼-SE¼ sec. 9, T. 6 N., R. 13 W.

Brassfield limestone:

160. *Platymerella* zone, a few inches above unconformity at base of formation, in SW¼SW¼ sec. 18, T. 10 S., R. 2 W.
156. Dolomitized. *Platymerella* zone, 3 feet above a wavy bedding plane that may mark the base of the formation. NW¼SE¼ sec. 11, T. 12 S., R. 2 W.
158. Dolomitized. *Platymerella* zone, 7 feet below top of formation, in center SE¼ sec. 23, T. 12 S., R. 2 W.
146. Dolomitized. *Platymerella* zone, in NW¼NW¼ sec. 21, T. 7 N., R. 13 W.
147 a and b. Dolomitized. *Platymerella* zone, in NE¼SE¼ sec. 17, T. 7 N., R. 13 W.

Brassfield limestone—Continued

148. Dolomitized. 6 feet above *Platymerella* zone (Colls. 147 a and b), in NE¼SE¼ sec. 17, T. 7 N., R. 13 W.

149. Dolomitized. 8 feet above Coll. 148 and 3 feet below sandstone, in NE¼SE¼ sec. 17, T. 7 N., R. 13 W.

151. 3 feet above sandstone, 1½ feet below top of formation and 6 feet above Coll. 149, in NE¼SE¼ sec. 17, T. 7 N., R. 13 W.

157. Dolomitized. 8 feet above *Platymerella* zone (Coll. 156) and in upper few inches of formation, in NW¼SE¼ sec. 11, T. 12 S., R. 2 W.

153. Dolomitized. 4 feet below top of formation, in SE¼-SE¼ sec. 15, T. 11 S., R. 2 W.

Brassfield limestone—Continued

52. In upper 3 feet of formation, in NW¼SW¼ sec. 27, T. 10 S., R. 2 W.

68 and 163. 1½ feet below prominent bedding plane that may mark top of formation, in NW¼SE¼ sec. 35, T. 9 S., R. 3 W.

Joliet limestone:

161. 6 feet above prominent bedding plane that may mark base of formation and 10 feet below top of formation (7½ feet above Colls. 68 and 163), in NW¼SE¼ sec. 35, T. 9 S., R. 3 W.

162. 8 feet above Coll. 161 and 2 feet below top of formation, in NW¼SE¼ sec. 35, T. 9 S., R. 3 W.

DEVONIAN SYSTEM

Collecting localities of Devonian fossils

[Fossils identified by T. E. Savage. Names revised, without review of identifications, by J. M. Berdan in consultation with G. A. Cooper, J. B. Knight, and Helen Duncan. Collections arranged in approximately stratigraphic order]

	Cedar Valley																				
	34	23 and 23a	37 and 37a	50	81a	36	47a	20	21	22	51	51a	51b	18	11	80	84	106	29	28	137
Aulacophyllum sp														X							
Cyathophyllum sp			X																		
Cystiphylloides americanum (Edwards and Haime)			X																		
Cystiphyllum sp		X	X					X													
Heliophyllum near *H. halli* Edwards and Haime			X																		
Hexagonaria "davidsoni" (Edwards and Haime)					X																
Striatopora sp									X												
Zaphrentis sp										X				X					X	X	
Melocrinus sp																	X				
Sulcoretepora sp	cf.											X									
Athyris fultonensis (Swallow)																				X	
Atrypa reticularis (Linnaeus)					X	X			X	X		X	X	X				X	X	X	X
Chonetes sp														X							X
Cranaena iowensis (Calvin)	X																			X	
Cranaena sp			X																	X	
Cyrtina umbonata (Hall)													X	X					cf.		X
Cyrtina sp						X															
Elytha subundifera (Meek and Worthen)											X				X					X	
Hystricina hystrix (Hall)					X			X				X									
Pentamerella arata (Conrad)			cf.				cf.														
Pholidostrophia iowensis (Owen)									X			X	X	X							
Platyrachella euryteines (Owen)					X	cf.						X		cf.					cf.	X	
Platyrachella iowensis (Owen)		X		X			X	X													cf.
Schizophoria iowensis (Hall)			cf.		X			X			X	X				X				X	
Schuchertella sp		X																			
"Spirifer" sp																				X	
Stropheodonta demissa									X	X	X	X		X						cf.	cf.
Stropheodonta sp													X							X	X
Tylothyris subvaricosa (Hall and Whitfield)					X									X						cf.	X

Cedar Valley limestone:

34. About 35 feet below top of formation, in SE¼NE¼ sec. 20, T. 11 S., R. 2 W.

23 and 23a. About 25 feet below top of formation, in SE¼NW¼ sec. 17, T. 11 S., R. 2 W.

37 and 37a. Lower or middle part of formation, in NE¼SW¼ sec. 29, T. 11 S., R. 2 W.

50. Probably in lower part of formation, in center NW¼ sec. 27, T. 10 S., R. 2 W.

81a. 10 feet below top of formation, in NE¼SW¼ sec. 27, T. 11 S., R. 2 W.

36. Probably in upper part of formation, in SW¼NE¼ sec. 29, T. 11 S., R. 2 W.

47a. In upper 8 or 10 feet of formation, in NE¼SW¼ sec. 35, T. 11 S., R. 2 W.

20. 11 or 12 feet below top of formation, in SW¼NE¼ sec. 32, T. 10 S., R. 2 W.

21. 2 feet below top of formation and 9 feet above Coll. 20, in SE¼NE¼ sec. 32, T. 10 S., R. 2 W.

22. Upper 1 foot of formation and 1 foot above Coll. 21, in SE¼NE¼ sec. 32, T. 10 S. R. 2 W.

51. 8 feet below top of formation, in SW¼SW¼ sec. 23, T. 10 S., R. 2 W.

Cedar Valley limestone—Continued

51a. 2 feet below top of formation and 6 feet above Coll. 51, in SW¼SW¼ sec. 23, T. 10 S., R. 2 W.

51b. Upper few inches of formation and 2 feet above Coll. 51a, in SW¼SW¼ sec. 23, T. 10 S., R. 2 W.

18. Upper 3 feet of formation, in NW¼SW¼ sec. 18, T. 10 S., R. 2 W.

11. In upper 2 or 3 feet of formation, in SW¼NW¼ sec. 20, T. 10 S., R. 2 W.

80. 2 or 3 feet below top of formation, in NW¼SE¼ sec. 27, T. 11 S., R. 2 W.

84. Upper 2 or 3 feet of formation, in SE¼SW¼ sec. 14, T. 12 S., R. 2 W.

106. In upper 3 feet of formation, in SW¼SE¼ sec. 11, T. 6 N., R. 13 W.

29. 2 feet below top of formation, in north center sec. 16, T. 11 S., R. 2 W.

28. Sandstone at top of Cedar Valley limestone. Upper 1½ feet of formation and 1 foot above Coll. 29, in north center sec. 16, T. 11 S., R. 2 W.

137. Sandstone at top of Cedar Valley limestone. Upper 2 feet of formation, in NW¼SW¼ sec. 28, T. 8 N., R. 13 W.

Collecting localities of Carboniferous (Mississippian) fossils

[Fossils determined by Dr. J. M. Weller.[1] Collections arranged in approximately stratigraphic order]

	Louisiana							Glen Park		Han-ni-bal	Chouteau									Se-dalia	Sedalia (?)				Burlington														Keokuk						Spergen			St. Louis												
	73	10	9	15	58	58a	49	55	66	181	79	107	16	47	53b	85	45a	87 and 114	115	116	48	13	57	64	53	53a	17	1	164	117	99	118	119	113	141	140b	142	133	123	136	135	134	102	124	92	91	103	194	184a	184b	3	193	192	109	110	111	112	93	104	105
"Zaphrentis" carinata Worthen																									?																																					
"Zaphrentis" cassedayi Milne-Edwards																																																					?								
"Zaphrentis" cliffordana Milne-Edwards and Haime																					X																																								
"Zaphrentis" tenella Miller											?			X				?																																										
"Zaphrentis" sp.																																X		X				X		X																				
Triplophyllidium dalei (Milne-Edwards and Haime)																																		X																											
Triplophyllidium pellaensis (Worthen)																																																					?								
Lithostrotionella proliferum (Hall)																																																	X	X		X			X	X				
Monilopora sp.																		X																																										
Syringopora sp.																																																								X	X			
Schizoblastus sayi (Shumard)																																		X																										
Orbitremites calcycinus (Rowley)																														?																														
Eutrochocrinus aff. E. planodiscus (Hall)																												X																																
Agaricocrinus sp.																														X																														
Platycrinus scrobinus Meek and Worthen																												cf.																																
Crinoid stems, plates		X	X											X				X		X							X			X	X	X		X		X		X	X			X		X											X					
Archaeocidaris plates																																																								X				
Stenopora sp.																																																		?										
Fenestella multispinosa Ulrich																																															?													
Fenestella serratula Ulrich																																																		X										
Fenestella tenax Ulrich																																																X		X										
Fenestella 1 or more sp.												X						X																		X							X	X	X	X									X				X	X
Fenestellid impressions										X																																																		
Hemitrypa sp.																																														X														
Archimedipora owenanus (Hall)																																										X																		
Lyropora sp.																																											?																	
Polypora varsoviensis Prout																																																X												
Polypora sp.																																																		X										
Rhombopora sp.											X																																							X		X								
Cystodictya lineata Ulrich																																	X						X				X			X				X		X							X	X
Cystodictya ocellata Ulrich																															X																													
Cystodictya pustulosa Ulrich																																	X																											
Cystodictya sp.																						?															?																							
Dichotrypa intermedia Ulrich																																																X				X								
Bryozoa unidentified, several sp.																		X																																										
Lingula sp.				X																																																							
Glossina sp.					X																																																						
Orbiculoidea sampsoni (Miller)																		X																																										
Leptaena analoga (Phillips)														X				X				X	X																																					
Leptaena sp.																		X																																										
Schuchertella lens (White)			X		X	X	X		?	?																																																		
Schuchertella sp.																		?																																										
Streptorhynchus ruginosum (Hall and Clarke)		?																																																								?		
Streptorhynchus sp.																																																		?										
Orthotetes kaskaskiensis (McChesney)																																																X							?			?		
Orthotetes keokuk (Hall)																										?																																	
Chonetes glenparkensis Weller																		X																																										
Chonetes illinoisensis Worthen																															X	X																												
Chonetes logani Norwood and Pratten			?																																																									
Chonetes multicosta Winchell																				X																																							
Chonetes ornatus Shumard		X		?		?																																																					
Chonetes sp.																								X																																			
Avonia concentrica (Hall)				X															X																																								
Productella pixidata (Hall)		X					X																																																				
Productella sp.																		X																																										
Linoproductus altonensis (Norwood and Pratten)																																													?	?	X													
Avonia blairi (Miller)																			X																																									
Dictyoclostus burlingtonensis (Hall)																						?										?																												
Dictyoclostus aff. D. burlingtonensis (Hall)																								X																								X												
Avonia (?) aff. A. indianensis (Hall)																			X																																									
Linoproductus ovatus (Hall)																																																		X	X							X		
Productina parvula (Winchell)										?			?																																														
Buxtonia setigerus (Hall)																				X																			?																					
Linoproductus tenuicostus (Hall)																																																												?
Marginicinctus wortheni (Hall)																																																		X										
Productids, 1 or more																		X			X													X		X			X	X				X							X								X	
Echinoconcha alternata (Norwood and Pratten)																																							X				X																	
Echinoconcha biseriata (Hall)																																														X	X													
Rhipidomella burlingtonensis (Hall)																				X	X	?																																						
Rhipidomella missouriensis (Swallow)			X																																																								
Rhipidomella tenuicosta Weller											cf.			cf.																																													
Rhipidomella sp.																											X											X																					
Schizophoria chouteauensis Weller											?		X																																													
Schizophoria swallovi (Hall)																									X	X										?	?																							
Camarophoria bisinuata (Rowley)																		cf.																																										
Camarophoria hamburgensis Weller									X																																																			
Camarotoechia chouteauensis Weller								X	X									X																																										
Camarotoechia mutata (Hall)																																														X													
Camarotoechia sp.																			X																																									
Shumardella missouriensis (Shumard)																		X	X																																									
Shumardella sp.														X																																													
Rhynchopora cooperensis (Shumard)																				?																																							
Dielasma fernglenense Weller																				X																																							
Dielasma osceolense Weller																																					?																						
Dielasma sp.																		X	X																											X													
Spiriferina salemensis Weller																																																?											
Spiriferina subtexta White											X																																																
Spiriferina sp.																		X																																										
Spirifer bifurcatus Hall																																																										?		
Spirifer forbesi Norwood and Pratten																						X			?	?	X																																		
Spirifer gregeri Weller																						X			X																																		
Spirifer grimesi Hall																						X				?				?		X	X	?			X	X																					
Spirifer incertus Hall																									X																																		
Spirifer keokuk Hall																																							?		X					X		X		X									
Spirifer aff. keokuk Hall																										X																																	
Spirifer latior Swallow																					?	X																																					
Spirifer logani Hall																																								X																			
Spirifer louisianensis Rowley	X													X				X																																										
Spirifer marionensis Shumard	X	X																																																									
Spirifer mundulus Rowley																X																				?																						
Spirifer aff. mundulus Rowley																											X																																
Spirifer rowleyi Weller																				?																																							
Spirifer tenuicostatus																																													?														
Spirifer vernonensis Swallow																				X																																							
Spirifer 1 or more sp.						X	X							X				X	X	X											X	X												X			X			X										
Brachythyris altonensis Weller																																																					X						
Brachythyris chouteauensis (Weller)												X		?				X			X	X			X	X																																	
Brachythyris peculiaris (Shumard)		?																X																																								
Brachythyris suborbicularis (Hall)																																					X		X			X																	
Brachythyris sp.																	X																										X															
Syringothyris hannibalensis (Swallow)					X				X																																																		
Syringothyris platypleurus Weller									X									X																																										
Syringothyris sp.																						X																X																				
Spiriferella latior Weller																				X												X							X																				
Ambocoelia parva Weller																X																																											
Ambocoelia sp.																		X																																										
Torynifer pseudolineata (Hall)																																								X				X															
Eumetria verneuiliana (Hall)																																															?												
Hustedia circularis (Miller)											X							X																																										
Nucleospira barrisi White																		?																																										
Cumarophorella missouriensis (Winchell)																?																																											
Athyris crassicardinalis White																?		?																																										
Athyris lamellosa (Leveille)																				X		X			X		X								X		X																						
Cleiothyridina glenparkensis Weller												X						X																																										
Cleiothyridina obmaxima (McChesney)																										X										X																							
Cleiothyridina tenuilineata (Rowley)																						X																					?																
Cleiothyridina sp.											X																																																
Composita globosa Weller																																																										X		
Composita trinuclea (Hall)																																													?		?					?		X	X					
Edmondia sp.							X		?																																																			
Parallelodon aff. cochlearis (Winchell)																		X																																										
Parallelodon sp.																		X																																										
Aviculopecten sp.																		X	X																											X				X										
Pterinopecten sedaliensis Miller																		X																																										
Pernopecten circularis (Shumard)																		X																																										
Pernopecten cooperensis (Shumard)																		X																																										
Modiola sp.																																																										X		
Allorisma worthenanum Miller																																																										cf.		
Allorisma sp.																		?																																										
Cypricardinia sulcifera (Winchell)																		X																																										
Pelecypod undetermined						X																																																					
"Pleurotomaria" northviewensis (Weller)																		X																																										
"Pleurotomaria" subcarbonaria Keyes																		?																																										
"Pleurotomaria" sp.																		X																																										
Euomphalus latus Hall																				X																																							
Euomphalus aff. planodorsatus Meek and Worthen																																																										X		
Cyclonema sp.																		X																																										
Loxonema sp.																		X																																										
Platyceras equilaterum Hall																																									X																		
Platyceras haliotoides Meek and Worthen														X																																													
Orthonychia acutirostris (Hall)																																										X																	
Gastropod undetermined															X																																												
Orthoceras chemungense Swallow																		?																																										
Griffithides bufo (Meek & Worthen)																																								?																			
Griffithides portlocki (Meek and Worthen)																																					?																						
Griffithides sp.																																																		?										
Fish scale									X																																																			

[1] Identifications made in 1929; generic names of some species of brachiopods and corals revised in 1949.

CARBONIFEROUS SYSTEM (MISSISSIPPIAN SERIES)

Louisiana limestone (thin shale here included in base of Louisiana):
- 73. Basal few inches of formation. Contains *Acervularia* reworked from underlying Devonian. In SE¼NW¼ sec. 12, T. 10 S., R. 3 W.
- 10. Shale only 6 inches thick here. In SW¼NW¼ sec. 20, T. 10 S., R. 2 W.

Louisiana limestone (limestone part of formation):
- 9. Upper 6 inches of formation, in SW¼NW¼ sec. 20, T. 10 S., R. 2 W.
- 15. In center SW¼ sec. 14, T. 10 S., R. 2 W.
- 58. NE¼SE¼ sec. 28, T. 10 S., R. 2 W.
- 58a. In SW¼SW¼ sec. 27, T. 10 S., R. 2 W.
- 49. In SE¼SE¼ sec. 10, T. 11 S., R. 2 W.

Glen Park formation:
- 55. "Hamburg oolite." In NW¼NW¼ sec. 14, T. 10 S., R. 2 W.
- 66. "Hamburg oolite." In SW¼NW¼ sec. 22, T. 10 S., R. 2 W.

Hannibal shale:
- 181. From 6 to 12 inches below top of formation, in SW¼NW¼ sec. 31, T. 9 S., R. 2 W.

Chouteau limestone:
- 79. 25 or 30 feet below top of formation, in NE¼SW¼ sec. 22, T. 11 S., R. 2 W.
- 107. Upper part of formation, in SW¼SE¼ sec. 11, T. 6 N., R. 13 W.
- 16. Exact position unknown. In center SW¼ sec. 14, T. 10 S., R. 2 W.
- 47. Exact position unknown. Collected from float, in NW¼SW¼ sec. 23, T. 11 S., R. 2 W.
- 53b. Exact position unknown; collected from float. In SW¼ sec. 14, T. 10 S., R. 2 W.
- 85. 15 feet below top of formation, in NW¼NW¼ sec. 32, T. 12 S., R. 2 W.
- 45a. Near top of formation, in south center sec. 2, T. 12 S., R. 2 W.
- 87 and 114. 2 feet below top of formation, in SW¼NE¼ sec. 32, T. 12 S., R. 2 W.
- 115. Uppermost inch of formation, in SW¼NE¼ sec. 32, T. 12 S., R. 2 W.

Sedalia limestone:
- 116. Lower few feet of formation, SW¼NE¼ Sec. 32, T. 12 S., R. 2 W.

Sedalia(?) limestone:
- 48. Lower few feet of Sedalia and Burlington unit, in NE¼NE¼ sec. 22, T. 11 S., R. 2 W.
- 13. Lower few feet of Sedalia and Burlington unit, in NW¼SE¼ sec. 27, T. 10 S., R. 2 W.
- 57. Lower few feet of Sedalia and Burlington unit, in NW¼NE¼ sec. 34, T. 9 S., R. 2 W.
- 64. About 4 feet above the base of the Sedalia and Burlington unit, in SE¼NW¼ sec. 26, T. 9 S., R. 3 W.

Burlington limestone:
- 53. From lower 50 feet of formation, in NE¼SE¼ sec. 28, T. 10 S., R. 2 W.
- 53a. From lower 50 feet of formation, in SE¼NE¼ sec. 28, T. 10 S., R. 2 W.
- 17. From lower 75 feet of formation, in center SW¼ sec. 14, T. 10 S., R. 2 W.
- 1. Lower 50 feet of formation, SE¼ sec. 4, T. 9 S., R. 2 W.
- 164. About the middle of formation, in SW¼SE¼ sec. 23, T. 9 N., R. 13 W.
- 117. Upper part of formation, in SE¼NE¼ sec. 32 T. 12 S., R. 2 W.

Burlington limestone—Continued
- 99. Upper part of formation, in NE¼NE¼ sec. 35, T. 12 S., R. 2 W.
- 118. A few feet higher than Coll. 99. In NE¼NE¼ sec. 35, T. 12 S., R. 2 W.
- 119. About 25 feet higher than Colls. 99 and 118. In NE¼-NE¼ sec. 35, T. 12 S., R. 2 W.
- 113. Upper part of formation, in NE¼NE¼ sec. 14, T. 6 N., R. 13 W.
- 141. Upper part of formation, in NW¼SE¼ sec. 14, T. 8 N., R. 13 W.
- 140b. 15 feet above Coll. 141. In SE¼SW¼ sec. 14, T. 8 N., R. 13 W.
- 142. Probably upper few feet of formation, in NE¼NE¼ sec. 11, T. 8 N., R. 13 W.
- 133. Uppermost part of formation, in NE¼NE¼ sec. 10, T. 9 N., R. 13 W.

Keokuk limestone:
- 123. About 10 feet above base of formation, in NW¼NW¼ Sec. 32, T. 12 S., R. 2. W.
- 136. Lower part of formation, in SE¼NE¼ sec. 14, T. 9 N., R. 13 W.
- 135. Near top of formation, in NW¼NW¼ sec. 13, T. 9 N., R. 13 W.
- 134. Near top of formation, in SW¼SE¼ sec. 11, T. 9 N., R. 13 W.
- 102. Upper few feet of formation, in center NW¼ sec. 13, T. 6 N., R. 13.
- 124. Upper few feet of formation, in NW¼NW¼ sec. 32, T. 12 S., R. 2 W.

Spergen limestone:
- 92. About 25 feet above base of formation, in NW¼SE¼ sec. 9, T. 6 N., R. 13 W.
- 91. 15 feet above Coll. 92. In NW¼SE¼ sec. 9, T. 6 N., R. 13 W.
- 103. About 25 feet below top of formation, in NW¼NW¼ sec. 13, T. 6 N., R. 13 W.

St. Louis limestone:
- 194. Upper 10 or 20 feet of formation, in SE¼SE¼ sec. 26, T. 13 S., R. 2 W.
- 184a. About 60 feet below top of formation, in center NE¼ sec. 5, T. 14 S., R. 1 W.
- 184b. About 15 or 20 feet below top of formation and 40 feet above Coll. 184a. In center NE¼ sec. 5, T. 14 S., R. 1 W.
- 3. About 25 feet below top of formation, in NE¼SE¼ sec. 28, T. 13 S., R. 1 W.
- 193. About 15 or 20 feet below top of formation, in center W½NW¼ sec. 27, T. 13 N., R. 1 W.
- 192. About 30 or 35 feet above base of formation and 40 feet below Coll. 109. In NW¼SE¼ sec. 9, T. 6 N., R. 13 W.
- 109. In lower limestone conglomerate about 75 feet above base of formation, 40 feet above Coll. 192 and 30 feet below Coll. 110. In NW¼SE¼ sec. 9, T. 6 N., R. 13 W.
- 110. About 100 feet above base of formation, 30 feet above Coll. 109 and 25 below Coll. 111. In NW¼SE¼ sec. 9, T. 6 N., R. 13 W.
- 111. Below upper limestone conglomerate, about 125 feet above base of formation, 25 feet above Coll. 110, and 20 feet below coll. 112. In NW¼SE¼ sec. 9, T. 6 N., R. 13 W.

St. Louis limestone—Continued

112. Above upper limestone conglomerate, about 35 feet below top of formation, 20 feet above Coll. 111 and approximately 10 feet below Coll. 93. In NW¼SE¼ sec. 9, T. 6 N., R. 13 W.

93. About 25 feet below top of formation and approximately 10 feet above Coll. 112. In NW¼SE¼ sec. 9, T. 6 N., R. 13 W.

St. Louis limestone—Continued

104. Probably about 25 feet below top of formation, in NE¼NE¼ sec. 14, T. 6 N., R. 13 W.

105. From cross-bedded sandy limestone. About 10 feet below top of formation. In NW¼NE¼ sec. 14, T. 6 N., R. 13 W.

CARBONIFEROUS SYSTEM (PENNSYLVANIAN SERIES)

Collecting localities of Carboniferous (Pennsylvanian series) fossils

[Fossils determined by Dr. J. M. Weller.[1] Collections arranged in approximately stratigraphic order]

	Carbondale						McLeansboro (?)	McLeansboro
	90	31	138	126	101	A	32	30
Petrified wood			X					
Fusulina girtyi (Dunbar and Condra)							X	
Axophyllum sp							X	X
Lophophyllidium sp							X	
Chaetetes milleporaceus Milne-Edwards and Haime			X					
Myzostomites sp							X	
Erisocrinus typus Meek and Worthen			X					
Crinoid stems					X		X	X
Archaeocidaris spines							X	
Fistulipora sp								X
Derbya crassa (Meek and Hayden)	X	X						
Mesolobus euampygus (Girty)	X	X						
Mesolobus mesolobus (Norwood and Pratten)	X							
Chonetina flemingi (Norwood and Pratten)							cf.	
Linoproductus prattenianus (Norwood and Pratten)	X					?		
Dictyoclostus portlockianus (Norwood and Pratten)	X						X	X
Echinoconchus semipunctatus (Shepard)								X
Marginifera muricatina (Norwood and Pratten)		X			X			
Marginifera wabashensis (Norwood and Pratten)				X			X	
Teguliferina armata (Girty)							X	
Wellerella osagensis (Swallow)	X							
Girtyella sp							?	
Spirifer boonensis Swallow						X		
Neospirifer triplicatus (Hall)	X	X					X	
Crurithyris planoconvexa (Shumard)	X							
Phricodothyris perplexa (McChesney)	X	X		X	X		X	X
Cleiothyridina orbicularis (McChesney)							X	
Composita argentia (Shepard)	X	X		X			X	
Myalina swallovi McChesney	?							
Aviculopecten aff. *A. hertzeri* Meek	X							
Aviculopecten sp	X							
Eucondria neglecta (Geinitz)	X							
Astartella sp	X							
Schizostoma catilloides (Conrad)	X							
Naticopsis tortum (Meek)								cf.
Soleniscus sp								X
Platyceras sp							X	
Gastropod unidentified							X	
Pseudorthoceras knoxense (McChesney)	X							
Metacoceras sp	X							
Fish tooth							X	

[1] Identifications made in 1929; generic names of some species of brachiopods and corals revised in 1949.

NOTE.—For Pennsylvanian plant collections see p. 56.

Carbondale formation:

90. Carbonaceous shale in basal 2 feet of formation, in SW¼SE¼ sec. 27, T. 13 S., R. 2 W.

31. Carbonaceous shale in lower few feet of formation. Collected from old mine dump in SW¼NE¼ sec. 1, T. 14 S., R. 2 W.

138. Limestone near top of formation. The *Chaetetes* occurs in upper nodular part. In SW¼SW¼ sec. 14, T. 13 S., R. 2 W.

126. Lower part of limestone near top of formation, in center NE¼ sec. 35, T. 13 S., R. 2 W.

Carbondale formation—Continued

101. Probably lower part of limestone near top of formation, in SW¼NW¼ sec. 13, T. 13 S., R. 2 W.

A. Upper nodular part of limestone near top of formation, in NE¼NW¼ sec. 1, T. 14 S., R. 2 W.

McLeansboro (?) formation:

32. Slumped block, probably from limestone in lower part of formation, in NW¼NE¼ sec. 1, T. 14 S., R. 2 W.

McLeansboro formation:

30. Lower part of limestone at base of formation, in NE¼NW¼ sec. 6, T. 14 S., R. 1 W.

QUATERNARY SYSTEM

Collecting localities of Quaternary fossils

[Collections arranged in approximate stratigraphic order. Identifications by F. C. Baker, 1928 and 1929. Nomenclature revised by J. P. E. Morrison, July 1948. Order of listing follows that of Thiele, Handbuch der systematischen Weichtierkunde 1929-34. Pulmonate land shells arranged according to H. A. Pilsbry, Land Mollusca of North America, 1939-48]

	A	B	C						D					E				F				G	H	I		J	K		L	
	Illinoian till	Lower part of Brussels formation	Interlaminated with stream deposits in Brussels formation						Loess overlying or in upper part of Brussels or equivalent formations					Upland loess—probably Sangamon age				Peorian (?) loess				Wisconsin (?) loess	Wisconsin or Recent calcareous tufa	Recent or late Wisconsin alluvium of Illinois River		Probably Indian refuse mixed with Sangamon loess	Probably introduced by human agencies		Recent or late Wisconsin stream deposits	
	127	122	121	120 and 190	42	24	63	96 and 128	130	125	59	60	62 and 177	21	35	98	179	176	54	27	131	132	78	44	200	94	97	76	39	129
Land species:																														
Hendersonia occulta			X	X						X	X	X	X		X	X				X	X					X				
Stenotrema hirsuta							X																							
Stenotrema hirsuta yarmouthensis				X																										
Stenotrema leai				X									X																	
Stenotrema leai peoriensis				X																	X									
Mesodon clausus						X																								
Mesodon elevatus								X																						
Mesodon appressus								X															X			X				
Tripodopsis multilineata																							X							
Triodopsis multilineata altonensis			X														X													
Triodopsis multilineata wanlessi					X				X			?	X						X											
Allegona profunda								X																						
Allogona profunda pleistocenica													X			X	X	X		X						X				
Haplotrema concavum												?								X			X							
Euconulus fulvus										X																				
Retinella electrina				X						X	X							X												
Anguispira alternata	X													X		X	X		X	X			X			X			X	X
Anguispira kochi																													X	
Discus cronkhitei																						X								
Discus macclintocki					X								X	X	X	X					X									
Discus macclintocki angulatus										X																				
Helicodiscus parallelus								X	X																					
Succinea ovalis																							X							
Succinea ovalis pleistocenica				X					X	X	X		X	X	X	X			X	X						X			X	
Succinea grosvenori gelida					X			X		X	X	X	X					X			X	X								
Gastrocopta pentodon				X																										
Vertigo modesta										X																				
Vallonia gracilicosta										X											X	X								
Vallonia sp.													X																	
Amphibious species:																														
Pomatiopsis scalaris [1]			X															X									X			
Fossaria parva [2]					X																									
Fossaria parva tazewelliana [2]																		X									X			
Freshwater species:																														
Viviparus subpurpureus																								X						
Ambloxis subsolidum																								X						
Lioplax subcarinata																								X						
Valvata tricarinata		X																						X						
Valvata tricarinata perconfusa		X																												
Amnicola lacustris																								X						
Amnicola sp. near *leightoni*		X																												
Cincinnatia integra																									X					
Birgella subglobosa isogona																									X					
Probythinella lacustris limafodens																								X						
Ceriphasia acuta tracta																									X					
Ceriphasia sp.																								X						
Physella gyrina						X																								
Physella integra							X																							
Physella sp.		X																												
Stagnicola caperata [3]					X																									
Helisoma anceps striatum		X																												
Helisoma trivolvis																								X						
Helisoma campanulatum		X																												
Gyralus altissimus		X			X																			X						
Fusconaia undata trigona																								X						
Amblema peruviana																										X				
Amblema rariplicata																								X					X	X
Quadrula quadrula																													X	
Quadrula pustulosa																								X						
Pleurobema cordatum																										X	X		X	
Elliptio crassidens																										X	X			
Elliptio dilatatus																										X	X			
Proptera alata megaptera																										X				
Lampsilis anodontoides																													X	
Lampsilis fallaciosa																										X				
Lampsilis siliquoidea																										X				
Lampsilis ventricosa																														X
Lampsilis ventricosa occidens																										X				
Sphaerium sulcatum		X																												
Sphaerium rhomboideum																											X			
Sphaerium sp.																								X						
Musculium truncatum		X																												
Pisidium sp.		X			X		X																	X						

[1] The *Pomatiopsis* is primarily to be considered a land shell, usually limited to flood plains of streams or other very moist areas (J. P. E. Morrison).

[2] The *Fossaria* is primarily fresh water, often limited to the exposed but wet muddy margins of streams, ponds, and the like, on the edge of or even out of water. In other words, it is a marginal fresh-water species (J. P. E. Morrison).

[3] The *Stagnicola caperata* may be considered as amphibious; it is characteristically limited to small, often temporary ponds (J. P. E. Morrison).

A. Illinoian till:
  127. A well-preserved snail shell with color markings within Illinoian till, in NW¼SE¼ sec. 28, T. 8 N., R. 13 W.

B. Brussels formation (lower part):
  122. Fossiliferous clay in base of Brussels formation, in NW¼ sec. 5, T. 13 S., R. 2 W.

C. Material definitely interlaminated with stream deposits in Brussels formation:
  121. Alternate layers of loesslike silt and laminated clay, in NE¼SE¼ sec. 17, T. 13 S., R. 1 W.
  120 and 190. Alternate layers of loesslike silt and laminated clay, in SE¼NW¼ sec. 27, T. 13 S., R. 2 W.
  42. Alternate layers of loesslike silt and laminated clay, in SW¼SW¼ sec. 32, T. 11 S., R 2 W.
  24. Alternate layers of loesslike silt and chert gravel, in SE¼SW¼ sec. 17, T. 11 S., R. 2 W.
  63. Alternate layers of laminated clay and chert gravel, in SE¼ sec. 5, T. 11 S., R. 2 W.
  96 and 128. Alternate layers of sand, loesslike silt, and laminated clay, in SE¼SE¼ sec. 9, T. 6 N., R. 13 W.

D. Loess overlying or in upper part of Brussels or equivalent formations:
  130. Loess overlying or in upper part of Brussels formation, in SW¼SW¼ sec. 1, T. 13 S., R. 2 W.
  125. Loess overlying or in upper part of Brussels formation, in SE¼SE¼ sec. 20, T. 12 S., R. 2 W.
  59. Loess immediately overlying and gradational into carbonaceous silt of Brussels formation, in SE¼SW¼ sec. 32, T. 10 S., R. 2 W.
  60. Loess immediately overlying and gradational into carbonaceous silt of Brussels formation, in NE¼SE¼ sec. 30, T 10 S., R. 2 W.
  62 and 177. Silty clay immediately overlying and gradational into carbonaceous silt of Brussels formation, in SE¼SW¼ sec. 19, T. 10 S., R. 2 W.

E. Upland loess, probably of Sangamon age:
  21. Loess on upland, in SE¼ sec. 31, T. 10 S., R. 2 W.
  35. Loess on upland, in SW¼NE¼ sec. 29, T. 11 S., R. 2 W.

E. Upland loess, probably of Sangamon age—Continued
  98. Loess on upland, in SW¼NE¼ sec. 9, T. 6 N., R. 13 W.
  179. Reddish-brown loess below yellowish-buff loess in road cut, SE¼ sec. 16, T. 7 N., R. 13 W.

F. Peorian (?) loess:
  176. Distinctly laminated loess or silt alongside road, in SE¼SW¼ sec. 1, T. 10 S., R. 3 W.
  54. Loess on upland, in SW¼SW¼ sec. 14, T. 10 S., R. 2 W.
  27. Light-buff loess above reddish-brown loess alongside road cut, in SE¼SE¼ sec. 9, T. 11 S., R. 2 W.
  131. Lower loess alongside abandoned road, in NW¼NW¼ sec. 32, T. 12 S., R. 2 W.

G. Wisconsin (?) loess:
  132. Upper loess alongside abandoned road, in NW¼NW¼ sec. 32, T. 12 S., R. 2 W.

H. Wisconsin or Recent calcareous tufa:
  78. Large cone of calcareous tufa, in NE¼NE¼ sec. 16, T. 11 S., R. 2 W.

I. Recent or late Wisconsin alluvium of Illinois River:
  44. Hard silty clay in river bank, in NW¼NW¼ sec. 19, T. 12 S., R. 1 W.
  200. Sample taken by Illinois Department of Public Works and Buildings, Division of Highways, from borings at Hardin bridge site. Elevation between 405 and 428. NW¼NW¼ sec. 12, T. 8 N., R. 14 W.

J. Probably Indian refuse mixed with Sangamon loess:
  94. Fresh-water and land shells associated with human bones in upland loess, in NW¼SE¼ sec. 9, T. 6 N., R. 13 W.

K. Probably introduced by human agencies:
  97. In or on top of upland loess, in NE¼SE¼, sec. 9, T. 6 N., R. 13 W.
  76. In or on top of upland loess, in SE¼SE¼ sec. 15, T. 10 S., R. 2 W.

L. Recent or late Wisconsin stream deposits:
  39. Silt and gravel in small streams. Contains chipped flints. In NW¼NW¼ sec. 32, T. 11 S., R. 2 W.
  129. Filled channel of alluvial silt. Contains chipped flints and potsherds. In SE¼SE¼ sec. 9, T. 6 N., R. 13 W.

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