Stratigraphy of the East Tintic Mountains Utah

GEOLOGICAL SURVEY PROFESSIONAL PAPER 361

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By H. T. MORRIS *and* T. S. LOVERING

With a section on QUATERNARY DEPOSITS

By H. D. GOODE

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A study of the sedimentary rocks with special emphasis on their regional correlation, variation in lithology, and importance as host rocks for replacement ore bodies

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By H. T. Morris and T. S. Lovering

ABSTRACT

The East Tintic Mountains in central Utah are near the eastern margin of the Great Basin and form one of the characteristic north-trending fault block mountain ranges of the Basin and Range province. The consolidated sedimentary rocks exposed in the range are of late Precambrian to Permian age and exceed 30,000 feet in total thickness; they are folded and strongly faulted and are partly overlain by volcanic tuffs and agglomerates and by extensive flows of porphyritic and vitrophyric quartz latite, latite, and trachyandesite of early Tertiary age—all locally concealed under deep late Tertiary and Quaternary alluvial deposits. In the central part of the range, the sedimentary and volcanic rocks are deeply dissected, and dikes, sills, and small stocks of porphyritic quartz monzonite, monzonite, and latite are exposed, cutting nearly every formation of the stratigraphic sequence and all but the uppermost units of the volcanic series.

The prevolcanic consolidated rocks of the East Tintic Mountains are marine sediments that were deposited during the late Precambrian and each of the periods of the Paleozoic era. Most were deposited in the eastern shelf areas of the great geosynclines that occupied the area of the Great Basin during the Paleozoic.

The oldest exposed rocks are unfossiliferous greenish-brown quartzites and gray-green phyllitic shales of the Big Cottonwood formation of late Precambrian age, which underlies the Tintic quartzite of Early Cambrian age with a slight unconformity. The base of the Precambrian sedimentary rocks is concealed, but approximately 1,675 feet of Precambrian beds crop out.

The Cambrian rocks are subdivided into 9 formations, whose aggregate thickness is about 6,000 feet. The Tintic quartzite, which is approximately 2,500 feet thick, consists mainly of buff to white well-bedded quartzite, interlayered with quartzite conglomerate. A remarkably widespread chloritized basalt flow, a few inches to 40 feet thick, occurs approximately 980 feet above the base. No fossils have been found in the Tintic quartzite in the East Tintic Mountains.

The Middle Cambrian rocks are chiefly carbonate rocks and shales, and include in ascending order: the Ophir formation, 275–430 feet thick: the Teutonic limestone, about 400 feet thick; the Dagmar dolomite, 60–100 feet thick; the Herkimer limestone, 350–430 feet thick; the Bluebird dolomite, 150–200 feet thick; and the Cole Canyon dolomite, 830–900 feet thick. All these units except the Dagmar dolomite have yielded Middle Cambrian fossils. In the Tintic and East Tintic mining districts, where the Ophir formation is 400–425 feet thick, it is further subdivided into a lower shale member, about 175 feet thick; a middle limestone member, about 160 feet thick; and an upper shale member, 70–90 feet thick. The Teutonic and Herkimer limestones resemble each other closely, both consisting of blue-gray mudstone-streaked limestone with some beds of oolitic limestone and flat-pebble conglomerate. However, these formation are separated by the distinctive, laminated Dagmar dolomite, which weathers creamy white; this unit is the most reliable marker in the Cambrian section. The Bluebird and Cole Canyon formations are both dominantly medium- to coarse-grained dusky blue-gray dolomites, but the Cole Canyon has in addition many interlayered beds of laminated dolomite that weather to light gray and resemble the Dagmar dolomite but are not as thick.

The Upper Cambrian rocks are subdivided into the Opex formation, 140–240 feet thick, and the Ajax dolomite, 520–730 feet thick. The Opex consists mainly of thin-bedded conglomeratic limestone, but it includes some shale, sandstone, and sand-streaked dolomite and limestone. The Ajax dolomite is chiefly dark-gray, massive-bedded, somewhat cherty dolomite. It is subdivided into a lower dolomite member 90–180 feet thick; an intermediate marker bed about 30 feet thick, which consists of medium- to coarse-grained creamy-white-weathering dolomite known as the Emerald member; and an upper dolomite member 265–520 feet thick. Both the Opex and Ajax formations contain sparse assemblages of Upper Cambrian fossils.

The Cambrian formations of the East Tintic Mountains are correlated with lithologically similar units, containing comparable fossils, that are exposed in the Sheeprock, Oquirrh, Wasatch, Canyon, Bear River, and other mountain ranges in central and western Utah.

Most of the Ordovician rocks of the East Tintic Mountains are included in the Opohonga limestone of Early Ordovician age and the Fish Haven dolomite of Late Ordovician age. However, the lower part of the Bluebell dolomite, which overlies the Fish Haven, also contains strata of Late Ordovician age. The Opohonga limestone, which ranges from 300 to about 850 feet in thickness, is composed of thin-bedded argillaceous limestone and limy flat-pebble conglomerate. It contains a fossil fauna similar to that found in the Garden City formation of northeastern Utah and in the lower part of the Pogonip group of Nevada. The Opohonga and Fish Haven are separated by a disconformity marked by the erosion of a considerable thickness of rocks in the upper part of the Opohonga. The age of the erosion interval is post-Chazy to pre-Richmond, as indicated by (a) stratigraphic relations and (b) the age of the Swan Peak formation and Eureka quartzite, which contain clastic sediments probably derived from the uplifted area.

The Upper Ordovician Fish Haven dolomite is from 270 to 350 feet thick and is composed chiefly of dark-gray to black dolomite, locally cherty. It contains a fairly well preserved fossil fauna of Richmond age and is correlated with the Fish Haven dolomite of northern and western Utah.

The Bluebell dolomite contains strata of Ordovician, Silurian, and Devonian age, but the systemic boundaries within the formation are not precisely established. The total thickness of the Bluebell ranges from about 300 feet to more than 600 feet. It is only sparsely fossiliferous but includes two beds near the base that contain Upper Ordovician fossils, two beds—one near the center and the other about 425 feet above the base—that contain Middle Silurian fossils, and several beds that contain poorly preserved Middle(?) and Upper Devonian fossils in the upper part of the formation. The Silurian beds of the Bluebell are correlated with the Laketown dolomite, and the Devonian beds are correlated with part of the Jefferson dolomite.

The Devonian strata above the Bluebell dolomite are subdivided into the Victoria formation and the Pinyon Peak limestone, both of Late Devonian age. The Victoria formation, about 280 feet thick, is composed of medium-grained, locally conglomeratic quartzite and sand-steaked dolomite. No recognizable fossils have been found in it. The Pinyon Peak limestone, 75–300 feet thick, overlies the Victoria formation above a slight disconformity. It consists mainly of argillaceous limestone, but locally it contains beds of massive dolomite, a few lenses of sandstone, and layers of sand-streaked limestone, especially near the base. The fauna of the Pinyon Peak is similar to those of the Three Forks formation of Idaho and Montana, the Ouray limestone of Colorado, and the Percha shale of New Mexico. The uppermost few feet of the Pinyon Peak limestone, however, apparently contains Mississippian fossils, suggesting uninterrupted deposition in the area from Late Devonian into Early Mississippian time.

The Mississippian rocks are grouped in this report into Lower Mississippian rocks and Upper Mississippian rocks. The Lower Mississippian rocks include the Fitchville formation and the overlying Gardison limestone. The Fitchville formation, about 300 feet thick, correlates with most of the strata formerly mapped as Jefferson(?) dolomite in the Oquirrh Mountains and the Wasatch Range but now known to be of Early Mississippian age. The Gardison limestone, about 500 feet thick, consists of a lower member of blue-gray well-bedded highly fossiliferous limestone and an upper, less fossiliferous member of blue-gray well-bedded cherty limestone. The Gardison fauna is typical of the Madison faunas of the western United States.

The Upper Mississippian rocks include four formations: the Deseret limestone, the Humbug formation, the Great Blue formation, and the Manning Canyon shale. The Deseret limestone, 700–1,100 feet thick, is chiefly blue-gray limestone, commonly cherty; it is fine grained and arenaceous in the lower half of the formation but coquinoid and comparatively free from sand in the upper part. The base of the Deseret is a highly carbonaceous phosphatic shale zone, 10–150 feet thick, which includes some beds rich in carbonate-apatite, vanadium minerals, and rare earth elements. Fossils are not common in the Deseret limestone except in the upper part. The Humbug formation, approximately 650 feet thick, is an alternating sequence of quartzitic sandstones and sand-streaked and pure limestones that include minor dolomite beds and a few thin layers of shale. Many of the limestone beds are fossiliferous. The Great Blue formation, about 2,500 feet thick, consists mainly of thin- and thick-bedded blue-gray limestone, but it also contains a 900-foot zone of shale and quartzite—the Chiulos member—about 1,000 feet above the base. The limestone beds range from nearly pure calcium carbonate to argillaceous, silty, and sand-streaked limestone. Most of the limestone and many of the shale beds contain a varied fauna of Chester age. Next above the Great Blue formation is the Manning Canyon shale, about 1,050 feet thick. This formation consists of two units composed mainly of shale, which are separated by a prominently exposed limestone unit 30–80 feet thick. Fossils from the Manning Canyon in areas adjacent to the East Tintic Mountains indicate that the Mississippian-Pennsylvanian boundary lies within the formation, probably near the middle limestone member.

Most of the Pennsylvanian rocks of the East Tintic Mountains are included in the Oquirrh formation, which also contains a considerable thickness of Permian rocks in the upper part. The aggregate thickness of the exposed parts of the formation is about 13,250 feet, but complex structure and the destruction of fossils as a result of severe dolomitization make it difficult to determine the relative thickness of Pennsylvanian and Permian strata. The Oquirrh formation is considerably less arenaceous in the East Tintic Mountains than in the Oquirrh Mountains and the Wasatch Range, and consists largely of carbonate rocks. However, it contains many thin and thick units of gray and brown sandstone and a few beds of green to brown shale, especially in the middle and lower middle parts.

Overlying the Oquirrh above an unconformity of considerable stratigraphic importance in the area is a formation 685 feet thick composed chiefly of red, buff, and yellow crossbedded sandstones, interlayered with gray limestones and dolomites in the lower 200 feet. No fossils were found in this unit, but owing to distinctive lithology and stratigraphic position it is provisionally correlated with the Permian Diamond Creek sandstone of the Wasatch Range and the Coconino sandstone of central and southern Utah.

The youngest pre-Tertiary rocks exposed in the East Tintic Mountains conformably overlie the Diamond Creek(?) sandstone at the south end of the range; they are correlated with the Permian Park City and Phosphoria formations. Only 1,620 feet of the latter formations is exposed, the uppermost beds having been cut out along a fault that brings the upper part of the upper or Franson member of the Park City against the Bluebell dolomite. The exposed rocks are principally hydrothermal dolomite, but about 735 feet above the base they include a zone of cherty shaly dolomite that contains some phosphorite. Some white chert and sandstone also occur in the lower part.

No rocks of Triassic or Jurassic age have been recognized in the East Tintic Mountains, but they are exposed on Long Ridge and in the southern Wasatch Range about 20 miles east and may once have covered the area. During the Cretaceous period the area of the East Tintic Mountains was uplifted, strongly deformed, and subjected to deep erosion. Coarse clastic sediments, evidently derived from the Cretaceous highlands that occupied the general area of the range, form thick deposits near Thistle, about 35 miles east of Eureka.

The Cenozoic deposits of the East Tintic Mountains include Eocene(?) conglomerate, middle Eocene volcanic and associated sedimentary rocks, Pliocene lake sediments, Pleistocene fan gravel, lacustrine deposits of the Lake Bonneville group, and Recent alluvial and eolian deposits. The Pleistocene and Recent deposits are thickest and of greatest variety in the intermontane basins; they thin greatly up the mountain valleys, but some thick colluvial deposits extend to the tops of the highest ridges.

The oldest Cenozoic rock is the Apex conglomerate, which consists of subangular fragments of limestone, quartzite, dolomite, and shale, well cemented by a red sandy calcareous matrix. The angularity and poor sorting of the fragments in it suggest that the conglomerate was deposited as colluvium or as talus. It occurs sparsely as erosional remnants which lie unconformably on Paleozoic rocks and lie under middle Eocene volcanic rocks; its thickness ranges from a few feet to several hundred feet. No fossils have been found in it, but it is probably of early Tertiary age and is considered Eocene(?) in this report.

The middle Eocene volcanic rocks are divided into the Packard and Fernow quartz latites (oldest), the Laguna Springs latite, and an unnamed basalt (youngest). These rocks are associated with intrusive rocks of similar composition which cut most of the lavas and older rocks and which occur principally near the ore producing centers of the Tintic and East Tintic mining districts. Both the Packard and Laguna Springs contain volcanic sediments including crystal, vitric, and lithic tuffs and agglomerates. These deposits are thickest near the eruptive centers in the central part of the range. In areas adjacent to the East Tintic Mountains on the east, the volcanic rocks intertongue with the Green River formation and include a lens of limestone, which Muessig (1951) has named the Sage Valley limestone member of the Goldens Ranch formation, containing plant fossils of late Green River (middle Eocene) age. An unnamed sequence of limestone and argillized tuff that may be correlative with this lens of limestone underlies basalt in the Fox Hills in the southern part of the Lake Mountains and the extreme northeastern part of the East Tintic Mountains.

Weakly lithified clay, marl, and tuffaceous sandstone beds, which probably are part of the Pliocene Salt Lake formation, are the only other Tertiary rocks in the area. A section of these beds about 200 feet thick is exposed, but the base is concealed and the top is either concealed or eroded. These sediments occur chiefly in Tintic and Rush Valleys but probably underlie younger deposits in the basins east of the mountains and were apparently deposited in freshwater lakes. The marl beds contain abundant remains of gastropods and ostracodes.

The oldest Pleistocene deposit is a loess, 40 feet thick. Only two exposures remain in the area, but such loessic deposits may have been a major source for the abundant silt in younger deposits.

Many thick alluvial fans have shorelines of Lake Bonneville carved on them, and other alluvial-colluvial deposits can be correlated with these pre-Lake Bonneville fans by lithologic character, geomorphic position, and relative soil development. The pre-Wisconsin—that is, pre-Lake Bonneville—soil is marked by a strong relict calcium carbonate concentration which normally would underlie reddish-brown clay; in most parts of this area, however, the clay is not present, as it occurs only in protected localities.

Lake Bonneville was formed during the Wisconsin glacial stage; its deposits in northern Utah Valley are divided into the Alpine, Bonneville, and Provo formations of the Lake Bonneville group. Near the East Tintic Mountains, the Alpine formation consists of moderately well bedded silt and fine sand, and commonly contains abundant gastropods and ostracodes. The Bonneville formation consists of rounded, commonly discoidal, pebbles and small cobbles deposited as beaches, bars, and spits at and near the Bonneville shoreline, which is at an altitude of about 5,140 feet. Deposits of the Provo formation have not been recognized within the area of the East Tintic Mountains but are extensive immediately to the east in Goshen Valley.

Alluvial and colluvial deposits were formed during and between the lake stages. Some alluvial silt has been provisionally correlated with the Alpine formation; extensive fluvial deposits of gravel and gravelly silt are believed to be of Provo age. Thin alluvial and colluvial deposits formed after the recession of the Provo-stage lake, and, in addition, eolian deposits developed reflecting the drier climate.

The Quaternary formations range in thickness from thin blankets and remnants to deposits several hundred feet thick: pre-Lake Bonneville fans and gravel exceed 70 feet; Lake Bonneville alluvial gravel reaches a maximum of about 40 feet; post-Lake Bonneville alluvial deposits are more than 15 feet thick; and younger dunes are only 2–3 feet high. The Lake Bonneville lacustrine deposits are probably thin; it is doubtful that the Alpine formation, the thickest formation of the Lake Bonneville group in northern Utah Valley, exceeds 25 feet in the East Tintic Mountains area.

INTRODUCTION

The ore deposits of the Tintic, East Tintic, and North Tintic districts are all in the East Tintic Mountains, about 60 miles south-southwest of Salt Lake City. Some of the richest and most productive mines exploited blind ore bodies whose presence was discovered by underground exploration based on "hunch," but of late years most of the ore mined has been found with the help of good geologic guidance. The ore bodies lie in many different geological formations and are controlled by many factors; there are still several promising areas that may be worth exploring, but the preparation of detailed geologic maps on which to base further exploration requires on the part of the field geologist an intimate knowledge of the stratigraphic section. This report summarizes the stratigraphic information resulting from many years of fieldwork in this district by members of the U.S. Geological Survey, in the hope that the revision of the stratigraphy in the East Tintic Mountains will be useful to all who are engaged in exploration—not only there but in the surrounding region.

LOCATION, TOWNS, AND ACCESSIBILITY

The East Tintic Mountains are in central Utah, in Juab, Utah, and Tooele Counties, lying between meridians 112° and 112°15′ west and parallels 39°40′ and 40°15′ north. They are near the eastern margin of the Great Basin and constitute one of the characteristic north-trending fault-block ranges of the Basin and Range province (pl. 1).

Eureka, which in 1955 had a population of about 1,000, is the principal community of the region. It is in the central part of the range, 55 airline miles south-southwest of Salt Lake City. The only other town of any size in the range is Mammoth, 1¾ miles south of Eureka, which had a population of about 130 in 1955. Dividend, the camp of the Tintic Standard Mining Co. and the only settlement in the East Tintic district, had a population of 9 in 1955, having decreased to that number from the maximum population of 499 in 1930. Silver City, a mile south of Mammoth, has experienced a similar decline, and the formerly thriving mining towns of Diamond, Knightville, Homansville, and Dragon have disappeared, but their sites are still useful as places of reference.

Two railroads serve the mining districts in the East Tintic Mountains. The Tintic Branch of the Denver and Rio Grande Railroad enters the range from the east and extends to Dividend and other points in the East Tintic district, and to Eureka. The main line of the Union Pacific Railroad follows Rush and Tintic valleys; from it spur lines extend to Eureka and to the site of Silver City.

The range is crossed by a modern paved highway, U.S. Routes 6 and 50, which passes through Eureka; several improved and unimproved dirt roads also cross the range, and others extend up most of the larger gulches, especially in the mineralized areas.

PHYSICAL FEATURES

The East Tintic Mountains rise only a few thousand feet above the level of the adjoining intermontane basins, forming a Y-shaped mountain mass whose arms join just north of Eureka. It is one of a linear series of mountain ranges that include, from north to south, the Promontory Mountains, Antelope Island in Great Salt Lake, the Oquirrh, East Tintic, and Gilson Mountains, and the Canyon Range. This series of ranges is generally regarded as the easternmost of the typical Basin Ranges, but between them and the great Wasatch Range, which forms the eastern boundary of the Basin and Range province in north-central Utah, there are several smaller ranges, also alined in a northerly direction, which subdivide the large eastern intermontane valleys into interconnected smaller valleys.

Three of these smaller valleys form the eastern boundary of the East Tintic Mountains (pl. 2). From north to south they are Cedar Valley, Goshen Valley, and Furner Valley. Cedar Valley, which is an enclosed basin, is separated from Goshen Valley by the main northeasterly spur of the East Tintic Mountains, the Selma Hills, and a group of discontinuous knobs, including the Mosida Hills, that extend from the Selma Hills to the southern tip of the Lake Mountains. Goshen Valley, which drains northward into Utah Lake and thence into Great Salt Lake, is separated from Furner Valley, which drains south into the Sevier River, by a group of low hills, made up of volcanic rocks, that extend eastward from the south-central part of the range to join the northern part of Long Ridge. To the west the East Tintic Mountains are bounded by two large desert basins, Rush Valley and Tintic Valley, which are separated by the low east-west ridge that connects the north-central part of the East Tintic Mountains with the central part of the West Tintic Range—an entirely separate and distinct mountain mass. Rush Valley is an enclosed basin that drains northward from the Tintic area to Rush Lake, a playa occupying the lowest part of the valley at its extreme north end. Tintic Valley drains southward from the divide toward Sevier Lake, but virtually all of the runoff in the intermittent streams that drain it is lost in the alluvium of the Sevier basin before it reaches the lake.

The northern and southern limits of the East Tintic Mountains are not sharp. The northern terminus of continuous bedrock exposure is Twelvemile Pass (pl. 2), which is 3⅛ miles south of the southernmost point of continuous bedrock exposure in the Oquirrh Mountains. Much of the intervening distance, however, is occupied by Topliff Hill and the Thorpe Hills, areas of more or less continuous bedrock exposure that are generally regarded as part of the East Tintic Mountains. The southern terminus of the range is also indefinite, but may arbitrarily be drawn at the valley of the intermittent stream that drains Dog Valley and flows west-southwest.

The East Tintic Mountains are approximately 42 miles long and 1½–12 miles wide, and trend practically due north. The sinuous main divide reaches its highest point in the south-central part of the range at Tintic Mountain, which has an elevation of 8,218 feet. The highest point in the range, Boulter Peak, which attains an elevation of 8,306 feet, is not on the main backbone divide but west of it, on a high spur between two gulches, one of which drains into Rush Valley and the other into Tintic Valley. Between Tintic Mountain and Boulter Peak are at least 12 other peaks that range from 7,700 feet to more than 8,100 feet in elevation, and two of these, Eureka Peak (7,916 feet) and Sunrise Peak (7,712 feet), are also on westward-trending spurs.

The topography is moderately rugged, but bluffs and precipitous slopes are not common. Less than 12 miles east of Mammoth Peak (8,108 feet), Goshen Valley descends to an elevation of only 4,500 feet, and it is a relatively flat bottomed basin over much of this distance. Tintic Valley, 5½ miles west of Tintic Mountain (8,218 feet), is slightly more than 5,300 feet above sea level. Thus the base level of the valleys that drain eastward from the crest of the range is nearly 1,100 feet lower than the base level of the valleys that drain westward. Consequently the slopes on the eastern side of the range are steeper than those on the western side, and most of them are more youthful in character.

The East Tintic Mountains are drained chiefly by canyons and gulches of small to moderate size, none of which cut entirely through the range. Almost without exception the gulches contain only intermittent streams, perennial streams being limited to short stretches below springs. Most of the principal drainage courses of the northern third of the East Tintic Mountains, including Miners, Mill, Black Rock, Scranton (on some maps Barlow), Edwards, and Bell Canyons, and probably also Broad Canyon, were cut by intermittent consequent streams that apparently originated on the inclined beds of the limbs and plunging crest of the North Tintic anticline. In the area of the much faulted Tintic syncline in the north-central part of the range, the larger canyons, principally Holdaway Canyon, the unnamed canyon that trends north from Homansville Pass, the canyon of Pinyon Creek, Burriston and Iron Canyons, Eureka Gulch, Mammoth Gulch, Ruby Hollow, and Diamond Gulch, are localized by such geologic features as faults, dike swarms, or contact zones. The drainage courses of the intermittent streams in the southern part of the range extend eastward and westward from the main divide of the range, chiefly in volcanic rocks. The streams that occupy four of these valleys—Copperopolis, Road, and Birch Canyons, and Hop Creek—are perennial, for short stretches at least, during the wetter years of the climatic cycle.

The edges of the range are marked by extensive sloping bajadas or compound alluvial fans, which have developed where the gradients of the intermittent streams abruptly decrease at the points the streams enter the flat-bottomed valleys. The component alluvial fans are relatively steep in their upper parts, but slope downward at decreasing gradients toward the valley centers, where they coalesce with fans from other mountain ranges or are overlapped by younger deposits.

In most of the basins that adjoin the East Tintic Mountains, the deep alluvial deposits are veneered below an elevation of about 5,140 feet with gravel, sand, silt, and clay that were deposited in Lake Bonneville during Wisconsin time. Shore features of that great body of water, such as beaches, bars, and wave-cut terraces, are clearly recognizable along the eastern slope of the range.

The map, plate 3, shows the location of measured stratigraphic sections and many geographic features referred to in the text. Figure 1 shows the Eureka Peak area where the stratigraphy was first studied carefully by Loughlin, Crane, Kildale, and others. The section is well exposed, but faulted.

Geographic and topographic features are shown in detail in the following 7½-minute series quadrangle maps published by the U.S. Geological Survey: Fivemile Pass, Goshen Pass, Boulter Peak, Allens Ranch, Tintic Junction, Eureka, McIntyre, Tintic Mountain, Santaquin, and adjoining sheets.

CLIMATE AND VEGETATION

The climate of the East Tintic Mountains is semiarid and is characterized by warm summers and moderately cold winters. The average annual precipitation at Eureka, the only point within the range where weather data are collected by the U.S. Weather Bureau, is 14.83 inches as determined over a 23-year period extending to 1954. Precipitation is evenly spread throughout the year; only June, September, and December deviate more than 25 percent from 1.23 inches, which is about $\frac{1}{12}$ of the average annual precipitation. September, with 0.62 inches of precipitation, is the driest month, and December, with 1.55 inches, the wettest. The frequent thunderstorms that are characteristic of the late summer in the mountains cause July and August to average well above June and September in precipitation.

Virtually all of the precipitation from November through March falls as snow. The first important storms usually arrive in October, but the early snows melt rapidly, at least from the lower slopes, and fieldwork can commonly be pursued until late November. The annual snowfall averages about 80 inches, but in some years this figure is greatly exceeded; during the winter of 1951–52 it reached 236.5 inches (U.S. Weather Bureau, 1954). Except from the highest north-facing slopes and deep protected ravines, virtually all the snow disappears before April 15, though snow showers are not uncommon as late as the middle of June.

No official temperature data are collected from any point in the East Tintic Mountains. The temperatures recorded at Elberta in Goshen Valley, about 8½ miles east of Eureka and almost 2,000 feet lower, range from 114° to −15°F (U.S. Weather Bureau, 1954). The maximum temperature is probably not much exceeded anywhere in the East Tintic Mountains, but the minimum temperature of many places in the range is probably somewhat lower than the Elberta minimum.

The character of the vegetation of the East Tintic Mountains is strongly influenced by precipitation, temperature, altitude, and depth to ground water. The higher north-facing slopes of the central and northern parts of the range carry limited stands of aspen (*Populus tremuloides*) and conifers that include yellow pine (*Pinus scopulorum*), Douglas fir (*Pseudotsuga taxifolia*), white fir (*Abies concolor*), and Engelmann spruce (*Picea engelmanni*). Virtually none of this timber is now being cut for mine use in the mining districts. The intermediate and lower slopes are mostly sage covered but nearly everywhere carry scattered piñon pines (*Pinus edulis* and *P. monophylla*) and thick stands of Utah and mountain

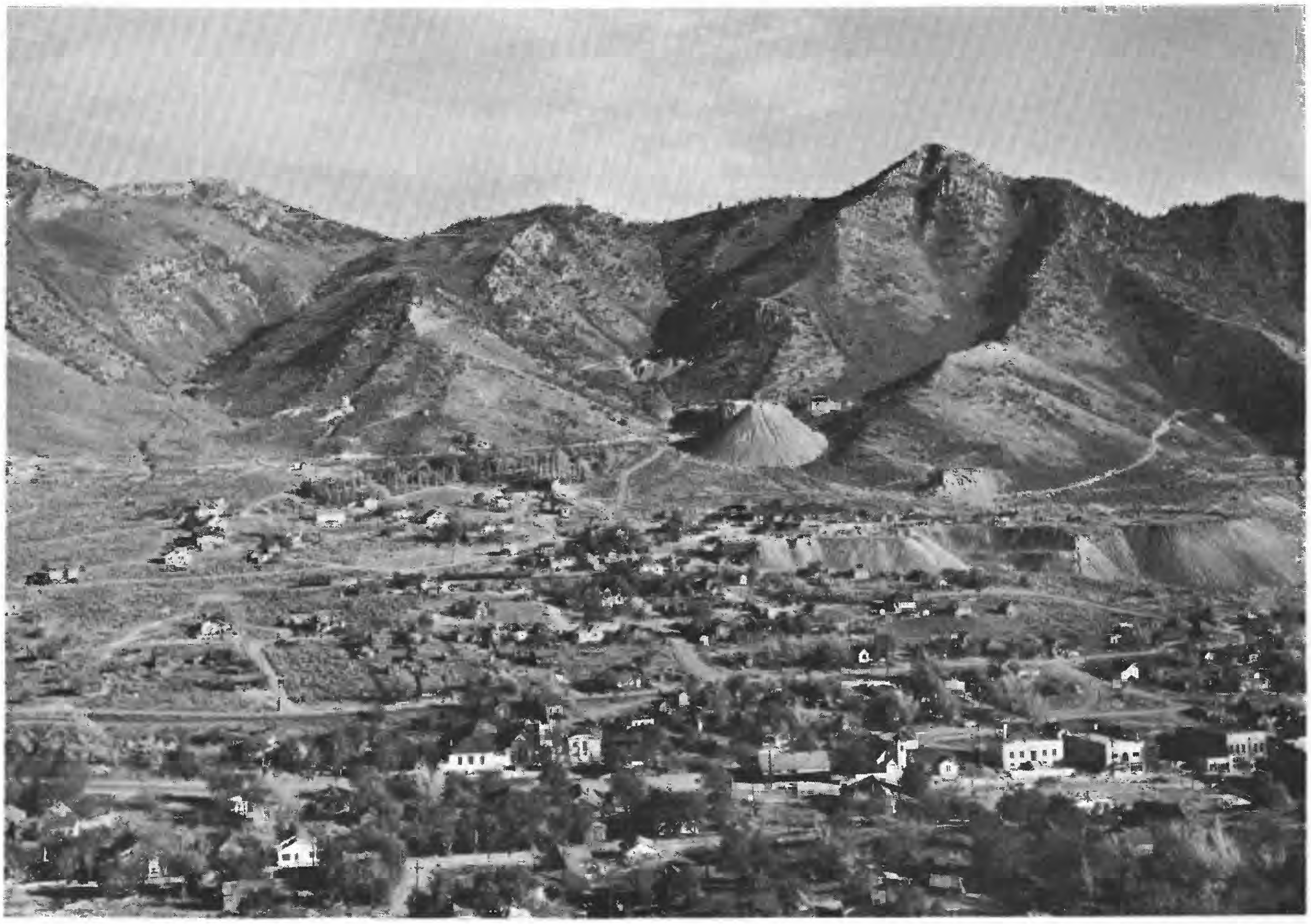

FIGURE 1.—View of Fitchville Ridge and Eureka Peak from the north. Gardner Canyon at far left of photograph is a strike valley in steeply dipping to vertical beds of Gardison limestone; contact of Gardison limestone and Deseret limestone is on left side of Gardner Canyon. Prominent outcrops at crest of Fitchville Ridge, bold spur to right of Gardner Canyon, mark Fitchville formation. Eagle Canyon in center of photograph is cut into steeply dipping beds of Victoria formation, Bluebell dolomite, and Fish Haven dolomite. Eureka Peak, the highest point on the ridge, is underlain by Opohonga limestone; contact of Opohonga limestone and Ajax dolomite in prominent gully to right of peak. Southeastern part of Eureka City in foreground. Mine buildings and large dump at right center is Chief No. 1 mine; mine with high conical dump is Eagle and Bluebell mine; small mine dump in Eagle Canyon above and to left of Eagle and Bluebell mine marks location of Victoria mine; small dump below and to right of Eagle and Bluebell dump marks location of Snowflake shaft.

red junipers (*Juniperus utahensis* and *J. scopulorum*). The higher rocky hillsides are characterized in addition by Brigham's tea (*Ephedra nevadensis*), curl-leaf mountain mahogany (*Cercocarpus ledifolius*), antelope brush (*Purshia tridentata*), cliff rose (*Cowania stansburiana*), hackberry (*Celtis reticulata* and *C. douglasii*), and juneberry (*Amelanchier alnifolia*). Drawf and big-tooth maples (*Acer glabrum* and *A. grandidentatum*), box elder (*Acer interior*), cottonwood (*Populus angustifolia* and *P. acuminata*), barberry (*Berberis repens*), gooseberry (*Ribes inerme*), choke cherry (*Prunus melanocarpa*), mountain alder (*Alnus tenuifolia*), and hawthorn (*Crataegus* sp.) line the bottoms of the canyons, especially near springs. The alluvial deposits of the larger valleys and the base of the mountains support chiefly sage (*Artemisia*) and rabbit brush (*Chrysothamnus*) of several species, prickly pear (*Opuntia*), hedgehog (*Pediocactus*), and other varieties of cactus, and some bunch grasses; but many of the pre-Lake Bonneville fans support piñons and junipers in addition to the above-named shrubs.

The somewhat scanty forage of the range yearly supports a few bands of horses, small herds of cattle, and moderate numbers of mule deer. During the spring and fall large flocks of sheep are also temporarily pastured in the East Tintic Mountains as they are driven from the wintering grounds in the western deserts to the high summer grazing areas in the Wasatch Range and back again.

FIELDWORK

PREVIOUS INVESTIGATIONS

The earliest systematic stratigraphic work in the East Tintic Mountains was that completed in 1897 by

G. W. Tower, Jr., and G. O. Smith (1899, p. 601–767). These geologists subdivided the sedimentary series "mainly on lithologic grounds into four formations—the Robinson quartzite, the Eureka limestone, the Godiva limestone, and the Humbug Intercalated series * * *" (p. 620).

This study was supplemented in 1905 by a small amount of paleontologic work by F. B. Weeks. Weeks' work is largely unpublished, but photographs of some of the fossils he collected, together with their age designations, have been presented in publications by C. D. Walcott (1912, p. 158, 196).

In 1917 Guy W. Crane (1917), for many years geologist for the Chief Consolidated Mining Co. at Eureka, published the results of his preliminary studies of the ore deposits of the Tintic district. Crane's careful measurements and detailed descriptions of the sedimentary rocks of this area are only summarized in his paper; his original notes, however, supplemented through the years by his continued observations, constitute an excellent source of data on the lithology and distinguishing characteristics of the formations in the upper part of the stratigraphic column. These notes are on file at the engineering office of the Chief Consolidated Mining Co. at Eureka and in 1943 were generously made available to the writers.

Crane's paper was shortly followed by the publication of U.S. Geological Survey Professional Paper 107, by Waldemar Lindgren and G. F. Loughlin (1919), which was based on fieldwork carried out in 1911, 1913, and 1914. The stratigraphic units and age assignments established by Loughlin included many of the same units recognized by Crane and were widely adopted and used. Loughlin's work is the foundation upon which the present report is based, and although the age designations have been substantially revised for some parts of the stratigraphic section, most of his formational units and many of the formation names that he introduced are retained in this paper.

Since the publication of Professional Paper 107 and prior to the present investigation, few if any fundamental stratigraphic studies were made in the East Tintic Mountains. During this interval, however, several papers appeared which are concerned chiefly with the structure and ore deposits of the Tintic and East Tintic mining districts and which contain only summary descriptions of the sedimentary rocks. The most important are those by Butler and others (1920), Billingsley and Crane (1933), and Kildale (1938)[1].

[1] Kildale, M. B., 1938, Structure and ore deposits of the Tintic mining district, Utah: Palo Alto, Calif., Stanford University unpublished dissertation.

PRESENT INVESTIGATION

The fieldwork upon which the present report is based was started in January 1943 and was virtually completed in 1955. During the course of the investigation the writers have been associated with or assisted by W. M. Stoll, A. H. Wadsworth, H. C. Wagner, B. F. Stringham, Lowell Hilpert, J. F. Smith, Alberto Terrones L., F. G. Bonorino, J. W. Odell, Eduardo Mapes V., C. H. Hill, Jr., John Lemish, Juan Rossi, P. D. Proctor, Allen M. Bassett, Irwin Lyons, A. E. Disbrow, and R. E. Lehner. All these men contributed in some measure to the study of the sedimentary rocks.

During short intervals in the summer months of the years 1949–55 we were joined in the field by the following members of the U.S. Geological Survey: Jean M. Berdan, Helen Duncan, Mackenzie Gordon, Jr., J. Steele Williams, Allison R. Palmer, Preston E. Cloud, and others, most of whom have also studied paleontologic collections from the district and have offered written comments concerning the age and correlation of many of the stratigraphic units. Berdan identified fossils from the Ordovician, Silurian, and Devonian strata; Duncan identified the corals and bryozoans and contributed remarks on these faunal elements. Gordon studied the Mississippian and Pennsylvanian faunas in detail and has contributed suggestions concerning regional correlations of the Gardison, Deseret, Humbug, and Great Blue formations. Palmer identified trilobites and brachiopods from some of the Cambrian units, and also supplied comments on the regional correlations of several of the Cambrian formations. A. E. Disbrow took many of the photographs and supplied much data regarding the Great Blue, Manning Canyon, and Oquirrh formations in the northern part of the East Tintic Mountains.

Several preliminary reports which are byproducts of the present investigation and which include descriptions of the sedimentary rocks have been published from time to time during the course of the fieldwork. The most complete of these reports are by Lovering and others (1949) and by Morris (1957). Most of the data given here are summarized in the earlier papers, but the present report includes details and refinements not given elsewhere, and emendations based on more detailed fieldwork, additional paleontologic collections, and more recent work in nearby areas.

ACKNOWLEDGMENTS

The writers are happy to acknowledge the wholehearted generosity, assistance, and hospitality of the various mining people of the Tintic and East Tintic mining districts. Every aid and convenience was freely extended by the Chief Consolidated Mining Co., the

Tintic Standard Mining Co., the International Smelting and Refining Co., the E. J. Longyear Drilling Co., the Bear Creek Mining Co., the Newmont Mining Co., and many individual mine operators and lessees in the district. Although it is virtually impossible to list all of the many individuals who have been helpful, the writers wish to acknowledge specifically the contributions made by C. A. Fitch, Sr., C. A. Fitch, Jr., H. J. Pitts, M. T. Evans, and the geological staff of the Chief Consolidated Mining Co.; James Wade, M. D. Paine, Fred Hansen, and Earl Hansen, of the Tintic Standard Mining Co.; M. B. Kildale, R. C. Thomas, W. P. Fuller Jr., of the North Lily Mining Co.; Donald Davidson, L. C. Armstrong, and R. C. Gebhardt, of the Longyear Drilling Co.; Meyer Hansen, of the Newmont Mining Co. and later of the Longyear Drilling Co.; R. N. Hunt, of the United States Smelting, Refining, and Mining Co.; L. Kenneth Wilson, of the American Smelting and Refining Co., and William Burgin, William M. Shepard, Douglas Cook, John B. Bush, Frank H. Howd, Roger Banghast, and James Anderson, of the Bear Creek Mining Co.

Measurements of the physical properties of some of the rocks of the Cambrian formations, made by A. A. Brant, were generously supplied by the Newmont Mining Co. The chemical analyses credited to R. E. Hamm of the University of Utah reflect the generosity of the university. Most of the other analyses were obtained from the mining companies mentioned above and are acknowledged where they appear in the report.

GENERAL GEOLOGIC FEATURES

The general form of the East Tintic Mountains strongly suggests an origin through massive but relatively simple block faulting; however, the stratigraphic record and internal structures of the range (pl. 2) record a complex history of stratigraphic and structural development that considerably antedates the block faulting. The sedimentary rocks are folded and faulted; they are partly overlain by volcanic tuffs, breccias, and extensive agglomerates, and also by flows of porphyritic and vitrophyric quartz latite and latite. Locally all of these rocks are concealed under alluvial deposits of several types. In the central part of the range, which was the site of the principal volcanic vents, the sedimentary and extrusive igneous rocks are deeply dissected, exposing many dikes, sills, and small stocks of quartz monzonite, monzonite, monzonite porphyry, and latite, which intrude most of the sedimentary rocks and all but the uppermost units of the volcanic series. In the northern and south-central parts of the range the youngest volcanic rocks are represented by fine-grained diabase dikes and sills, and by basalt flows.

The structure of the prevolcanic sedimentary rocks is complex. The rocks are compressed into strongly asymmetric folds and cut by faults of several different types. The most prominent folds in the East Tintic Mountains, beginning on the west, are the North Tintic anticline, the Tintic syncline, and the East Tintic anticline—all in the northern half of the range. The west limbs of the North Tintic and East Tintic anticlines have average westerly dips of about 30°, but the common limb of the North Tintic anticline and the Tintic syncline is nearly vertical and is locally overturned toward the east as much as 25°. The folds are 7–9 miles wide, and have an amplitude of 10,000–16,000 feet or more. They plunge to the north at 15°–30°, but local steepening and flattening of the plunge are common. In the southern part of the range the sedimentary rocks strike generally eastward and dip steeply to moderately to the south and southeast.

The faults exposed in the East Tintic Mountains are broadly classified into four groups: (a) faults formed during folding, (b) faults formed after folding but before volcanic activity, (c) postvolcanic mineralized faults and fissures, and (d) late normal faults of the Basin and Range type.

The faults in group a, which formed concomitantly with the folds, are structures resulting from compressive forces and include bedding-plane, thrust, and transcurrent strike-slip faults. Some of these faults are themselves folded. The bedding-plane faults are the least conspicuous, though probably the most common of the faults related to folding. In the steep western limb of the Tintic syncline nearly every bedding surface shows some evidence of movement. In areas of vertical and overturned strata some of the bedding-plane faults diverge from the bedding planes, transect several beds, and then again become coincident with bedding, thus locally cutting out or repeating many feet of strata.

The thrust faults exposed at the surface and in mine openings in the Tintic and East Tintic districts are relatively small, having displacements that range from less than a hundred feet to probably not more than several thousand feet. However, regional stratigraphic and structural studies indicate that the late Precambrian and Paleozoic sedimentary rocks exposed in the range are equivalent to units exposed on the upper plate of the great Charleston-Nebo thrust of the Wasatch Range and to units exposed on the lower plate of the similarly large Sheeprock thrust of the West Tintic Mountains. These relations indicate that a thrust fault of great magnitude and displacement probably underlies the East Tintic Mountains below the deepest mine openings, and that a similar large fault may at one time have extended above the rocks now exposed in the range. The exposed thrust faults are closely associated with the northeast-trending strike-slip faults and are commonly delimited by them. Some of the thrusts are restricted to shaly or thin-bedded strata in the gentle limbs of the folds, but several cut through more competent rocks and may be traced through a strike length of several hundred feet. With the exception of the Bradley thrust fault, which dips to the east, all the thrust faults dip to the west, and show evidence that the upper plate overrode the lower plate from the west.

The transcurrent strike-slip faults are the dominant faults exposed in the East Tintic Mountains. They occur as a conjugate system of northeast- and northwest-trending shear faults, several of which cut entirely across the range and are recognized in adjoining ranges. These transcurrent strike-slip faults cut the axes of the major north-trending folds at angles 25°–55°; nearly all of them dip steeply to the south, or are vertical. The dominant displacement on most of them is horizontal or nearly so, but many show evidence of greater or lesser amounts of vertical movement, chiefly with the southeast or southwest sides of the faults relatively down. In general the northeast-trending faults have greater displacements than the northwest-trending faults, but with the possible exception of the Tintic Prince and Beck faults and the unnamed faults in the southern part of the range, this displacement diminishes toward the western edge of the range, where several of the northeast-trending faults terminate against, or are offset by, northwest-trending transcurrent faults. The displacement on the Beck and perhaps several other northeast-trending faults is largely the result of the opposing fault blocks moving horizontally past each other following the main period of folding, but much of the horizontal displacement on other northeasterly faults is the result of differential folding and thrust faulting of the beds on the two sides of the fault plane. The northwest-trending faults appear to have originated contemporaneously with the northeast-trending faults as shear fractures, but many of the northwesterly faults show chiefly vertical displacements. However, it is almost impossible to determine if the displacement on these faults is the result of vertical movement or horizontal movement, or both, where they are not exposed in mine workings or at the crest of plunging folds.

Faults in group b, which developed in response to tensional forces, came into existence after the main period of folding and transcurrent shear faulting, but before volcanic activity. Although the few transcurrent faults that show dominantly vertical movement may possibly be assigned to this group, only the east-trending, north-dipping normal fault of large displacement that cuts the sedimentary rocks near Packard Peak and the similar fault east-northeast of Mammoth are included in this category. These two east-trending normal faults do not cut the volcanic rocks, which overlie them, but they seem to cross and displace some of the transcurrent faults. The northern of these two faults is partly concealed by the lobe of Packard quartz latite underlying Packard Peak; it has been named the Dead Horse fault in the western part of the range, and its probable continuation has been named the Homansville fault near Homansville Canyon. The displacement on the Dead Horse segment is 1,300–1,700 feet and on the Homansville segment is about 3,600 feet. The east-trending normal fault near Mammoth has been named the Sioux-Ajax fault. It is exposed for about 4,000 feet, striking due east and dipping 80° or more to the north; east of the Iron Blossom No. 3 mine it is concealed by monzonite and the Laguna Springs latite, and west of the Mammoth mine it is concealed by alluvium. Displacement on the Sioux-Ajax fault near the axis of the Tintic syncline is about 1,600 feet. The eastward extension of the Sioux-Ajax fault in the East Tintic district is not known with any confidence.

The veins that cut the igneous rocks, and the mineralized fissures that are associated with the replacement ore bodies of the Tintic and East Tintic mining districts, occupy fissures and faults of small displacement; these are classified as group c faults. These structures are obviously younger than the volcanic rocks but are considerably older than the basin-and-range normal faults. Where the mineralized faults and fissures cut homogeneous rock such as monzonite, lava, and massive, low-dipping quartzite and limestone they trend north-northeasterly and dip steeply to the west. Where they cut the steeply dipping sedimentary rocks in the Tintic district they commonly follow the earlier north-trending bedding-plane faults of group a. In the East Tintic district the north-northeast faults and fissures have been intruded by dikes of monzonite porphyry and pebble dikes and are marked by linear zones of hydrothermally altered lava; at depth these structures also localize narrow veins.

Basin-and-range normal faults, which constitute the faults of group d, clearly mark the western border of the range 2 miles northwest of Boulter Pass and in the general area of Jericho Pass and Furner Valley. Similar faults are exposed at the west base of Pinyon Peak and are probably concealed by alluvium near the west edge of the Selma Hills. A gravimetric survey conducted by Cook and Berg (1955) indicates that the concealed border fault not far east of Boulter Pass is part of a continuous fault zone, nearly 60 miles in length, that forms the western margin of the Oquirrh and East Tintic Mountains. Physiographic evidence and the actual exposure of fault breccias between Riley Canyon and Jericho Pass strongly suggests that this fault zone extends the entire length of the western side of the East Tintic Mountains. The gravimetric data (K. L. Cook, oral communication, 1957) indicate further that the valley-fill deposits are about 7,200 feet thick in Tintic Valley 5 miles west of Eureka.

The normal faults that mark the western border of Pinyon Peak and the Selma Hills extend into the central part of the East Tintic district and apparently follow one or more earlier fault zones; however, the segments of the faults that cut bedrock do not have strong physiographic expression and probably have not been active as recently as some of the border faults.

No basin-and-range faults are exposed along the eastern side of the East Tintic Mountains, but the general straightness of the central part of the east side of the range and the physiography of Goshen Valley and the hills that border it on its southern and eastern sides suggest that the valley is a graben. However, geophysical data do not strongly support this interpretation.

SEDIMENTARY AND IGNEOUS ROCKS

The sedimentary rocks of the East Tintic Mountains range in age from Precambrian to Recent. Most of the indurated strata, however, are of Paleozoic age. As interpreted by the writers, correlations of these Paleozoic rocks with others in well-known areas nearby are shown in plates 4 and 5.

Except for a basalt bed in the lower Cambrian Tintic quartzite and tuffaceous sandstones in the Pliocene Salt Lake(?) formation, the igneous rocks are middle Eocene in age and consist of porphyritic intrusive bodies and associated volcanic rocks. The volcanic rocks include beds of sedimentary origin, which are treated in some detail in this report, but the other volcanic rocks are only briefly described.

PRECAMBRIAN SYSTEM

Upper Precambrian rocks are widespread in northern Utah and elsewhere, in the western United States, and their presence in the East Tintic Mountains was suspected long before their actual discovery. Less than 1,700 feet of these rocks is exposed in the Tintic Junction quadrangle and the base is concealed, but regional correlations suggest that their total thickness may exceed 10,000 feet. They are unconformably overlain by the Cambrian Tintic quartzite, and in the neighboring Wasatch Range and on Antelope Island in Great Salt Lake they are underlain by lower Precambrian gneisses and schists referred to either the Farmington Canyon complex of Eardley and Hatch (1940) or the Little Willow series, which are assigned to the older Precambrian on the basis of their higher degree of metamorphism and greater structural complexity.

BIG COTTONWOOD FORMATION

The rocks here assigned to the Big Cottonwood formation consist of an incomplete section of gray-green phyllitic shales and greenish-brown medium-bedded vitreous quartzites, both cut by numerous narrow veinlets of milky-white quartz. The generally thin bedded character of the formation causes it to weather into subdued outcrops or more commonly to be covered by a mantle of soil and rock rubble from overlying formations. Its position is well marked, however, by the highly distinctive purple basal conglomerate of the overlying Tintic quartzite.

DISTRIBUTION

The Big Cottonwood formation is exposed only in the low foothills at the head of Tintic Valley, and much of it is concealed beneath valley-fill deposits. The best exposures occur as an almost continuous band of partly covered outcrops along the east side of Van Wagoner Canyon, which has been eroded along the axis of the North Tintic anticline. Related but isolated outcrops are exposed in the bottom of the main gulch about 600 feet west of the Van Wagoner prospect, and on the low hill 4,600 feet directly north of Snell ranch. The occurrence of purple conglomerate in the Tintic quartzite south of the mouth of Eureka Gulch suggests that Big Cottonwood rocks may underlie a thin cover of colluvium and fanglomerate at the west edge of Quartzite Ridge, but a careful search in this locality failed to disclose any exposures of either Precambrian rocks or the basal bed of the Tintic quartzite. A prominently exposed section of the upper Precambrian rocks crops out a short distance east of the East Tintic Mountains in the drainage basin of Slate Jack Creek, which drains the northern part of Long Ridge, the low hills that border Goshen Valley on the south.

THICKNESS

The partial section of Precambrian rocks exposed below the Tintic quartizite in the East Tintic Mountains is 1,673 feet thick in the most extensive exposure known in the range. Comparison with other sections of similar rocks in central Utah suggests, however, that the beds exposed in the East Tintic Mountains represent a relatively small part of an irregular but commonly thick unit of upper Precambrian rocks. The maximum thickness of the upper Precambrian rocks in the central Wasatch is reported by Crittenden (oral communication, 1955) to be about 20,000 feet. These rocks overlie the lower Precambrian Little Willow series of schists, gneisses, amphibolite, and metaquartzites. Eardley (1933, p. 312–313) reports a much thinner section of upper Precambrian rocks on Dry Mountain, which is 22 miles due east of the exposures in the East Tintic Mountains. In that area a wedgelike mass of dark-red quartzites, graywackes, and red, maroon, and yellow shales, ranging from 500 to 1,000 feet in thickness, is separated from the Tintic quartzite by an unconformity with a discordance of 15°–25° (Eardley, 1933, p. 315). However, this section was probably much thinned by pre-Tintic erosion, for more than 2,800 feet of argillites, graywackes, arkosites, and quartzites are present below the Tintic quartzite on Long Ridge on the south side of Goshen Valley, a relatively few miles west of the Wasatch Range (Muessig, 1951, p. 193–194), and more than 10,000 feet of upper Precambrian rocks are present in the Sheeprock Mountains, about 20 miles west of the East Tintic Mountains (R. E. Cohenour, oral communication, 1955).

LITHOLOGIC CHARACTER

The Big Cottonwood formation consists of gray-green, olive-green, and brownish-green phyllitic shales, argillites, quartzites, quartzite conglomerates, and at least one thin bed of limestone—all of which are only slightly metamorphosed or deformed. The argillaceous units may be variously termed slates, shales, phyllites, or argillites, but in view of their overall characteristics, phyllitic shale seems to be the most appropriate general descriptive term for those exposed in the East Tintic Mountains (fig. 2). On the whole, they are laminated to well bedded, micaceous, and locally streaked with clean sand. In most exposures the cleavage or parting planes of the rock are parallel to the original bedding, which is marked by color bands and interbedded sandstone lenses. Where the shales have been tightly folded or faulted at the axis of the North Tintic anticline, however, the shaly beds have a silky sheen, owing to the development of fine-grained mica, and the cleavage makes an angle of 25°–30° with the bedding. The shales form units several hundred feet thick, which have relatively uniform lithologic characteristics but locally enclose scattered thin lenses of conglomerate and quartzite.

FIGURE 2.—Close-up view of shale in Big Cottonwood formation. Outcrop in gulch 600 feet west of Van Wagoner prospect, Tintic Junction quadrangle. Knife is 3½ inches long.

The quartzite units are thinner; they range from a few feet to about 150 feet in thickness and are made up of well-defined beds a few inches to a few feet thick. The average rock contains scattered grains of feldspar but consists chiefly of rounded to subrounded quartz grains that give the appearance of being derived from smoky vein quartz. Numerous flakes of white mica and chlorite, a few millimeters across, are disseminated through most of the rock. Some beds that contain abundant fragments of feldspar and chips of phyllitic shale could properly be termed arkosites or graywackes. On fresh fracture both the quartzite and graywacke are pale greenish brown, but the weathered surface, and especially joints and other surfaces, are coated with a rusty-brown stain suggesting the weathering of an iron mineral, presumably a carbonate. No pyrite was noted.

Quartzite conglomerates are common in the formation but nowhere can they be termed abundant. They range in texture from fine grits to conglomerates with pebbles ¼–2 inches in diameter. The pebbles are moderately well rounded and include chiefly smoky or milky quartz that has pronounced hackly fracture; chips of phyllitic shale from underlying beds are moderately common; a few small pebbles or fragments of red and black cryptocrystalline quartz can generally be found, and rarely there are subrounded fragments of brown quartzite.

The quartzites and conglomerates, and locally also the phyllitic shales, are cut by narrow veinlets of dense milky-white quartz about one-fourth inch wide and 3–6 inches long. Such veinlets do not occur above the base of the Tintic quartzite; they appear to be the principal source of the pebbles in the basal conglomerate of that formation. Some of these veinlets and some quartz pebbles from the conglomerates of the Big Cottonwood were tested for precious metals, but the assays showed them to be barren of gold and silver.

A thin bed of dolomitic limestone was found near the lowest beds of the Big Cottonwood formation exposed 1 mile south of the Van Wagoner prospect in NW¼-NE¼ sec. 10, T. 10 S., R. 3 W. It is medium grained and is gray on fresh fracture, weathering to a rusty brown. Owing to the thinness of the bed it is concealed by colluvium and soil except at and near a small prospect pit.

Isolated exposures of the Big Cottonwood rocks might be confused with some outcrops of the shales of the Middle Cambrian Ophir formation (see p. 19–22) or with the shale beds near the top of the Tintic quartzite (see p. 15), especially where these beds are deformed and have recrystallized, developing secondary cleavage. Normally, however, the shales in the Ophir are much less micaceous and somewhat less laminated than the shales in the Big Cottonwood, and the relatively abundant limestone in the Ophir and its stratigraphic position commonly serve to distinguish it. The quartzites of the Tintic are less well bedded than those of the Big Cottonwood, and are also finer grained, less micaceous, and more commonly white, pink, or tawny brown, in contrast to the rusty-weathering gray to olive-green colors of the quartzites of the Big Cottonwood. Both the quartzites and phyllitic shales of the Big Cottonwood are also cut by many veinlets of white quartz, which are rare in the younger rocks.

The following detailed section, which was measured over the most continuous and characteristic exposure in Van Wagoner Canyon, is typical of the Big Cottonwood in the East Tintic Mountains.

Stratigraphic section of Big Cottonwood formation measured on curving ridge 3,500 feet due south of Van Wagoner prospect, North Tintic district, in the E½ sec. 3, T. 10 S., R. 3 W. (loc. 1, pl. 3)

	Thickness (feet)	*Distance between base of Tintic quartzite and base of unit (feet)*
Tintic quartzite:		
Basal conglomerate composed mainly (95 percent) of moderately well rounded ½- to 1-in. pebbles of fractured milky-white vein quartz, but containing some pebbles of pink quartzite, a few scattered chips of green argillite, and rare ¼-in. fragments of orange-red jasper; these are all in a grit-sized matrix of frosted subrounded quartz grains. The matrix is streaked and irregularly banded with fine-grained hematite, which imparts a red-purple color to the unit		0
Unconformity.		
Big Cottonwood formation:		
1. Quartzite, brownish-green, fine-grained; some thin lenses of gray-green phyllitic argillite	17	17
2. Shale, gray-green, locally siliceous and micaceous; includes a few lenses and beds of dense, brown-weathering quartzite	106	123
Big Cottonwood formation—Continued		
3. Quartzite and graywacke, gray- to brownish-green, medium-bedded, medium-grained; weathers rusty brown. Cut by numerous veinlets of white quartz ¼ in. wide and 3 in. long, similar to quartz forming pebbles of basal conglomerate of the Tintic quartzite	140	263
4. Shale, phyllitic, gray-green to olive-green; weathers rusty brown. Encloses several flat lenses of quartzite 8–10 ft thick. Both quartzite and phyllite cut by 6-in. veins of white quartz. Contains a bed of quartzite conglomerate 2–5 ft thick just below center of unit, composed of subrounded pebbles of clear to smoky vein quartz ¼–2 in. in diameter	202	465
5. Zone of closely spaced beds of quartzite, arkosite or graywacke, and quartzite conglomerate 2–10 ft thick, interlayered with gray-green phyllite. Quartzite composed of clear grains of quartz; weathers rusty brown. Conglomerate composed of ¼–2-in. pebbles of vein quartz, brownish-red jasper, and brown quartzite. Quartzite and conglomerate cut by narrow, short veins of white quartz	60	525
6. Shale, phyllitic, gray- to olive-green, micaceous, moderately well laminated. Encloses a few 4- to 10-ft beds of rusty-weathering quartzite and many 6-in. pods of quartzite and sand-streaked argillite	470	995
7. Quartzite and graywacke, olive-green, weathering rusty brown; medium grained, moderately well bedded. Lower third of unit contains some interlayered gray-green shale	128	1,123
8. Phyllite, gray- to olive-green, micaceous; more or less concealed by soil and surface debris. Encloses a few scattered flat lenses of brown-weathering clean quartzite and at least one thin bed of medium-grained gray, brown-weathering dolomitic limestone. Base concealed	550	1,673
Total exposed part of Big Cottonwood formation	1,673	

AGE AND CORRELATION

Because of their lack of fossils, the upper Precambrian rocks in the East Tintic Mountains may be correlated with contemporaneous rocks only on the basis of stratigraphic relations, lithologic composition, and color. The type section for upper Precambrian rocks in Utah is in the central Wasatch Range, where Crittenden, Sharp, and Calkins (1952, p. 3–6) recognize three formational units: (a) the Big Cottonwood formation, 16,000 feet thick, oldest; (b) the Mineral Fork tillite, as much as 3,000 feet thick, and (c) the Mutual formation, approximately 1,200 feet thick, youngest. The Big Cottonwood formation is recognized and defined principally on the basis of its position above the crystalline metamorphic rocks of the older Precambrian and below the widespread Precambrian tillite. It is characterized by the general gray-green color of its interlayered argillites, phyllites, quartzites, and graywackes.

The Mineral Fork tillite and related rocks are characterized by large cobbles and pebbles of gray, red, purple, and white quartzite, medium-grained aplite, and light-gray limestone set in a dark, nearly black, fine-grained matrix composed of quartz flour and complexly intergrown biotite, magnetite, and other minerals. The dark color bleaches at low temperatures and is apparently due to carbon, although carbon constitutes only 0.5 percent of the rock (Crittenden, oral communication, 1959). Rarely, where the tillite is relatively free from coarse material it is laminated and shows ripple marks not unlike those found in varved glacial clays. The Mineral Fork tillite is unconformably overlain by the Mutual formation, and its relations with the Big Cottonwood rocks which underlie it indicate that it was deposited in broad basins glacially eroded in the Big Cottonwood formation.

The Mutual formation consists predominantly of purple, red, and red-purple argillites and quartzites with a few interlayered gray-green beds of the same rocks. It is recognized as a formational unit chiefly on the basis of its characteristic color, its unconformable position above the Mineral Fork tillite, and the slight but regionally important unconformity between it and the Tintic quartzite.

This general sequence of upper Precambrian rocks is also recognized in the Sheeprock Mountains (Eardley and Hatch, 1940, p. 823–827), although the section there is somewhat complicated by faulting, and in the southern part of the Deep Creek Mountains, where Bick,[2] described more than 23,000 feet of rocks underlying the Prospect Mountain quartzite that closely resemble the Mutual formation, Mineral Fork tillite, and Big Cottonwood formation. Elsewhere in Utah where upper Precambrian rocks are exposed, complete sections are not preserved, and the Tintic quartzite rests on tillite, the Big Cottonwood formation, or directly on the gneisses and schists of earlier Precambrian age.

The problem, therefore, of dating the rocks older than the Tintic quartzite in the East Tintic Mountains is complicated by the lack of extensive or continuous exposures, and by the existence in nearby areas of two upper Precambrian units that are lithologically similar in consisting of alternating quartzites and argillities—the Mutual and Big Cottonwood formations. It is further complicated by the absence in the East Tintic Mountains of any rocks recognized in the field as tillites or as having been derived from tillites. However, the dominantly gray-green coloration of the pre-Tintic rocks of the East Tintic Mountains resembles more closely the typical colors of the Big Cottonwood formation, and it is on this basis that the correlation of these two units is tentatively made, and that the name Big Cottonwood is used for the pre-Tintic rocks described in this report.

[2] Bick, Kenneth F., 1958, Geology of the Deep Creek quadrangle; New Haven, Conn., Yale University unpublished dissertation.

CAMBRIAN SYSTEM

TINTIC QUARTZITE

DISTRIBUTION

The Tintic quartzite, which in the East Tintic Mountains is 2,300–3,200 feet thick, is extensively exposed along the axis of the North Tintic anticline, from the head of Broad Canyon to the head of Tintic Valley, and thence southward along the western limb of the Tintic syncline at the west edge of the range to Mammoth Gulch. In the East Tintic district it crops out in an isolated exposure on the small hill surrounded by lava near the crest of the East Tintic anticline, 1,900 feet due north of the Tintic Standard No. 2 shaft. In the central part of the East Tintic Mountains the Tintic quartzite is exposed in several small windows eroded in the volcanic rocks between Riley Canyon and Volcano Ridge. The contact of the Tintic quartzite and the Big Cottonwood formation is well exposed in two areas, one on the low-curving spur 3,500 feet due south of the Van Wagoner prospect in the E½ sec. 3, T. 10 S., R. 3 W., and the other near the crest of the low ridge extending about one-half mile north from the same point. The conglomerate zone just above the basal contact is also exposed on the northwest side of Van Wagoner Canyon and on the west side of the range a few hundred feet south of the mouth of Eureka Gulch.

The Tintic quartzite underlies the Packard quartz latite through a considerable part of the East Tintic district, and is within a few feet of the surface in the footwall block of the Eureka Standard fault, one-fourth of a mile southwest of the Apex Standard No. 1 shaft. Underground in the East Tintic district it has been penetrated by thousands of feet of workings in the larger mines, where it has the same lithologic character and stratigraphic relations as where well exposed in the west-central part of the East Tintic Mountains.

LITHOLOGIC CHARACTER

The Tintic quartzite is dominantly a vitreous, buff to white, medium- to coarse-grained quartzite of very low porosity. It contains some clastic mica, and rounded grains of zircon, rutile, tourmaline, and sphene sparsely distributed in many beds. In the coarser grained and conglomeratic facies, allogenic feldspar and apatite also are common. The quartz grains are peppered with minute vacuoles lined with an isotropic dust of unknown identity, probably iron and aluminum compounds. Except in the vicinity of fault zones, most of the quartz grains are surprisingly free from strain shadows and form a mosaic of interlocking elongate anhedra. Before enlargement by secondary growth, the original quartz grains were mostly well rounded or smoothly ellipsoidal and were only moderately well sorted.

In the East Tintic district the exposure of Tintic quartzite north of the Tintic Standard No. 2 shaft has a rusty appearance, but the iron oxide pigmentation was derived chiefly from the weathering of hydrothermally introduced pyrite. Elsewhere the Tintic is white, pinkish, or tawny brown, but in the lower 500 feet some beds occur that range from light red to dark red-purple. Unlike the quartzites of the Big Cottonwood formation, the Tintic quartzite is relatively free from iron minerals and weathers to a lighter hued, cleaner surface.

The contact of the Tintic quartzite with the Big Cottonwood formation is well marked by a basal conglomerate; the formations are probably unconformable, but in the exposures in the East Tintic Mountains the angular discordance apparently does not exceed 3°. The line of contact is sharp, essentially parallel to the bedding planes, and only slightly channeled, indicating a surface of low relief at the time of deposition.

Quartzite conglomerate beds are common in the lower 650 feet of the formation and are the dominant rock within 300 feet of the base. On the spur north of the Van Wagoner prospect the basal unit is approximately 25 feet thick and composed of moderately well rounded pebbles, 1–1½ inches in diameter, comprising fractured milky-white quartz (95 percent), pink quartzite, chiplike fragments of gray-green phyllitic shale, and rare fragments of orange-red jasper, in a grit-sized matrix of subangular quartz grains. The matrix is streaked with irregular dark purplish-red bands of fine-grained hematite that coats the sand grains and impregnates the cementing silica, giving it a dark color (figs. 3, 4).

The bedding surfaces are covered with abundant white mica and locally are coated with iron oxide. A mile to the south this unit is overlain by a gray-green grit streaked with lenses 1–4 inches thick consisting of milky-white quartz pebbles, many of which are subangular. These two rock types alternate in the lower 650 feet of the formation, but the amount of conglomerate and the purple coloration decrease upward and give way about 800 feet above the base to well-bedded white or buff medium- to fine-grained quartzite with only scattered lenses of conglomerate, which become rare in the upper 1,600–1,800 feet of the Tintic.

Many of the quartzite beds in the middle and upper parts of the Tintic are massive, and some show almost no planes of stratification. On fresh fracture the dense quartzite is white, light pink, gray, cream or buff.

FIGURE 3.—Conglomerate within 50 feet of base of Tintic quartzite. Exposure near the Van Wagoner prospect, Tintic Junction quadrangle.

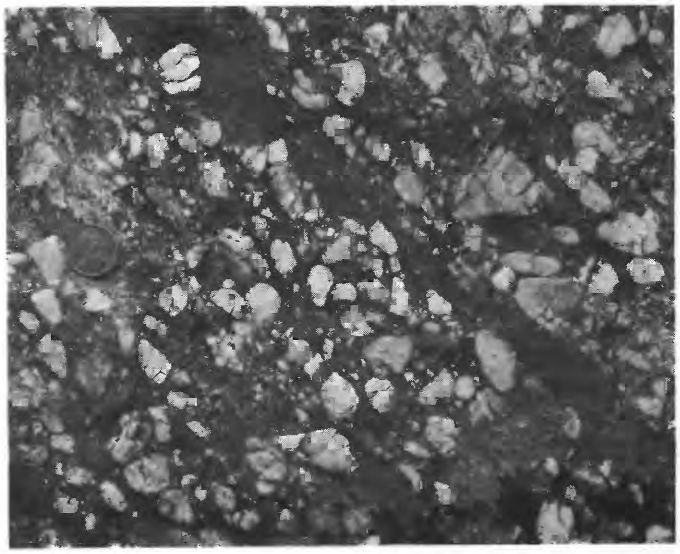

FIGURE 4.—Close-up view of pebbles in basal conglomerate of Tintic quartzite. Pebbles chiefly milky-white quartz; note degree of rounding. Same bed as pictured in figure 3. Coin is 0.75 inch in diameter.

Much of it is hard and apparently structureless, and nearly everywhere fractures break through the quartz grains as readily as around them. Where the quartzite is prominently bedded, the bedding planes are marked by ¼- to 3-inch layers of phyllitic shale that commonly bear the imprint of pebbles of adjacent beds, and a few ill-defined and questionable trails and markings (fig. 5).

A tabular mass of finely porphyritic highly altered basic igneous rock is interlayered with the quartzite about 980 feet above the base of the formation. This unit ranges from a few inches to about 40 feet in thickness, and appears to be conformable with the bedding. On the freshly broken surface it is gray green or locally dark red purple in color, and shows prominent planar structure and lineation of the phenocrysts.

Thin sections of porphyritic material collected near the Golden Sunset mine in the NE¼NE¼ sec. 26, T. 10S., R. 3W. show the texture to be subophitic to trachytic. The feldspars are completely altered to fine-grained aggregates of kaolinite, sericite, and possibly quartz, but retain sharp crystal outlines. The interstitial areas, which were probably filled with augite and possibly olivine in the original rock, are now filled with aggregates of chlorite, limonite, hematite, leucoxene, and minor calcite. Considerable quartz is also present as amygdules and intergranular fillings, and as included fragments of quartzite.

Although this unit is assumed to be a chloritized basalt flow that was erupted at a time when the accumulating Tintic quartzite was not below marine waters, no direct evidence was found in the East Tintic Mountains to establish that it is not a diabase sill. However, the unit does not anywhere transect bedding, and it conforms entirely to the structural pattern and attitude of the quartzite that encloses it. On Long Ridge, 10½ miles southeast of Eureka, a similar layer of much altered, originally scoriaceous igneous rock in the Tintic quartzite contains inclusions of quartzite near the base and is channeled at the top; this rock has been described by Abbott (1951, p. 9–10) as a flow. Similar flows occur in the Cambrian and upper Precambrian (?) rocks exposed on Promontory Point in Great Salt Lake, and Eardley and Hatch (1940, p. 801–902) conclude that extrusive volcanic activity was taking place in adjacent areas during the general interval when the sedimentary rocks were being deposited. The center of this volcanism is unknown.

The upper part of the Tintic quartzite contains many thin lenses of sandy shale interlayered with well-bedded quartzite; the individual strata as a rule range in thickness from 6 inches to 5 feet. The shale is micaceous, hard, and moderately fissile; beds more than 2 feet thick are rare, and most of the contacts of shale and quartzite are gradational. Individual beds are not persistent, and the amount of shale in the section varies in quantity from place to place, but nowhere does the shale make up more than about 15 feet of a 100-foot section. In the North Lily and Apex Standard mines in the East Tintic district, where the upper part of the formation is well exposed underground, the shaly, thin-bedded part of the quartzite extends through a stratigraphic thickness of several hundred feet and is most evident within 500 feet of the contact with the Ophir formation.

The contact of the Tintic quartzite and Ophir formation locally appears to be gradational, but in most places the base of the Ophir is marked by a bed of dark-brown to greenish-gray laminated shale, which is overlain by a more resistant, commonly better exposed, bed of dark greenish-brown porous sandstone which intergrades with the shale along the strike. In general the shales of the Ophir are less phyllitic than those of the Tintic and tend to be olive or brownish-green rather than silky gray-green. In areas of steep dips the contact is commonly concealed in a saddle that is covered by soil or by chips of shale, quartzite, and sandstone, but the massive, light-hued beds of Tintic quartzite almost invariably crop out within a short distance of the actual contact.

The following generalized section is typical of the Tintic quartzite throughout the East Tintic Mountains.

FIGURE 5.—Crossbedded layers and conglomerate zones in Tintic quartzite. Steeply dipping beds exposed on Quartzite Ridge, Tintic Junction quadrangle. Top of beds to right of photograph.

Composite stratigraphic section of Tintic quartzite. Lower half measured easterly from top of Big Cottonwood formation beginning at a point 5,750 feet N. 45° W. of Victoria Northwest shaft, North Tintic district, in E½ sec. 3, T. 10 S., R. 3 W. (loc. 2a, pl. 3). Upper half measured westerly from base of Ophir formation in saddle 1,200 feet N. 58° W. of Victoria Northwest shaft, North Tintic district, in the NE¼ sec. 11, T. 10 S., R. 3 W. (loc. 2b, pl. 3).

	Thickness (feet)	Distance above base (feet)
Ophir formation:		
Base marked by olive- to brownish-green laminated shale, overlain by dark greenish-brown sandstone; underlain by white or light-gray dense vitreous quartzite of Tintic quartzite. Actual contact not well exposed but apparently conformable		2,517
Tintic quartzite:		
9. Quartzite and phyllitic shale interbedded; quartzite dominantly white, medium grained to fine grained, poorly bedded and exhibiting a hackly fracture. Shale gray green, hard, micaceous; mostly concealed. Quartzite beds a few inches to a few feet thick; shale units not more than 12–18 in. thick. About	500	2,017
8. Quartzite, white, buff, gray and pale pink, medium- to fine-grained, moderately to poorly bedded, massive in lower part. Scattered lenses of quartz-pebble conglomerate 3 in.-2 ft. thick, pebbles ½–2 in. in diameter. About	1,000	1,017
7. Basalt flow interbedded with quartzite. Gray green on fresh fracture, dark red purple on weathered surface. Finely porphyritic, pronounced trachytic texture. Filled vesicles locally abundant. Discontinuous along strike	42	975
6. Quartzite, mostly buff, pink, or tawny brown, massive. Quartzite conglomerate beds fairly common	350	625
5. Quartzite, buff to tawny brown, medium- to coarse-grained, interstratified with layers of quartzite grit and beds of fine- to medium-grained conglomerate 3 in.–2 ft. thick composed chiefly of white quartz pebbles. Some beds colored red-purple by fine-grained hematite	257	368
4. Quartzite, pale pink to buff, fine- to medium-grained, medium-bedded to prominently bedded, with scattered lenses of grit and fine quartzite conglomerate 3–6 in. thick.	60	308
3. Conglomerate composed of subrounded pebbles of milky-white quartz (+95 percent) and chips of olive-green shale or argillite in granular coarse-grained matrix of quartz grains irregularly cemented; streaked or colored purplish-red by hematite. Some pebbles break out whole.	147	161
Tintic quartzite—Continued		
2. Quartzite grit, composed of beds of subrounded to subangular fragments of clear and milky-white quartz, interlayered with 1- to 4-in. beds of quartz pebble conglomerate, many pebbles subangular; dominant color gray, but two zones near center, each about 10 ft. thick, are dark purplish red.	138	23
1. Basal quartzite conglomerate, composed of moderately well rounded pebbles of milky-white quartz with some chips of gray-green phyllitic shale and some fragments of quartzite and jasperoid in a grit-sized matrix of subangular quartz grains all cemented by clear and purplish-red quartz	23	
Total Tintic quartzite	2,517	
Unconformity.		
Big Cottonwood formation (upper bed only): Quartzite, gray-green, medium-grained; weathers rusty brown.		

THICKNESS

In the relatively few areas in the East Tintic Mountains where both the lower and upper contacts are exposed, the Tintic quartzite appears from the map to be about 2,300–2,800 feet thick. There is some suggestion that the formation thickens southward and that it may exceed 3,200 feet in thickness on Quartzite Ridge; however, the basal units are covered in this area and the beds exposed may include concealed strike faults. Muessig[3] reports a thickness of about 2,340 feet on Long Ridge, but this section was probably measured across a thrust fault, the displacement on which is unknown. On Dry Mountain, east of Santaquin in the southern Wasatch Range, Eardley (1933, p. 314–315) describes 900 feet of typical light-colored Tintic quartzite, including at the base a 6-foot bed of light-colored conglomerate which unconformably overlies 500–1,000 feet of late Precambrian rocks, consisting largely of red and green shale and red quartzite or conglomeratic quartzite. These relations indicate a substantial thinning of the Tintic quartzite in the 20 miles between the East Tintic and the southern Wasatch Ranges. In the Sheeprock Mountains, 20 miles west of the East Tintic Mountains, the stratigraphic section given by Eardley and Hatch (1940, p. 825–826) includes about 2,700–3,200 feet of beds that are probably Tintic quartzite. In the Cottonwood–American Fork area the thickness is generally less than 1,000 feet (Calkins and Butler, 1943, p. 10).

[3] Muessig, S. J., 1951, Geology of a part of Long Ridge, Utah: Columbus, Ohio, the Ohio State University, unpublished dissertation.

AGE AND CORRELATION

No fossils have been found in the Tintic quartzite in the Tintic district, but recently the Early Cambrian trilobite *Olenellus* was reported [4] from the Tintic quartzite in Long Ridge a few miles to the east. Walcott (1891, p. 319–329) reports that species of "*Cruziana*" and *Olenellus gilberti* were collected by him from the base of the Ophir formation just above the Tintic quartzite in Big Cottonwood Canyon, 50 miles northeast of the Tintic district, and that *Olenellus gilberti* was determined in collections brought in by the Wheeler survey from the same horizon in the Ophir district, 30 miles north of Tintic. The Early Cambrian age of the Tintic quartzite would thus seem to be well established, but diligent search of the lower part of the Ophir formation at Ophir by Gilluly (1932, p. 12) and at the same horizon in the East Tintic Mountains by the writers failed to reveal any specimens of *Olenellus*.

Wheeler (1943, p. 1808–1811) has suggested that the Tintic quartzite represents the shore facies of a sea that transgressed slowly northeastward during Early and Middle Cambrian time. In discussing the Tintic area he repeats Loughlin's conclusions (Lindgren and Loughlin, 1919, p. 24) that the boundary between Lower and Middle Cambrian is near the top of the Tintic quartzite, but that the uppermost beds may be Middle Cambrian. However, Wheeler does not comment further on the Lower-Middle Cambrian boundary at Tintic, although his composite correlation diagram (Wheeler, 1943, pl. 2) indicates the boundary to be at the contact of the Tintic quartzite and Ophir formation. On the basis of the evidence at hand it is not possible to fix the position of the boundary with any degree of certainty, but pending the actual discovery of Middle Cambrian fossils in the upper part of the Tintic quartzite or the rediscovery of the *Olenellus* beds at the base of the Ophir formation, the writers arbitrarily place the boundary at the top of the Tintic quartzite.

The Tintic quartzite, according to Wheeler (1943, p. 1808–1811), is the facies equivalent and the partial time equivalent of the Prospect Mountain quartzite in eastern Nevada and westernmost Utah, and of the Brigham quartzite in northeastern Utah.

STRUCTURAL HABIT

In the East Tintic mining district and other places in the East Tintic Mountains the thick, massive Tintic quartzite acted as a competent buttress or basement during the Laramide orogeny, localizing movement and structural adjustment along its contact with the Ophir formation. Where deformation was severe, this locus of movement also involved the less competent beds in the upper part of the quartzite, and evidence of both bedding-plane adjustments and low-angle faulting is conspicuous at or near the Ophir-Tintic contact in many places. The low-angle faults between the quartzite and shaly parts of the Ophir are persistent and are commonly accompanied by gougy clays; locally, where they bring quartzite against limestone, dolomite, or quartzite, the crushed zone is a sandy breccia. Within the quartzite, cross-breaking faults with displacements of only a few feet are marked locally by zones of coarse breccia several feet wide; faults with much greater movement show little increase in the width of the fault zone, but they are characterized instead by a selvage zone in which fine-grained breccia or sandy gouge fills the interstices of coarse breccia.

In places where the quartzite is well bedded but relatively unfractured, the Tintic is an excellent rock for mine openings because it breaks well, needs no timber even close to heavy, moving ground, and remains open indefinitely. The massive quartzite stands equally well but is more difficult to crosscut. The shaly zones of the Tintic are readily excavated; they also stand well except where the shale is pyritized.

TOPOGRAPHIC EXPRESSION

The Tintic quartzite is more strongly resistant to erosion than any other sedimentary formation in the East Tintic Mountains. The prominently jointed, medium-bedded strata crop out in blocky, linear masses that are easily recognized even at a distance. The more massive beds stand out in bold relief but weather to rounded contours; their buff or gleaming white color, distinguishes them from any other massive formation in the range. Where the beds are vertical, they form dominant serrated ridges; but where they dip gently, they form rounded hills.

CHEMICAL AND PHYSICAL PROPERTIES

Much of the Tintic quartzite contains more than 90 percent silica, and a quarry one-half mile southwest of Eureka has been producing high-grade "silica rock" since 1937. Most of the analyses of material from the Tintic presented in table 1 are from churn-drill samples; they represent the beds just below the Ophir formation, or beds of some unknown horizon below a fault exposed in mine galleries. Much of the iron reported is in pyrite. The partial analyses of the cuttings from churn-drill holes probably include all of the silica and titanium dioxide and more than one-half of the alumina present under "acid insoluble," but the unavoidable salting of some samples by material from higher in the

[4] Peterson, D. O., 1953, Structure and stratigraphy of the Little Valley area, Long Ridge, Utah: Provo, Utah, Brigham Young University unpublished thesis.

TABLE 1.—*Chemical analyses of Tintic quartzite*

[In weight percent. Samples 1 and 2, R. E. Hamm, analyst; samples 3-6, data from Tintic Standard Mining Co., published by permission]

Sample No.	Footage in drill holes	Acid insoluble	SiO_2	Al_2O_3	Fe_2O_3	FeO	MgO	CaO	Na_2O	K_2O	H_2O+	H_2O-	TiO_2	P_2O_5	MnO
1	-----	-----	56.65	25.79	1.19	3.19	1.33	1.00	0.23	6.40	1.63	0.55	1.45	0.86	<0.001
2	-----	-----	61.67	25.61	1.02	2.14	1.44	.27	.18	4.80	1.20	.30	1.31	.28	<.001
Average	-----	-----	59.16	25.70	1.10	2.67	1.38	.63	.20	5.60	1.42	.43	1.38	.57	<.001
3	0-5	91.6	-----	-----	3.1	-----	.7	1.9	-----	-----	-----	-----	-----	-----	-----
	5-15	91.7	-----	-----	2.6	-----	.7	1.5	-----	-----	-----	-----	-----	-----	-----
	15-23	94.4	-----	-----	3.0	-----	.4	.6	-----	-----	-----	-----	-----	-----	-----
	23-26	92.4	-----	-----	2.4	-----	.6	1.2	-----	-----	-----	-----	-----	-----	-----
	26-31	93.0	-----	-----	3.1	-----	.5	.6	-----	-----	-----	-----	-----	-----	-----
4	0-6	95.8	-----	-----	2.4	-----	.1	.9	-----	-----	-----	-----	-----	-----	-----
5	0-5	-----	87.0	3.6	2.3	-----	.12	.95	-----	-----	-----	-----	-----	-----	-----
6	0-10	*(92.5)	-----	-----	(1.7)	-----	(1.05)	(1.4)	-----	-----	-----	-----	-----	-----	-----
	10-20	(76.1)	-----	-----	(2.3)	-----	(4.54)	(6.5)	-----	-----	-----	-----	-----	-----	-----
	20-40	96.1	-----	-----	2.0	-----	.0	.6	-----	-----	-----	-----	-----	-----	-----
	40-55	94.2	-----	-----	2.4	-----	.0	.7	-----	-----	-----	-----	-----	-----	-----
	55-70	95.9	-----	-----	2.0	-----	.0	.6	-----	-----	-----	-----	-----	-----	-----
	70-85	95.5	-----	-----	2.3	-----	.05	.2	-----	-----	-----	-----	-----	-----	-----
	85-105	95.1	-----	-----	2.4	-----	.05	.3	-----	-----	-----	-----	-----	-----	-----
	105-125	92.4	-----	-----	6.4	-----	.15	.4	-----	-----	-----	-----	-----	-----	-----

*Percentages in parentheses indicate samples possibly contaminated by fragments of shale and limestone from overlying Ophir formation.
1. Composite sample of 3 shale beds in uppermost part of Tintic quartzite, 900 level, Tintic Standard mine (Eureka Standard crosscut, 960–1,100 ft south of branch to No. 1 shaft). Sum 100.27.
2. Composite sample of shale beds in upper part of Tintic quartzite north of and stratigraphically below No. 1, in same crosscut but north of branch to No. 1 shaft. Sum 100.22.
3. Tintic Standard churn drill hole No. 7, near pyritized fissure 3240 ft NNE. of Tintic Standard No. 2 shaft.
4. Tintic Standard churn drill hole No. 4, 1,780 ft ENE. of Tintic Standard No. 2 shaft.
5. Tintic Standard churn drill hole No. 13, 325 ft SE. of Tintic Standard No. 2 shaft.
6. Tintic Standard churn drill hole No. 9, 320 ft SSE. of Tintic Standard No. 2 shaft.

hole has probably diluted the silica fraction to some degree. The shales in the upper part of the Tintic quartzite (see analyses 1 and 2, table 1) contain notable amounts of K_2O, and a surprisingly large concentration of TiO_2. Both oxides are believed to reflect the abundance of coarse clastic mica, some of which is probably altered biotite. The proportion of Al_2O_3 and K_2O suggests that nearly 80 percent of the shale is white mica, probably a hydrous variety; the remainder is chiefly quartz silt containing a little calcium phosphate. This phosphate may represent either comminuted trilobite tests or fine detrital apatite.

Only a few of the physical constants have been determined for specific samples of the Tintic quartzite, but the known values, together with figures for comparable rocks from other localities, are given in table 2.

The high thermal conductivity of the quartzite as compared with the shale of the Ophir formation tends to make the thermal gradient gentle to moderate in the quartzite. Temperatures consequently increase in the quartzite at a smaller rate per hundred feet of depth than in the shale; they are relatively high, however, in the quartzite near its contact with the overlying shale blanket. Commonly the gradient in the shale is about two to three times that in the quartzite. In areas where the quartzite carries disseminated oxidizing pyrite, the temperature of rock undisturbed by mining ranges from 100° to 145°F at depths of 500–1,500 feet.

TABLE 2.—*Physical properties of Tintic quartzite and similar rocks*

	Silty shale	Quartzite
Density:		
Bulk	[1] 2.4	[1] 2.63
Powder	-----	[1] 2.64
Porosity ... percent	-----	[1] .8
Elasticity:		
Young's modulus (*E*) ... 10^{11} dynes per cm^2	-----	6.7±0.2
Rigidity modulus (*G*) ... 10^{11} dynes per cm^2	-----	[1] 3.25
Velocity of compressional waves ... km per sec	-----	[1] 6.1
Velocity of shear waves ... do	-----	[1] 3.5
Thermal characteristics:		
Conductivity (*k*) [1] ... $\frac{10^{-3} \text{ cal}}{\text{sec cm deg}}$	5±[1]	14 (0 °C); 12 (100 °C)
Specific heat (*c*) [1] ... cal per gm	.185	0.167 (0 °C); 0.232 (200 °C); 0.27 (400 °C)
α to β quartz ... 3.99 cal, endothermic	-----	573±3°C
Electrical:		
Resistivity [2] ... ohms per cm, × 10^3	[3] 10–25	[4] 25–35; [5] 700–900; [1] 3,000
Magnetic susceptibility	Very low	Very low

[1] Data are for similar rocks taken from Birch, Schairer, and Spicer, 1942.
[2] Resistivity measurements made on rock in place by A. A. Brant, 900 level, Apex Standard mine, data courtesy of the Newmont Mining Co.
[3] Gray upper part of Tintic quartzite near Ophir formation contact.
[4] Pyritic brecciated shaly quartzite, 150 ft SE. of Hansen fault, 900 level Apex Standard mine, data courtesy of the Newmont Mining Co.
[5] Yellowish slightly iron-stained well-bedded quartzite remote from ore.

ALTERATION

Disseminated pyrite is abundant in the Tintic quartzite in the general vicinity of mineralized areas. The pyrite extends along barren fissures in the quartzite for thousands of feet from known commercial ore, and fault contacts between quartzite and Ophir formation are commonly pyritized for a distance of several hundred feet from replacement ore bodies. Brecciated quartzite close to main channels of mineralization is locally kaolinized, sericitized, or alunitized, but in most places only the finely crushed matrix of the breccia is altered, and the larger fragments are little changed. Pyrite, in contrast, develops both in breccias and in fairly solid rocks where joints and bedding planes allowed the ingress of sulfur-bearing solutions. The presence of a few percent of iron in the unpyritized quartzite suggests that some iron carbonate is present in the Tintic quartzite in the Tintic district in a manner similar to that noted by Calkins and Butler (1943, p. 10–11) locally in the Cottonwood–American Fork area. The disseminated pyrite may result from the alteration of earlier siderite and reflect only substitution of sulfur for the carbonate radical.

ECONOMIC IMPORTANCE

The Tintic quartzite is quarried for ganister used in the manufacture of silica brick, which is in demand by the smelting industry of Utah. A quarry 1.3 miles southwest of Eureka ships its product to the Murray Refractories Corp. at Murray, Utah, where it is processed and fabricated.

The Tintic quartzite in the East Tintic district is an important host rock for pyritic copper-gold veins, but only a few small lead-zinc ore shoots have been found between quartzite walls. The gross value of ore from veins in the quartzite is about 25 million dollars (Cook, 1957, p. 65) and has been derived chiefly from the Eureka Standard, North Lily, and Tintic Standard mines. No ore has been mined in the Tintic quartzite elsewhere in the East Tintic Mountains, with the possible exception of very small quantities from the Golden Sunset mine on Quartzite Ridge.

OPHIR FORMATION

The Ophir formation was named by B. S. Butler from the mining town of Ophir in the Oquirrh Mountains, 30 miles north-northwest of the Tintic district (see Lindgren and Loughlin, 1919, p. 25). Its average thickness in the East Tintic Mountains is about 380 feet but ranges from 275 to 430 feet. It consists principally of shale with interlayered sandstones at the base and from 1 to 5 or more limestone beds in the middle member.

The formation is subdivided into three members: the lower shale member, the middle limestone member, and the upper shale member. The lower shale member consists of shale, sandstone, and shaly sandstone, with a single carbonate bed about 10 feet thick that occurs 70–90 feet above the base. This bed is an excellent horizon marker and is here named the carbonate marker bed of the lower shale member; it is dolomite throughout the mineralized areas but elsewhere it is limestone. The middle member of the Ophir is composed chiefly of limestone interstratified with lenses and beds of shale and shaly limestone. The basal unit of this member is a fossiliferous limestone bed that is an excellent horizon marker in the East Tintic district. The upper shale member of the Ophir, which is about 90 feet thick, consists largely of shale but contains many small lenses of calcareous sandstone and sandy shale. No marker beds have been found in it.

DISTRIBUTION

The Ophir crops out as a series of faulted segments in a narrow strip that extends from Mammoth Gulch in the Eureka quadrangle northward to the head of Broad Canyon, where it is offset more than 7,000 feet to the east by the Tintic Prince fault. Beyond the Tintic Prince fault the Ophir is exposed in a linear group of discontinuous outcrops along the east side of Rattlesnake Canyon northwest of Bismark Peak north to the Gardison Ridge fault, which again displaces it about 4,500 feet to the east. It is prominently exposed north of the Gardison Ridge fault on Gardison Ridge for nearly 1 mile, until the outcrop curves westward and disappears under the alluvium of Broad Canyon. Scattered, much faulted exposures of the Ophir also nearly surround the hill of quartzite northeast of the Hot Stuff prospect, five miles northwest of Eureka, and are present on the northwest side of Iron Canyon in the vicinity of the Tintic Prince mine. The only extensive exposures of the Ophir formation in the East Tintic district are those on the south side of the Silver Pass road; these exposures extend 2,500 feet southwest from the Apex Standard No. 1 shaft, and on both sides of Silver Pass Canyon near the Trump shaft. In both of these localities incomplete sections are moderately well exposed. The Ophir is also close to the surface in the vicinity of the Copper Leaf mine, north of U.S. Route 6, but it crops out in only one small area 450 feet northeast of the shaft.

The Ophir has been penetrated by many underground workings in the East Tintic district, where the limestone beds of the formation have proved excellent host rocks for ore. The several readily recognizable marker beds within the formation were found to be almost indispensible in deciphering geologic structure underground. In the main Tintic district the Ophir has been explored in the Evans, Golden Ray, and other mines, but no ore bodies were discovered in these workings. In the North Tintic district, copper ores in the limestones of the middle member were explored many years ago by shallow adits and pits at the Hot Stuff prospect, but so far as known production was negligible.

LITHOLOGIC CHARACTER

LOWER SHALE MEMBER

The shales and sandstones of the lower shale member of the Ophir represent the transition from the clastic sediments of the Lower Cambrian to the predominantly calcareous and dolomitic deposits of the Middle and Upper Cambrian. The base of the Ophir is marked in most places by a shale bed 1–9 feet thick that separates the white or light-gray quartzite of the Tintic from the dark-brown and greenish sandstone of the lowermost Ophir. This shale bed is greenish gray and thinly laminated, and it commonly contains small lenses of sandstone that are altered to quartzite in some places. In localities where this basal shale is not present, the contact is easily distinguished by the contrasting color of the dark grayish brown sandstone of the Ophir and the light-gray or white quartzite of the Tintic.

The sandstones of the Ophir normally are slightly calcareous and somewhat porous, a feature that serves to distinguish them from the Tintic; except where the sandstone of the Ophir has been intensely silicified, air can usually be sucked through a piece of it. Where locally silicified by hydrothermal action, the sandstones of the Ophir closely resemble the Tintic quartzite; they can be distinguished, however, by their much darker color, and by the common occurrence in them of fresh or weathered pyrite and other sulfides.

The sandstone near the base of the Ophir grades upward, through a section in which shaly beds become increasingly prominent and sandy beds less common, into a greenish-gray fissile shale, which contains a minor amount of fine-grained sericite on the bedding planes. Some of the shale beds are calcareous but most are not, and some of the interlayered sandstone beds are glauconitic and slightly limy.

The shale beds immediately above the middle of the lower shale member are lighter colored than those below and grade through a zone of nodular dolomitic shale into the carbonate marker bed of the lower shale member. This bed is a light-gray, dense, moderately coarse grained dolomite or fine-grained limestone from 6 to 15 feet thick. In the East Tintic district it averages about 10 feet in thickness, and lies about 90 feet above the Tintic quartzite. Where limestone beds of the same thickness in the middle member of the Ophir are exposed in restricted areas, they may be confused with the carbonate marker bed of the lower member, but elsewhere this bed is easily recognized by its stratigraphic position. Where it consists of hydrothermal dolomite it is coarsely crystalline and very light gray in color; this facies can best be seen underground on the 1450-level, about 650 feet west of the Tintic Standard No. 2 shaft. Its only good exposure at the surface in the East Tintic mining district is in a small outcrop 1,800 feet S. 54° W. of the Apex Standard No. 1 shaft on the north wall of a small gully. In this outcrop it is dolomite and weathers brown to buff, unlike the limestones in the middle member of the Ophir. On the ridge 1,200 feet N. 55° W. of the Victoria Northwest shaft in the North Tintic district, the lower carbonate marker is about 10 feet thick, and consists of dense, fine-grained dark-blue limestone not unlike the limestones of the middle member in the same area.

The carbonate marker bed of the lower shale member has been called the K bed or the K limestone by geologists of the Tintic region, but its stratigraphic position in the vicinity of the Tintic Standard mine does not appear to have been precisely known, since its contacts are gradational; in a few places the marker bed is so argillaceous that it could be classed as a dolomitic shale.

Overlying the lower carbonate marker bed is 65–75 feet of fissile noncalcareous green and gray shale containing a few discontinuous calcareous zones. On fresh fractures the dominant color of this shale is light brownish green; but it commonly weathers into thin chips which grade from flesh color to dusky brownish red. Locally, however, the shale is light gray, stained ocherous brown on the weathered surface, especially along joints and bedding planes. In the upper part a few thin beds have a dark-green color and granular texture that suggest the presence of glauconite.

The surfaces of many of the shale beds of the lower member of the Ophir are marked by ropy structures and irregular grooves that have been variously interpreted as the burrows or trails of soft-bodied animals, or as molds of such animals, of the trailing fronds of seaweed, or appendages of free-floating coelenterates; none of these organisms, however, have been found preserved as fossils in the shale.

The average thickness of the lower shale member in the East Tintic district is about 175 feet.

MIDDLE LIMESTONE MEMBER

The middle member as a whole consists of several limestone beds interlayered with lenses and beds of green to light bluish-green shale. In the central part of the East Tintic district, where it is an important host rock for replacement ore bodies, four limestone beds are separated by three beds of limy shale whose contacts with the limestone beds are gradational. These limestone beds are designated by numbers, the No. 1 limestone being the lowest limestone bed in the member.

The lower contact of the middle limestone member of the Ophir is placed at the base of the No. 1 limestone. The thickness of this bed throughout the East Tintic district ranges from 5 to 10 feet. It is a reliable marker bed that occurs about 175 feet above the top of the Tintic quartzite. The contact between the No. 1 limestone and the underlying shale commonly is sharp; the basal 6 inches is a zone of fragmented fossils, none of which is well enough preserved to be identified. These fragments are thin, curved and tabular shards that suggest the broken glabellae of trilobites, or pieces of thin brachiopod shells. In cross section this bed has a characteristic "broken line" or hatched appearance that readily identifies it. In many places a 1- to 2-inch layer crowded with globular colonies of closely packed *Girvanella*(?) occurs immediately above the bed of fragmented fossils or is interlayered with it. The individual algal globules range from less than 3 mm to 15 mm in diameter. A concentric structure within the single colonies is conspicuous on bedding planes, and, unlike circular sections of *Girvanella*(?) in the Teutonic limestone, the colonies in the Ophir range from ovoid to irregularly circular in section.

The greater part of the No. 1 limestone has a granular texture and is moderately dark bluish gray; bedding planes, which are well developed in the lower half or more, are commonly marked by argillaceous partings 0.1–1 inch thick.

The upper, or No. 4, limestone bed ranges from 28 to 75 feet in thickness and is generally the thickest. Locally, however, the No. 3 limestone bed is thicker, and this appears to be true in the Tintic Standard mine. On the east side of Silver Pass Canyon, where the middle limestone member of the Ophir crops out south of the Hansen fault, the No. 3 and No. 4 limestones and the intervening shale are probably represented by a single limestone unit more than 100 feet thick, which may also include the No. 1 and No. 2 beds (see fig. 6).

The base of the middle limestone member is not well exposed at this locality, but evidently nearly all of the member is limestone. Lateral gradation of limy shale into limestone is common in the zone between the No. 1 and No. 4 limestones.

Much of the limestone in the middle member of the Ophir is dark bluish gray and some beds are bluish black, but in some places the uppermost limestone is light gray to nearly white. The darker beds are mottled or striped with light yellowish-brown slightly argillaceous bands that commonly stand in relief on weathered surfaces (see fig. 7). Some of the beds are strongly striped, the light and dark bands presenting a ribboned aspect that is not found in the Teutonic limestone of the same general appearance. The argillaceous bands are ½–2 inches thick and range from irregular pods a few inches long to layers that persist for many yards without a break. In some strata their color is reddish brown, pink, or reddish gray, but a yellowish-brown color is most common.

Several of the limestone beds of the Ophir are oolitic, but oolite is less common in the Ophir than in the Teutonic and Herkimer limestones. The oolites of all these formations are characteristically flattened. The average thickness of the middle member is about 145 feet but ranges from less than 100 feet to 175 feet.

UPPER SHALE MEMBER

The upper member of the Ophir, 70–90 feet thick, is a light greenish-gray fissile shale that weathers tan, ocherous brown, or light brownish green with a yellow cast. It contains numerous pods and lenses of cal-

FIGURE 6.—Characteristic exposure of middle limestone member of Ophir formation. Outcrop on east side of Silver Pass Canyon, NW¼NW¼ sec. 27, T. 10 S., R. 2 W., Eureka quadrangle. Juniper tree near center of photograph is about 12 feet high.

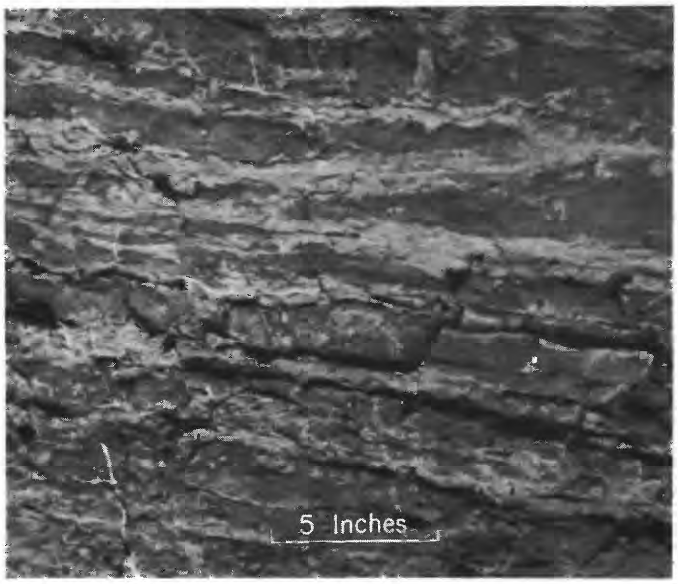

FIGURE 7.—Banded limestone, middle limestone member of Ophir formation. Outcrop on east side of Silver Pass Canyon, NW¼NW¼ sec. 27, T. 10 S., R. 2 W., Eureka quadrangle.

careous sandstone and arenaceous shale, which might be confused with those of the basal beds of the Ophir; however, the sandstone of the upper shale does not occur in definite beds, but only in lenticular pods 1–4 feet thick and rarely more than 12 feet long. These pods are less persistent, thinner, more calcareous, and less indurated than the thicker, more siliceous beds near the base. The sandstone lenses occur chiefly in the lower part of the upper shale member, where the associated shale contains fine-grained but easily discernible clastic mica. A dense light-gray paper shale that is moderately persistent in the East Tintic district lies about 30 feet above the base, about at the top of the arenaceous zone. The upper part of the upper shale member is somewhat limy and contains many discontinuous lenses of limy shale and limestone ½–2 inches thick. The shale of the upper member commonly weathers in parallel-sided splinters ¼–½ inch in diameter and 2–4 inches long, suggesting the name "pencil shale." (See fig. 8.) This characteristic form was not seen in the shales of the lower and middle members.

FIGURE 8.—Pencil-shaped fragments of weathered shale, upper shale member of Ophir formation. Outcrop on east side of Silver Pass Canyon, NW¼NW¼ sec. 27, T. 10 S., R. 2 W., Eureka quadrangle.

AGE AND CORRELATION

In the lower shale member of the Ophir formation, the shale above the lower carbonate marker bed has yielded an early Middle Cambrian fauna. A. R. Palmer of the U.S. Geological Survey reported on fossils he collected in September 1953 as follows:

Collection No. USGS 1386 CO. Lower shale member of Ophir formation, 20 feet south of prospect pit in saddle at crest of Eureka Ridge, 3420 feet west-southwest of Eureka Peak, Eureka quadrangle. Zone of fossils is a few feet stratigraphically below the lowest limestone bed of the middle limestone member of the Ophir.

Alokistocare sp.
Glossopleura sp.
Nisusia sp.
Zacanthoides sp.

The trilobites from the lower member of the Ophir formation are characteristic of the Chisholm shale at Pioche, Nevada, and the shales in the Abercrombie formation in the Gold Hill district and indicate an early Middle Cambrian age. Inasmuch as scraps of *Olenellus* occur in the Busby quartzite in the Gold Hill district, the Ophir formation in the East Tintic Mountains is younger than the Busby quartzite and is a correlative of the lower part of the Middle Cambrian Abercrombie formation. The Busby quartzite, Cabin shale, and Prospect Mountain quartzite in the Gold Hill district are certainly older than any fossil-bearing units at Tintic.

The Middle Cambrian fossils *Obolus mcconnelli* and *O. rotundatus* were also found by Weeks in 1905 in the lower part of the lower shale member just above the carbonate marker bed of the lower shale member (Walcott, 1912, p. 196). These fossils would seem to establish the early Middle Cambrian age of the Ophir formation, but the Early Cambrian trilobite *Olenellus gilberti* is reported by Gilluly (1932, p. 11) as having been collected by members of the Wheeler survey apparently in the lowermost part of the Ophir formation in the Ophir mining district. Gilluly himself failed to find any Early Cambrian fossils in the Ophir, and collected several Middle Cambrian forms within 50 feet of the base; however, on the basis of the *Olenellus* discovery and Walcott's report (1912, p. 164–165, 261) Gilluly ascribed an Early and Middle Cambrian age to the Ophir formation in the Oquirrh Mountains (Gilluly, 1932, p. 11–12).

In view of the more recent paleontologic and stratigraphic work on the Cambrian formations of the Great Basin area, it now seems logical to assign the entire Ophir formation to the Middle Cambrian until additional evidence is found that the basal beds of the Ophir are of earlier age.

The stratigraphic position of the Ophir above the thick prism of Tintic quartzite and beneath a thick dominantly limestone section makes it relatively easy to correlate it with its facies equivalents in other districts nearby. Calkins and Butler (1943, p. 12–14) have described the Ophir formation in the Cottonwood and American Fork districts, 15 miles southeast of Salt Lake City. Eardley (1933, p. 316–317) reports its occurrence in the southern part of the Wasatch Range, 20 miles east of the Tintic district, and he also describes it in the north-central part of the Wasatch Range (Eardley, 1944, p. 828) a few miles east of Ogden, Utah. An equivalent unit also crops out in the Sheeprock Mountains 20 miles west of the East Tintic Mountains, in the Drum Mountains 50 miles southwest of the Tintic district, and in the Canyon Mountains 20 miles south of Eureka.

Wheeler (1943, p. 1811–1815) believes that the Pioche shale of the Pioche area, Nevada, is continuous with the Ophir at Tintic. He believes, however, that the shale becomes progressively younger to the east, until its facies equivalent in the Tintic district, the Ophir formation, is entirely Middle Cambrian. If Wheeler's ideas are accepted, the greater part of the Ophir formation is probably younger than the Pioche shale, which may be chiefly equivalent in time to the upper shaly zone of the Tintic quartzite; the uppermost part of the Ophir is probably the time equivalent of the Lyndon limestone, Chisholm shale, and possibly the lower part of the Peasley limestone of Wheeler (1940) in the Pioche district.

On the basis of the fossils it contains, the Ophir is also contemporaneous with the Howell formation and perhaps the lower part of the Dome limestone of the House Range (Deiss, 1938, p. 1144–1145), with parts of the Langston and Ute limestones of northeastern Utah (Reiss, 1938, p. 1119–1121), and with parts of the Eldorado dolomite of the Eureka area, Nevada (Nolan, Merriam, and Williams, 1956, p. 9–11).

STRUCTURAL HABIT AND UNDERGROUND EXPRESSION

The Ophir is the most incompetent formation in the Paleozoic section of the East Tintic Mountains, and, lying as it does beneath a great mass of limestone and above a thick mass of quartzite, it has undergone much crumpling, brecciation, and low-angle shearing adjacent to folds or to the low-angle faults which commonly occur at its contact with the Tintic quartzite. Adjustment has generally occurred on this contact in the East Tintic district; it is especially evident where the contact is exposed in the workings of the Eureka Standard, Tintic Standard, and North Lily mines, and also in the steep limb of the Tintic syncline in the northern part of the East Tintic Mountains.

Much of the extensive low-angle movement of the rock masses was localized in the lower shale member. The faults have produced comparatively thin laminated gouge seams in the shale, and much wider breccias where the interbedded limestones of the middle member were involved. The deformation of the shale beds apparently increases their permeability even where no brecciation is obvious, and the limestones of the Ophir formation are extensively altered to dolomite, jasperoid, and ore for some distance adjacent to mineralized fissures.

In zones of steeply dipping or overturned folds, as on the western side of the main Tintic district, the lower shale commonly shows slaty cleavage, and part of it is metamorphosed to phyllitic slate. Locally it is squeezed and faulted out by the quartzite, and in areas of strong deformation it may be thinned by as much as 100 feet.

The Ophir formation stands well underground except where it is sheared or carries pyrite, which is common near the Tintic quartzite contact. Even where the shale is moist there is little tendency for it to squeeze in and close up drifts and crosscuts if it is unaltered and unfractured, but where it is crushed and pyritized, whether it be wet or dry, it has a strong tendency to swell slowly and to slough into mine openings. Shear zones in the shale generally require support where they carry water but stand well in places where they are dry and unaltered. Unfractured limestone of the middle member of the Ophir formation always stands well in underground openings.

TOPOGRAPHIC EXPRESSION

The preponderance of shale in the Ophir formation makes it far less resistant to erosion than the quartzite and limestone formations that border it; a broad saddle between outcrops of the Tintic quartzite and the Teutonic limestone always marks its position on transverse ridges, and Ophir commonly underlies strike valleys or gulches that lead up to saddles at the divide. The limestones of the middle member of the Ophir crop out in many areas as low bluffs partly buried in the shale and limestone debris that litters the gentler slopes, but in some areas where erosion is rapid, as in the vicinity of the Hot Stuff prospect or near the Apex Standard No. 1 shaft, the Ophir crops out on moderately steep slopes that are almost free of talus and debris.

CHEMICAL AND PHYSICAL PROPERTIES

The shale of the lower member of the Ophir formation contains decidedly less K_2O than the more coarsely micaceous shale of the underlying Tintic quartzite (see table 3). The shale above the carbonate marker bed contains almost no visible sericite and contains about one-third as much K_2O as the shale beneath. Although some of the lower shale reacts slowly with dilute HCl, the average $CaCO_3$ content is apparently less than 1 percent, and the clay shale above the marker bed is even less calcareous. Thermal analyses of this shale indicate that its chief mineral is a hydrous variety of mica, but one that has an unusually low K_2O content.

The analyses suggest that the impurities in the middle member of the Ophir are chiefly clay and calcium-magnesium-iron-manganese carbonate. The molecular proportions of the bases when allocated to CO_2 closely approximate ankerite, with a Ca : Mg : Fe : Mn ratio of 20 : 10 : 10 : 1. In the relatively impure No. 1 limestone in the East Tintic district, the argillaceous fraction is about 10 percent; and the ankerite (calculated) about 20 percent; dolomite, if present, less than 2 percent; and calcite about 70 percent.

The amount of CO_2 in analysis 3 is very close to the amount required (0.10 percent in excess) to combine with all the CaO, MgO, FeO, and MnO reported; it seems probable, therefore, that these bases are present as carbonates. The isomorphous substitution characteristic of the ankerite group makes it unlikely that more than two carbonates precipitated, and it is probable that the limestone is essentially a primary calcite-ankerite rock with argillaceous impurities.

TABLE 3.—*Chemical analyses of rocks in Ophir formation*

	1	2	3	4	5
Acid insoluble					3.00
SiO_2	65.99	63.76	6.63	2.00	
Al_2O_3	21.25	23.99	2.15	2.00	2.70
Fe_2O_3	.79	2.42	1.08		
FeO	3.64	4.16	2.72		
MgO	1.79	1.96	3.13	.33	1.45
CaO	.63	.31	43.34	52.78	52.00
Na_2O	.59	.58	None		
K_2O	2.04	.75	.57		
H_2O-	.32	.31	.18		
H_2O+	1.59	.76	None		
TiO_2	1.04	1.04	.09		
CO_2	n.d.	n.d.	38.35	[1] 41.78	[1] 42.05
P_2O_5			.10		
SO_3			2.52		
MnO	.007	.004	.18		
Total	99.677	100.044	101.04	98.89	101.20
Density, bulk			2.61		
powder			2.71		
Porosity (percent)			[1] 3,69		

[1] Calculated.

1. Composite sample of shales between Tintic quartzite and carbonate marker bed of the Ophir formation, 1000 level, Eureka Standard mine. R. E. Hamm, analyst.
2. Composite sample of shale between the carbonate marker bed and the No. 1 limestone of the Ophir formation. R. E. Hamm, analyst.
3. Unaltered No. 1 limestone of middle limestone member of Ophir, 1450 level, Tintic Standard mine. M. K. Carron and R. E. Stevens, analysts.
4. Composite sample (73 ft.) of No. 4 limestone, uppermost limestone bed of the Ophir formation; collected by G. W. Crane. Courtesy Chief Consolidated Mining Co.
5. Composite sample of light-gray layer (14 ft. thick) at top of the No. 4 limestone of the Ophir formation, collected by G. W. Crane. Courtesy Chief Consolidated Mining Co.

The SiO_2, Al_2O_3, Fe_2O_3, and K_2O stand in the molecular ratio of 4:1.45:0.49:0.44, suggesting the mixed layer–montmorillonite group of clay minerals. The formulas of minerals from the type locality at (1) Montmorillon, France, and (2) from Cameron, Ariz. (typical mixed layer aggregate, Kerr and others 1950, p. 56), and also (3) the molecular proportions of the oxides calculated from analysis 3, table 3, are shown below:

1. $(Al_{1.64}Fe^{+3}_{.05}\ Mg_{.36})\ (Al_{.12}Si_{3.88})\ O_{10}\ (OH)_2\ 4.34\ Ca$
2. $(Al_{1.45}Fe^{+3}_{.44}\ Mg_{.15})\ (Al_{.27}Si_{3.73})\ O_{10}\ (OH)_2K^{25}Ca^{19})$
3. $(Al_{1.45}Fe^{+3}_{.48})\ Si_{4.0}\ O_{10.9}$

The lack of both H_2O+ and H_2O- in the analysis may be due to the history of the rock and the difficulty of determining small amounts of water that are not released until the decomposition of the enclosing carbonates is well under way. The analyzed sample was collected within a few hundred feet of mineralized fissures and may have been heated by conduction during the period of ore deposition to a point well above the temperature at which low-temperature water is lost. It is difficult to believe that the Al_2O_3 and Fe_2O_3 are present in anhydrous minerals in a limestone that when fresh shows no hint of a red color or detrital heavy minerals. Where it is weathered, however, the No. 1 limestone shows pink or ocherous argillaceous partings.

No detailed analyses of the upper limestones are available, but partial analyses shown in table 3 indicate a limestone of the same general mineral composition as the No. 1 limestone, but with a $CaCO_3$ content ranging from 90 to 95 percent.

ALTERATION

The Ophir formation is more extensively altered in the East Tintic district than any other Paleozoic formation, but this is believed to be the result of its position immediately above a thick sequence of essentially nonreactive quartzites rather than the result of its greater susceptibility to alteration. The most common and widespread change is the introduction of pyrite into the shale near the Tintic quartzite contact in the vicinity of mineralized fissures. In some places, especially near monzonite intrusives, the shale is argillized, with the consequent development of kaolin minerals, increased porosity, and a bleached appearance. Close to mineralized channels the shale of the Ophir is locally converted to fine-grained dark-colored jasperoid, some of which shows a ribbonlike banding.

Near some of the intrusive plugs, the limestones of the middle member of the Ophir are bleached or converted to tactites, but hydrothermal dolomitization is much more widespread. The hydrothermal dolomite is slightly darker and coarser grained than the original limestone and contains a little more MnO and FeO and less SiO_2.

Near many mineralized conduits the limestones are extensively altered to jasperoid. The jasperoid ranges from white to black, from dense to vuggy and from barren to highly metalized. The dark color is commonly caused by disseminated pyrite, and in localities where the rock has been exposed to air for several years, the oxidation of the sulfide may give rise to a brown color. Jasperoid can be distinguished from the quartzites by its greater porosity and the common occurrence of small irregular vugs; jasperoidized shale and jasperoidized limestone are indistinguishable in some exposures, but relict bedding in the shale commonly gives the jasperoid derived from it a penciled or riboned appearance that identifies the parent rock.

Hydrothermal dolomite above and around jasperoidized limestone is porous or even cavernous in many places, and near jasperoid contacts it may be weakly cemented and "sandy" (to use the local descriptive terminology). This alteration facies was accomplished by acid argillizing solutions that followed dolomitization and preceded jasperoidization (Lovering and others, 1949, p. 25–28).

ECONOMIC IMPORTANCE

About 60 percent of the 110-million-dollar gross production credited to the East Tintic district was derived from ore in the middle and lower members of the Ophir formation. The lower carbonate marker bed and the limestones of the middle member account for most of this ore, but a substantial amount has been mined from jasperoidized shale in both members. Relatively little ore has been found in the upper shale member. The ore bodies in the Ophir formation thus far mined have been dominantly lead-silver ores containing minor zinc, copper, and gold.

Current exploration in the Burgin mine indicates that substantial tonnages of ore occur in thrust fault gouge formed chiefly from limestone and shale of the Ophir formation. This unmined ore apparently contains a much higher proportion of zinc than ores previously produced from the East Tintic district.

TEUTONIC LIMESTONE

The Teutonic limestone is typical of the mottled, dark-colored limestones that are common in the Cambrian of the western United States. Its type locality is Teutonic Ridge, 1 mile west-northwest of Eureka, where its thickness is about 420 feet.

DISTRIBUTION

In the main Tintic district the Teutonic limestone is well exposed in faulted outcrops from Mammoth Gulch northward to the edge of the Packard quartz latite on the north side of Jenny Lind Canyon near the North Beck shaft. In the North Tintic district it is exposed as a nearly continuous but faulted band about 500 feet wide from the Dead Horse fault, 1,000 feet south of the Victoria Northwest shaft, north-northwestward to the Tintic Prince fault. North of that fault it is exposed on both sides of the axis of the North Tintic anticline in the upper part of Broad Canyon, and in the general area of the Hot Stuff prospect and Tintic Prince mine. In the East Tintic district scattered outcrops of the formation are confined to a zone extending northward from the Hansen fault zone, on the east side of Silver Pass Canyon, to the vicinity of the Copper Leaf mine, a short distance north of U.S. Route 6. The middle and upper parts of the formation are well exposed in lower Homansville Canyon northwest of the Copper Leaf mine, and on Mineral Hill east of the Iron King No. 2 shaft. The lower part of the Teutonic crops out prominently about 700 feet southwest of the Apex Standard No. 1 shaft. It also has been penetrated in many of the mines in the East Tintic district and in the Evans and Golden Ray prospects near Eureka, but the lack of readily recognizable horizon markers within the formation makes it difficult to estimate the stratigraphic position of a drift cutting it except at its contacts with the Ophir formation or the Dagmar dolomite. The Teutonic limestone is also exposed in the extreme southeastern part of the East Tintic Mountains in the SE 1/4 sec. 15, T. 12 S., R. 2 W.; and, in an isolated exposure surrounded by lava, limestone that may be the Teutonic crops out on the crest of Volcano Ridge a short distance west of Buckhorn Peak.

LITHOLOGIC CHARACTER

In the East Tintic Mountains, the Teutonic limestone is dominantly a medium-bedded light- to dark-gray limestone with irregular ribbonlike bands and mottlings of argillaceous limestones (fig. 9). Oolitic and pisolitic beds are locally common in the upper two-thirds of the formation. In the area southwest of the Apex Standard No. 1 shaft the lowermost bed, 1–2 feet thick, is characterized by abundant *Girvanella* (?) spherules, about 1 centimeter in diameter, which help to distinguish this limestone from all but one of the limestone beds of the middle member of the Ophir formation below it. Above the *Girvanella* (?) bed the lower

FIGURE 9.—Mottled limestone in Teutonic limestone. Outcrop on west side of Gardison Ridge, Boulter Peak quadrangle.

part of the Teutonic is a dark blue-gray limestone striped with gray, buff, or yellowish-brown argillaceous bands, most of which are parallel to the bedding. Throughout the East Tintic district a zone of dark blue-gray thin-bedded fine-grained clastic limestone

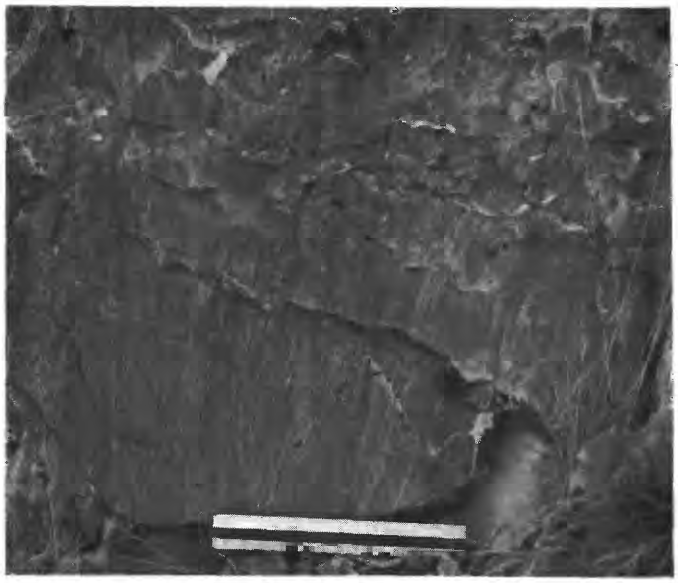

FIGURE 10.—Vertical beds of crossbedded clastic limestone in Teutonic limestone. Outcrop on west side of Gardison Ridge, Boulter Peak quadrangle. Top of beds to right.

(fig. 10) occurs about 80 feet above the base of the formation, and locally this zone contains laminated beds resembling the varvelike layers of the Dagmar dolomite.

Above the zone of laminated beds oolitic limestone is common, some of which is cross bedded. From 135 feet to 300 feet above the base the oolitic limestones are interbedded with pisolitic limestone, and also with banded and mottled limestones identical in appearance with those found in the lower part of the formation. Beds containing *Girvanella*-like bodies are also present in the uppermost part of the formation. In the upper 100 feet of the Teutonic limestone some thin, discontinuous beds of laminated lighter colored limestone are present, and oolites are even more abundant than in the strata below. The laminated beds, however, make up only a small proportion of the section. The upper part of the Teutonic is thinner bedded and finer grained than the limestone below, and a zone of especially thin bedded limestone about 25 feet thick separates the prominently pisolitic part of the section from the finely oolitic, locally laminated rocks above. In many places the contact with the overlying Dagmar dolomite is gradational through a zone about 10 feet thick.

Except for the basal bed, with its distinctive globular algal structures, which locally crops out prominently above the upper shale member of the Ophir formation, no well-defined markers have been found in the Teutonic limestone.

The section of Teutonic limestone given below was measured on the east slope of Eureka Ridge in the main Tintic district.

Stratigraphic section of Teutonic limestone measured on Eureka Ridge near saddle east of Quartzite Ridge, main Tintic district, near center sec. 24, T. 10 S., R. 3 W. (loc. 3, pl. 3)

	Thickness (feet)	Distance above base (feet)
Dagmar dolomite:		
Dolomite, buff to cream-colored, calcareous		400
Contact conformable.		
Teutonic limestone:		
12. Limestone, argillaceous, dark-gray, mottled and finely banded; interbedded with oolite that is especially prominent near the top. Beds in upper 10 ft locally laminated, resembling Dagmar dolomite; some laminae finely crossbedded. Lower 20 ft so thin bedded as to give a varved appearance	100	300
11. Limestone, light bluish-gray, crossbedded, oolitic; oolites less than 1 mm in diameter	2.5	297.5
10. Limestone, medium-gray, obscurely mottled, medium- to thick-bedded; contains many orbicular bodies that may be large pisolites or *Girvanella*(?)	25	272.5
9. Limestone, light-gray, with indistinct mottling; contains many pisolites or *Girvanella*(?) about 1 cm in diameter	9	263.5
8. Limestone, light-gray, sparsely and indistinctly mottled, thin-bedded; bedding not prominent	23	240.5
7. Limestone, thin-bedded, light- to medium-gray; conspicuous elongated mottles parallel to the bedding	16	224.5
6. Limestone, medium-gray, mottled; interbedded with pisolitic and oolitic limestone. Pisolites 2–5 mm in diameter, are irregularly distributed through the lower 20 ft. Upper part is marked by a discontinuous *Girvanella*(?) bed	80	144.5
5. Limestone, medium-gray, massive, oolitic; somewhat crossbedded in upper part	30	114.5
4. Limestone, light-gray, crossbedded, oolitic; oolites less than 1 mm in diameter. USGS coll. 1387–CO from base of unit	25	89.5
3. Limestone, dark-gray, with prominent light-gray argillaceous partings parallel to bedding, commonly 1–2 in. apart. Many of the 1-in.-thick argillaceous seams show fine laminations resembling those of the Dagmar dolomite. A thin non-persistent bed of flat-pebble conglomerate, containing fragments from ¼–1 in. in diameter occurs 10 ft below top of the member	21	68.5

	Thickness (feet)	Distance above base (feet)
Teutonic limestone—Continued		
2. Limestone, medium to dark bluish-gray, thin-bedded, mottled and striped with tan-colored argillaceous limestone. Markings in lower part are irregular and have coarse graphic texture, whereas argillaceous limestone seams in upper part of member are much more regular and mostly parallel to bedding	60	8.5
1. Covered zone 15 ft thick; chiefly limestone. Base of Teutonic assumed to be 8.5 ft below top of this zone	8.5	
Total Teutonic limestone	400	

Contact conformable.

Ophir formation (upper beds only):

Shale, green, fissile; weathers yellowish-brown.

AGE AND CORRELATION

Middle Cambrian fossils were collected from the lower part of the Teutonic limestone in September 1953 by A. R. Palmer, who writes:

> Collection No. USGS 1387-CO. Teutonic limestone at base of unit 4 of measured section; Eureka Ridge, Eureka quadrangle.
>
> *Alokistocare* cf. *A. subcoronatum* (Hall and Whitfield)
> *Kootenia* sp.
>
> These species have also been collected from the Abercrombie formation in the Gold Hill district.

Limestones similar in age and lithologic composition to the Teutonic are widespread in northern and west-central Utah. This formation is believed to correlate with the lower part of the Hartmann limestone of the Ophir district—specifically with Gilluly's units 9–13 (1932, p. 13). This correlation is based on the belief that the dolomitic limestone of the Dagmar is equivalent to the thin-bedded, sandy facies of the Hartmann limestone, units 7 and 8 of Gilluly's section, and that the hornfels at the base of the Bowman limestone corresponds to the shale member of the Herkimer limestone. Olmstead (1921, p. 440) follows Wichman (1920, p. 561) in correlating the Hartmann with both the Teutonic and Dagmar, ascribing the upper 120 feet of the Hartmann to the Dagmar. The chief basis for Wichman and Olmstead's correlations seems to have been the thickness of the formations and their distance above the top of the Ophir formation. We believe it more justifiable, however, to regard units 7 and 8 as facies equivalents of the Dagmar. Gilluly (1932, p. 13–14) was unwilling to attempt to correlate the Dagmar with any part of the section in the Ophir district, but he says (p. 14): "There is little doubt, however, that the lower part of the Hartmann as here described is equivalent to the lower part of the Teutonic limestone of Tintic."

The lithologic composition and succession of the Middle Cambrian beds in the Cottonwood–American Ford area is strikingly similar to that in the Tintic district. There is much evidence, both stratigraphic and lithologic, that the lower Maxfield limestone as defined by Calkins and Butler (1943, p. 14–17) is equivalent to the Teutonic and Dagmar of the Tintic district. The Dagmar is correlated with the finely laminated light-colored dolomite at the top of the lowest member of the Maxfield limestone. The part of the lowest member of the Maxfield lying below that dolomite is about 200 feet thick.

Nolan (1935, p. 10) correlates the Abercrombie formation of the Gold Hill mining district with the Teutonic, Dagmar, and Herkimer formations at Tintic, but the writers would also include the middle and upper parts of the Ophir formation as equivalents of the lower part of the Abercrombie formation. The Teutonic formation is believed to be equivalent to the middle part of the Abercrombie lying below the laminated gray limestone and assocated shales and above the thick shale 550 feet above the base. The total thickness of this part of the Abercrombie is 604 feet, a thickness about 50 percent greater than that of the equivalent Teutonic.

The Millard, Burrows, Burnt Canyon, and Dome limestones, as defined by Wheeler (1948), in southern and eastern Nevada and western Utah are belived to be approximately equivalent to the Ophir, Teutonic Dagmar, and Herkimer section of the Tintic area.

STRUCTURAL HABIT AND UNDERGROUND EXPRESSION

The Teutonic limestone is a strong uniform limestone that fractures into coarse breccias rather than gougy fissures. Near the incompetent upper shale member of the Ophir formation, which underlies it, and the relatively incompetent, laminated Dagmar dolomite above it, the Teutonic shows the greatest degree of brecciation along bedding-plane fractures. In localities where bedding-plane faults are prominent in the Teutonic, strong low-angle movement has almost invariably taken place in the incompetent beds adjacent to it. In many places where no dislocation is apparent near these contacts, the permeability of the Teutonic formation has obviously been increased, reflecting the readjustment of the more competent beds to movement that was absorbed in the shales of the Ophir formation by minor crumpling.

TOPOGRAPHIC EXPRESSION

The Teutonic limestone commonly crops out in steep-sided hills rising above the strike valleys or saddles that mark the Ophir formation. Its nearly uniform character results in comparatively smooth slopes unbroken by persistent cliffs and ledges.

CHEMICAL AND PHYSICAL PROPERTIES

The Teutonic limestone is slightly argillaceous, but averages more than 90 percent calcium carbonate. As shown in table 4, the alumina and silica together average less than 6 percent. The iron oxides average approximately 0.75 percent, and where the rock is undolomitized, the magnesia content averages about 1.6 percent. The first three analyses given in table 4, however, should not be considered superior analyses. Comparison of analyses 5 and 6 show the changes in composition resulting from hydrothermal alteration of limestone to dolomite. There is an obvious gain in both MgO andCO_2 and a marked loss in SiO_2 and and CaO; there is also a suggestion that FeO and the halogens have increased slightly during dolomitization. Although it is not possible from the data available to be certain of the mineralogical composition of the Teutonic limestone, it seems probable that it is similar to the limestones of the Ophir formation and contains a minor amount of ferruginous ankerite, and ferruginous clay minerals.

TABLE 4.—*Chemical analyses of limestone and dolomite from the Teutonic limestone*

	1	2	3	4	5	6
Acid insoluble	3.2	3.8				
SiO_2			1.9		14.11	2.56
Al_2O_3 Fe_2O_3	2.8	2.1	2.1		1.08	1.01
FeO			.20		.07	.18
MgO	2.15	.24	20.13	21.7	2.53	19.98
CaO	50.03	52.33	29.5	30.4	44.15	29.93
Na_2O					.00	.02
K_2O					.41	.43
H_2O-					.06	.07
H_2O+					.20	.18
TiO_2					.05	.06
MnO_2					.10	.06
P_2O_5					.03	.03
CO_2	[1] 41.62	[1] 41.33	[1] 44.82	47.9	36.92	45.21
Cl					.01	.04
F					.02	.03
BaO					Tr.	Tr.
Total	99.80	99.80	98.65	100.0	99.74	99.79
Less O					.01	.02
Total					99.73	99.77
Density, bulk			2.795		2.692	2.790
powder				2.87	2.71	2.840
Porosity (percent)					[1] .66	[1] 1.76

[1] Calculated.

1. Composite sample of upper 200 ft of Teutonic limestone, courtesy Chief Consolidated Mining Co. Collected by G. W. Crane.
2. Composite sample of lower 200 ft of Teutonic limestone, courtesy Chief Consolidated Mining Co. Collected by G. W. Crane.
3. Composite sample of dolomite from Teutonic limestone, courtesy Chief Consolidated Mining Co. Collected by G. W. Crane.
4. Pure dolomite (theoretical).
5. Bed 6 inches thick, 50 ft below Dagmar dolomite, west of dolomitized area, 75 ft above Canyon floor, Homansville Canyon. (Lucile N. Tarrant and E. J. Tomasi, analysts.)
6. Same bed as No. 5, but across fissure 12 in. east, where it is hydrothermally dolomitized. (Lucile N. Tarrant and E. J. Tomasi, analysts.)

ALTERATION

In many areas the Teutonic limestone is dolomitized from top to bottom as far as several hundred feet from hydrothermal conduits that cut the formation. In other localities the dolomitization extends out along the uppermost and lowermost beds far beyond the zone in which the middle part is altered. The apparent difference in susceptibility probably reflects permeability induced by bedding-plane movement in the adjacent, less competent formations, and a correspondingly greater penetration by the dolomitizing solutions. The hydrothermal dolomite is somewhat more porous than the original limestone and is more strongly jointed.

The hydrothermal dolomite stands well in mine openings, except in those places where it has been strongly altered by argillizing solutions. Where this type of alteration is extreme, the rock is reduced to a noncohesive mass of dolomite sand. Clay minerals are associated with the sanded dolomite in some localities, especially in the vicinity of jasperoid.

The chemical susceptibility of the Teutonic limestone is like that of the limestone in the Ophir formation, especially near the channels of mineralization. The Teutonic, like the Ophir, was readily changed to jasperoid and to ore where the appropriate solutions gained access to it. In the vicinity of the Tintic Standard ore body, sanded dolomite and fresh hydrothermal dolomite derived from the Teutonic formation adjoin the main ore-bearing area for a distance of several hundred feet. The dolomitization also extends a similar distance above the highest level of ore deposition. An extensive mass of hydrothermally dolomitized Teutonic limestone also crops out in Homansville Canyon northwest of the Copper Leaf shaft, but little exploration has been carried out in this altered area. South of the Apex Standard No. 1 shaft an extensive zone of dolomitization also affects the Teutonic, Dagmar, and Herkimer; but here also there has not been enough exploration to establish the presence or absence of ore.

ECONOMIC IMPORTANCE

The Teutonic limestone contained a substantial amount of ore in the Tintic Standard and the Eureka Lilly mines, and smaller amounts in the North Lily mine. Wherever mineralizing solutions gained access to broken or permeable limestone or dolomitic beds of the Teutonic limestone, ore seems to have been deposited in quantity and grade comparable to that replacing the limestone of the Ophir formation in a similar structural setting.

DAGMAR DOLOMITE

The Dagmar dolomite is only about 80 feet thick, but it is the most distinctive and useful marker bed in the lower part of the stratigraphic section. It is a light-gray, fine-grained, laminated formation that weathers to a light buff or cream color, in marked contrast to the dark blue-gray limestones above and below it. In the East Tintic district the Dagmar crops out only in areas of extensive hydrothermal alteration, and for this reason the exposed Dagmar in this part of the range is a true dolomite. In some of the excellent exposures in the main Tintic district, however, the Dagmar contains about 20 percent calcite and is more accurately described as a silty calcareous dolomite.

DISTRIBUTION

The Dagmar is conspicuously exposed across Eureka Ridge from Mammoth Gulch to Eureka Gulch, and northward along the west limb of the Tintic syncline to a point a short distance beyond the North Beck shaft, where it is covered by lava. It emerges from the lava 400 feet northeast of the Victoria Northwest mine, and extends northward near the western edge of the range to the south border of the Boulter Peak quadrangle. Between this point and the Tintic Prince fault it is cut out by a steep fault of moderate displacement. Between the Tintic Prince and Gardison Ridge faults the Dagmar is exposed on both limbs of the North Tintic anticline, but north of the Gardison Ridge fault it is exposed only on the east limb, where it crops out for about 1 mile, trending north-northwestward before it swings toward the anticlinal axis and is buried under the alluvium of Broad Canyon. It is also moderately well exposed in the North Tintic district on the northwest side of Iron Canyon, in a series of fault blocks north and west of the Tintic Prince mine.

In the East Tintic district the Dagmar crops out on both sides of U.S. Route 6 in the vicinity of the White Star adit, near the mouth of Homansville Canyon. The exposures are excellent in this area, but the formation is so complexly broken by steep and low-angle faults that its full thickness can be measured in only a few places. Parts of the Dagmar are well exposed in the strongly faulted area between the Eureka Lilly and Tintic Standard No. 1 shafts, but no complete section is well exposed in any single fault block. The Dagmar is also exposed on Mineral Hill and in several fault blocks south and southwest of the Apex Standard No. 1 shaft in Burriston Canyon, but these exposures are relatively small and unsuited to a detailed study of the formation.

A laminated limy dolomite believed to be the Dagmar also crops out in the extreme southeastern part of the East Tintic Mountains in the SE¼ sec. 15, T. 12 S., R. 2 W., and in the south-central part of the range near the Tintic Chief prospect in the NW¼ sec. 24, T. 12 S., R. 2½ W.

The Dagmar has been cut underground in several of the mines in the East Tintic and Tintic districts, the most important of which are the Tintic Standard, Eureka Lilly, Apex Standard, Lower Mammoth, and Dagmar mines. The small thickness and distinctive characteristics of the unit make it invaluable in deciphering complex structure underground in these mines and also at the surface, especially in the relatively small areas of sedimentary rocks that are surrounded by lava in the East Tintic district.

THICKNESS AND LITHOLOGIC CHARACTER

The Dagmar ranges in thickness from about 60 to 100 feet, but the transitional character of the beds at the base does not permit selection of the basal contact within several feet in some areas. The minimum thickness was measured in the East Tintic district and the maximum was measured on Eureka Ridge southwest of Eureka.

Almost all of the Dagmar is a thin-bedded fine-grained laminated limy dolomite that weathers with a characteristic blocky fracture and a creamy white color (figs. 11 and 12). In the section exposed on Eureka Ridge, the basal part of the formation contains intraformational conglomerate in beds a few inches thick through a zone of about 10 feet. In the Homansville Canyon section, however, the base of the formation is characterized by several thin layers of siltstone, which are dominatly quartz; the upper part of the section, 10 feet below the Herkimer limestone, is marked by a shaly zone about 3 feet thick, which grades from shaly dolomite at the top and bottom to fissile green shale in the middle. Elsewhere in the Tintic and East Tintic districts neither shale nor quartz siltstone was observed in the Dagmar. The section measured in Homansville Canyon is given below.

FIGURE 11.—Characteristic outcrop of Dagmar dolomite. Note blocky fracture. Outcrop on Bluebird Spur, Tintic Junction quadrangle.

Stratigraphic section of Dagmar dolomite measured 2,000 feet northwest of the Copper Leaf shaft, East Tintic district, in the NE¼NE¼ sec. 9, T. 10 S., R. 2 W. (loc. 4, pl. 3)

	Thickness (feet)	Distance above base (feet)
Herkimer limestone (lowest bed only):		
Limestone, dark blue-gray, dolomitic		65.5
Contact conformable.		
Dagmar dolomite:		
16. Dolomite, silty, slightly limy, laminated	0.2	65.3
15. Dolomite, light-gray, laminated; beds 3–8 in. thick, weathers creamy white	3.5	61.8
14. Siltstone, limy	.1	61.7
13. Dolomite, light-gray, laminated	1.0	60.7
12. Siltstone, limy	.1	60.6
11. Dolomite, light-gray, laminated; beds 4–6 in. thick, separated by shale and silt partings	5.5	55.1
10. Shale, silty, gray to buff; slightly calcareous, laminated, laminae paper-thin	3.	52.1
9. Dolomite, light-gray; paper-thin laminae	5.7	46.4
8. Siltstone, limy	.1	46.3
7. Dolomite, light-gray; in beds 1–3 ft. thick marked by narrow darker gray bands, separated by light-gray laminated silt beds about 1 in. thick	9.3	37.0
6. Dolomite, medium-gray, laminated	4.0	33.0
5. Dolomite, light- to medium-gray, thinly banded; beds 6 in. to 1 ft. thick, separated by laminated siltstone	10.0	23.0
4. Dolomite, light gray, thinly banded; beds 1–4 in. thick, separated by beds of silty dolomite ½–1 in. thick	8.5	14.5
3. Dolomite, light-gray, laminated; beds are paper thin	2.5	12.0
2. Siltstone, gray, finely laminated; weathers cream to buff	.4	11.6
1. Dolomite, medium-gray, laminated; beds 6 in. to 2 ft. thick, separated by beds of buff laminated siltstone ¼–1 in. thick. Siltstone at the base resembles novaculite	11.6	
Total Dagmar dolomite	65.5	
Contact conformable.		
Teutonic limestone (upper bed only):		
Limestone, Hydrothermally dolomitized, dark blue-gray.		

AGE AND CORRELATION

No fossils have been found in the Dagmar dolomite, but it must be Middle Cambrian in age, for faunas of this age have been found in rocks that are both higher and lower than the rocks in the section.

In the Cottonwood–American Fork area, 50 miles northeast of the Tintic district, a finely fluted pale yellowish-white sandy dolomite at the top of the lower member of the Maxfield limestone is strikingly similar in appearance to the Dagmar dolomite of the Tintic district. Its stratigraphic position about 200 feet above the Ophir shale (Calkins and Butler, 1943, p. 16), the lack of any similar beds above or below it, and the similarity of the rest of the lower member of the Maxfield to the Teutonic limestone strongly suggest that this pale yellowish-white bed is equivalent to the Dagmar. No beds showing the distinctive laminated dolomite layers so characteristic of the Dagmar are known in the Stockton and Fairfield quadrangles, 30 miles north of the Tintic district, and Gilluly, (1932, p. 13–14) therefore, did not attempt to correlate the Dagmar with any specific member of the Cambrian in the Ophir district. The silty and argillaceous character of the Dagmar in the Tintic district is distinct from the cleaner limestones above and below it, and suggests the possibility of a correlation with similar limestones in other districts, even though the laminated beds are missing. It is therefore of interest to note that the Hartmann limestone of the Ophir district contains a sandy member 307 feet above the upper part of the Ophir formation; this member (unit 8) is described by Gilluly (1932, p. 13) as follows:

FIGURE 12.—Laminated, white-weathering dolomite characteristic of Dagmar dolomite. Outcrop near crest of Eureka Ridge, Eureka quadrangle.

Limestone, dark blue, weathering lighter blue-gray, in beds ½ inch to 1½ inches thick separated by buff- to cream-weathering sandstone in layers ⅛ to ½ inch thick Sparsely fossiliferous; 102 feet thick.

The Hartmann limestone, which is 654 feet thick, contains no other member that seems a probable equivalent of the Dagmar.

The Cambrian section of the Gold Hill district, 100 miles west of Eureka, Utah, is much thicker than that of the East Tintic Mountains, and Nolan has subdivided it into thicker units. Nolan (1935, p. 10) correlates the Abercrombie, which is 2,708 feet thick, with the Teutonic, Dagmar, and Herkimer formations of Tintic. It is believed by the writers that the two shale beds and the interlayered laminated gray limestone, totaling 534 feet in thickness, which occur 858 feet below the top of the Abercrombie formation may be equivalent to the Dagmar dolomite of the Tintic district. It is probable that Nolan's collection of Middle Cambrian fossils, No. 17 (*Obolus* sp.; *Elrathia* sp.), came from this member of the Abercrombie.

STRUCTURAL HABIT

The Dagmar is an incompetent formation and in the East Tintic district it has been the locus of low-angle movement. The granulation or brecciation that accompanied the movement increased the permeability of the formation and made it especially susceptible to hydrothermal alteration. In most places it has been altered to dolomite, but in areas of intense mineralization it has been argillized, jasperoidized, or replaced by ore. It is somewhat more competent than shale, and few cross-breaking faults die out in the Dagmar, as many do in the shales of the Ophir formation.

TOPOGRAPHIC AND UNDERGROUND EXPRESSION

The Dagmar dolomite differs little from the overlying and underlying beds in its resistance to weathering. Its thin-bedded character is responsible for outcrops that are somewhat more ledgy than those of the thicker bedded limestones that overlie and underlie it. The Dagmar is more strongly jointed than the Herkimer and the Teutonic formations, and underground the characteristic blocky fracture of the formation is a valuable aid in its identification. The joint blocks are comparatively small, commonly only an inch or more on a side. In spite of its tendency to break into such small blocks, the formation stands well and requires no timber for support where it is not argillized or converted to sand-textured solution breccias.

CHEMICAL AND PHYSICAL CHARACTER

As shown in analyses 1–3 in table 5, the Dagmar dolomite is a siliceous limy dolomite containing approximately 65 percent dolomite, 20 percent calcite, and about 15 percent quartz, clay, and iron oxide.

No information is available concerning the physical properties of the Dagmar dolomite other than the figures given in table 5 for density and porosity.

ALTERATION

The Dagmar dolomite is more extensively altered in the East Tintic district than any bed above the Ophir formation. This probably reflects the permeability induced by extensive low-angle readjustments in the laminated beds of the Dagmar during tectonic disturbances, and the lack of similar deformation in the more massive overlying and underlying limestones. In the Tintic Standard mine the Dagmar is dolomite wherever it is exposed, but near ore it has been converted to jasperoid, silica, or clay minerals, or has been "sanded"—that is, delithified by solutions to a sandy-feeling but coherent aggregate of granular dolomite crystals—with a resulting porosity as much as 30 percent.

TABLE 5.—*Chemical analyses of fresh and hydrothermally dolomitized Dagmar dolomite*

	1	2	3	4
Acid insoluble	--	10.4	--	--
SiO_2	10.79	--	14.8	10.60
Al_2O_3	2.48	} 2.8	{ 1.9	1.31
Fe_2O_3	.14		.95	.87
FeO	.82	--	.35	.25
MgO	14.08	13.6	16.6	18.24
CaO	31.40	32.0	25.9	26.89
Na_2O	.08	--	--	None
K_2O	.41	--	--	.50
H_2O+	.04	--	--	.18
H_2O-	.59	--	--	.56
TiO_2	.05	--	--	.06
CO_2	38.96	[1]38.8	37.4	40.74
P_2O_5	.02	--	--	.02
SO_3	--	--	--	--
MnO	trace	--	--	.09
Total	99.86	97.6	97.90	100.31
Density, bulk	2.805	--	2.767	2.05
Density powder	--	--	2.845	2.85
Porosity (percent)	--	--	2.74	28.07

[1] Calculated.

1. Composite sample of least-altered limy dolomite of the Dagmar dolomite from ridge south of Eureka, 2,700 ft west of Eureka Peak. R. E. Hamm, analyst, University of Utah, Salt Lake City, Utah.
2. Composite sample of limy dolomite of the Dagmar dolomite collected by Guy W. Crane, locality unknown. Partial analysis courtesy Chief Consolidated Mining Co.
3. Composite sample of limy dolomite of the Dagmar dolomite, collected 300 ft northwest of Tintic Standard No. 1 shaft and 100 ft west of jasperoid area. B. W. Deason, analyst, Salt Lake City, Utah.
4. Coherent dolomite sand resulting from partial hydrothermal leaching of hydrothermally dolomitized dolomitic limestone of the Dagmar dolomite, 800 level Tintic Standard mine, 465 ft north of No. 2 shaft. R. E. Stevens, analyst.

ECONOMIC IMPORTANCE

Small to moderate amounts of ore have been mined from the Dagmar dolomite in the Tintic Standard, Eureka Lilly, Lower Mammoth, and other mines, but it is difficult to estimate the exact amount because the formation is hard to recognize where it has been greatly altered. The total amount, however, is probably less than $1 million in value.

HERKIMER LIMESTONE

The Herkimer limestone is closely similar in appearance to the Teutonic limestone, but these two units are regarded as separate formations because they are separated by the distinctive Dagmar dolomite. The Herkimer consists chiefly of moderate- to well-bedded limestone but includes 20–30 feet of interbedded green fissile shale and shaly limestone about 180 feet above the base. This shaly unit is here named the shale member of the Herkimer limestone, and the limestone units are named the lower member of the Herkimer limestone and the upper member of the Herkimer limestone. The lower limestone member is dominantly dark-blue fine-grained limestone, mottled or striped

FIGURE 13.—Mottled limestone in lower part of Herkimer limestone. Note similarity to limestones in Ophir formation and Teutonic limestone; top of beds to right. Outcrop on Gardison Ridge, Boulter Peak quadrangle. Compass is 2¾ inches square.

with bands and stringers of mudstone that weather buff, pink, or yellowish gray (fig. 13). It is locally oolitic but generally contains less oolite than most of the Teutonic limestone. The upper limestone member is lithologically similar to the lower limestone member but contains thin beds of flat-pebble conglomerate (fig. 14), which are almost lacking in the Teutonic.

The thin-bedded upper part of the Herkimer resembles some of the limestone units of the Opex formation and the Opohonga limestone, but it is not as fossiliferous or as red-weathering as the Opex and does not contain as many beds of flat-pebble conglomerate as the Opohonga.

FIGURE 14.—Flat-pebble limestone conglomerate in upper member of Herkimer limestone. Exposure on west side of Gardison Ridge, Boulter Peak quadrangle. Specimen from zone a few feet above shale member.

DISTRIBUTION

The outcrop of the Herkimer closely follows that of the Dagmar dolomite described on page 29, but the shaly limestones of the Herkimer are generally much less well exposed than the dolomites of the Dagmar, which are more resistant to weathering. On the whole, the Herkimer in the main Tintic district can best be studied in the exposures that cross Eureka Ridge near the Herkimer shaft, from which the formation was named. In the East Tintic mining district it is considerably faulted and hydrothermally dolomitized. In the North Tintic district the Herkimer is well exposed on the west slopes of County Line and Gardison Ridges and in numerous fault blocks west of the Hot Stuff and the Tintic Prince prospects. The lower part of the Herkimer is also exposed in the south-central part of the East Tintic Mountains near the Tintic Chief prospect in the NW¼NW¼ sec. 24, T. 12 S., R. 2½ W.

THICKNESS

The widespread occurrence of faults in the prominently exposed sections of the Herkimer limestone in the East Tintic Mountains makes it difficult to give satisfactory estimates of the formation's thickness. In the various sections that were measured the thickness ranges from about 350 feet to more than 430 feet. The thickest section measured is in the North Tintic district, and the thinnest in the East Tintic district.

LITHOLOGIC CHARACTER

Although the limestone members of the Herkimer are similar to mud-streaked limestone beds in the Ophir, Teutonic, and other formations, they are distinctive in many details. The lower member of the Herkimer is principally blue-gray limestone, thin- to medium-bedded, streaked and mottled with irregular lighter colored argillaceous layers which are commonly less than one-half inch thick. Near the base it contains a few thin beds of pisolite, flat-pebble conglomerate, and clastic crossbedded limestones; near the top zones of oolitic and pisolitic limestone are prominent.

The shale member of the Herkimer is composed chiefy of fissile green shale and flat-pebble conglomerate interbedded with thin layers of shaly limestone. The most prominent shale layer is from 10 to 20 feet thick and is part of a zone of interbedded shale and limestone 20–30 feet thick.

The upper limestone member of the Herkimer is dominantly a thin-bedded mottled blue-gray limestone but contains many beds of flat-pebble conglomerate and a few beds of oolite. Shale partings are common in the uppermost part of the unit, and the argillaceous material that seams and mottles the limestone commonly weathers yellowish-gray to pink.

The section given below is typical of the Herkimer limestone throughout the East Tintic Mountains but is somewhat thicker than average.

Stratigraphic section of Herkimer limestone measured 3.5 miles north-northwest of Eureka, along ridge east of Hannifin Peak, North Tintic district, in the NW¼ sec. 35, T. 9 S., R. 3 W. (loc. 5, pl. 3)

	Thickness (feet)	*Distance above base (feet)*
Bluebird dolomite:		
Dolomite, dusky blue-gray, twiggy		427.5
Contact conformable.		
Herkimer limestone:		
Upper member:		
21. Limestone, blue-gray, mottled with irregular seams of greenish-gray argillaceous material both parallel with and at an angle to the bedding; contains some blotchy mottles caused by lenticular accumulations of clastic limestone. Both types of mottled limestone are interbedded with thin layers of oolitic and flat-pebble conglomerate	27.0	400.5
20. Limestone, light blue-gray, well-bedded, with argillaceous layers from ½–2 in. thick, chiefly parallel with the bedding	19.5	381.0
19. Limestone, light blue-gray, well-bedded, streaked with argillaceous layers ½–2 in. thick, parallel with bedding, that weather yellowish-gray; some pinkish-gray mottled layers present locally. Contains a few thin layers of flat-pebble conglomerate and some green shale partings most abundant about 80 ft above uppermost shale bed of shale member of the Herkimer	159.0	222.0
Shale member:		
18. Clay shale, dominantly green to buff with no visible mica or sericite, in beds from 3 in. to 10 ft thick, interlayered with lenticular limestone and flat-pebble conglomerate beds from 3 in. to 2 ft thick	21.0	201.0
Lower member:		
17. Limestone, light-gray, fine-grained, thin-bedded	12.0	189.0
16. Limestone, light-gray, thin-bedded, possibly contains some shale but is poorly exposed	8.0	181.0
15. Limestone; light-gray, fine-grained, thin-bedded; flat-pebble conglomerate at base	3.5	177.5
14. Limestone, light-gray, fine-grained; occurs chiefly as nodular masses in a matrix of yellow mudstone	43.0	134.5
Herkimer limestone—Continued		
Lower member—Continued		
13. Limestone, medium blue-gray mottled with yellowish-gray, fissile; contains many beds of pisolites and oolites, some of which grade along strike into yellowish mottled gray limestone	11.5	123.0
12. Limestone, blue-gray, coarsely mottled with greenish-gray branching argillaceous blotches and seams, interbedded with medium-bedded, light blue-gray limestone containing many oolites	3.0	120.0
11. Limestone, light-gray, finely fragmental and slightly fissile	6.0	144.0
10. Limestone, light-gray, fissile; contains some nodular chert	3.0	111.0
9. Limestone, gray, irregularly thin-bedded; contains argillaceous blotches about ½ in. thick and 2 in. long that weather pink	6.0	105.0
8. Limestone, light-gray, finely fragmental and somewhat fissile	2.0	103.0
7. Hydrothermal dolomite, dark blue-gray, with sparse light-colored twiggy markings, medium-grained, massive to medium-bedded	10.0	93.0
6. Hydrothermal dolomite, pinkish-gray, coarsely crystalline; weathers buff	2.0	91.0
5. Hydrothermal dolomite, light-blue, granular; contains thin layers of dark blue-gray, fine-grained dolomite 1–10 in. apart	24.5	66.5
4. Hydrothermal dolomite, blue-gray, thin-bedded; interlayered with dark blue-gray argillaceous dolomite ¼–2 in. thick	27.5	39.0
3. Hydrothermal dolomite, light blue-gray, thin-bedded; streaked with short, thin, noticeably discontinuous bedding-plane partings of dark-gray argillaceous dolomite	5.0	34.0
2. Hydrothermal dolomite; originally cross-bedded clastic limestone and intraformational breccia made up of fragments up to one-half inch in diameter	5.0	29.0
1. Hydrothermal dolomite, dark blue-gray; mottled with irregular light blue-gray slightly argillaceous dolomite. Some of the lighter colored material is thinly laminated; dolomite is siliceous in upper part and pisolitic in lower 6 ft	29.0	0
(Fault at the base of this hydrothermal dolomite member repeats it, but the member is entirely limestone on the southwest side of the fault. Both the limestone and the dolomite equivalent may be seen in conformable contact with the Dagmar dolomite below the pisolitic bed.)		
Total Herkimer limestone	427.5	

As may be seen from the above section, the most distinctive features of the Herkimer limestone are the shaly beds in the middle part of the formation (unit 18), the lack of sand, and the absence of chert.

CONDITIONS OF DEPOSITION

The thick section of Cambrian limestone in central and western Utah suggests deposition in a slowly sinking geosyncline adjacent to land masses having little relief. The presence of *Girvanella* (?) in many of the limestones suggests shallow water, and the abundance of intraformational conglomerate, oolites, pisolites, and cross-bedded structure indicate deposition in strongly agitated water and intermittent withdrawals of the sea (Eardley, 1938, p. 1359 and 1387; Pettijohn, 1949, p. 301).

Although the oolites probably formed in the zone of wave action, they are believed to represent an environment somewhat different from that in which the intraformational conglomerates formed. The flat-pebble conglomerates in the Herkimer limestone commonly grade laterally into shale, but in a few places they grade laterally into oolitic limestone. The writers nowhere observed oolitic limestones grading directly into shale. Pisolitic beds locally grade into flat-pebble conglomerate in one direction and into oolitic beds in the other, and the oolitic beds in turn grade into the mottled slightly argillaceous limestone that is an especially characteristic feature of the Cambrian carbonate rocks.

The gradational changes of the oolites, flat-pebble conglomerates, and related rocks may be chiefly related to the environment of deposition of sediments of somewhat different composition. Pisolites and oolites, like the source beds of flat-pebble conglomerates, may have been exposed above the level of wave action. The oolites , however, consist of relatively pure calcite with a minimum of admixed detrital clay, quartz, and mica. Such material, when exposed to the wind and air, might have accumulated in dunes, just as dunes of oolites now accumulate during low-water stages on the shores of Great Salt Lake. Where the sediment contained an appreciable amount of clay, exposure to the air might result in calcareous mud flats gradually desiccating and giving rise to mud cracks with resultant mud chips and spalls; when waves advanced over this surface, much of the material would be incorporated as flat-pebble conglomerates, but an appreciable part of the fine mud fraction could be carried out to sea to be deposited as clay, ultimately to form the shale that grades laterally into the flat-pebble conglomerate. However, submergence of the oolite dunes, would yield no flat-pebble conglomerate beds but might well result in a cross-bedded oolite that grades laterally into flat-pebble conglomerates and outward into fine-grained limestone, rather than into shale.

AGE AND CORRELATION

With the exception of some trilobite fragments that occur in the shale member, the Herkimer limestone in the East Tintic Mountains has not yielded any fossils that could be identified. However, the stratigraphic position of the Herkimer, above the Middle Cambrian Ophir and Teutonic formations and below the Middle Cambrian Bluebird and Cole Canyon dolomites, shows that it also is Middle Cambrian. On Long Ridge, a few miles east of the East Tintic district, Muessig (1951[5], p. 26, 199–200) collected brachiopods from a shale zone about 100 feet below a dolomite unit that he correlated with the Bluebird dolomite. These brachiopods were identified by G. A. Cooper (written communication quoted by Muessig, 1951[5], p. 26) as ". . . *Lingulella* . . . These *Lingulella* suggest *L.* (*Westonia*) *wasatchensis* Walcott but the ornamentation of the valves is not quite correct."

The Herkimer limestone is correlated with the middle member of the Maxfield limestone of the Cottonwood-American Fork area (Calkins and Butler, 1943) chiefly because of the lithologic similarity. The light-colored dolomite, which is just below the base of this member, strongly resembles the Dagmar, and the fissile olive-green shale interbedded with nodular, mottled limestone in a zone extending from 145 to 220 feet above the base of the middle member correlates well with the shale facies of the Herkimer in the Tintic district. The lithology of the middle part of the Maxfield both above and below the shaly zone is also strikingly similar to that of the Herkimer above and below the shale zone in the Tintic district. The thickness of the middle part of the Maxfield is 270 feet (Calkins and Butler, 1943, p. 17). Fossils found in the shaly zone of the middle part of the Maxfield have been classed by L. D. Burling as representing the lower part of the Middle Cambrian (Calkins and Butler, 1943, p. 18).

Correlation of the Tintic section with the rocks exposed in the Stockton and Fairfield quadrangle (Gilluly, 1932) is more difficult, even though the Fairfield quadrangle is only 25 miles north of the East Tintic district. Reasons for correlating the Dagmar with the middle part of the Hartman limestone have been given on page 30. It is believed that the upper 207 feet of the Hartman limestone correlates with the lower member of the Herkimer limestone, and that the shale member of the Herkimer can be correlated

[5] See footnote, p. 16.

with the prominent limy argilite now represented in the Ophir district by the hornfels bed 41 feet thick that forms the base of the Bowman limestone. The upper member of the Herkimer is correlated with the Bowman limestone above the basal argillite, because of the strikingly similar appearance of this part of the Bowman to the upper member of the Herkimer limestone. The presence of shale in the Herkimer limestone apparently was unknown before the present study of the East Tintic Mountains, and Gilluly (1932, p. 15) was uncertain of the correlation of the Herkimer limestone but states "* * * it [is] highly probable that the rocks of the Bowman as here defined are at least in part equivalent to a portion of the type Herkimer * * *"

The Herkimer is tentatively correlated with the upper beds of the Abercrombie formation in the Gold Hill district, where the beds believed to be equivalent to the Herkimer are 858 feet thick and include a shale bed, 46 feet thick, 188 feet below the top of the formation (Nolan, 1935, p. 9).

STRUCTURAL HABIT AND UNDERGROUND EXPRESSION

The relatively incompetent Dagmar dolomite below the lower limestone member of the Herkimer and the even less competent shale member of the Herkimer have both been loci of low-angle movement at many places in the East Tintic Mountains. The more massive limestone between these two zones is locally brecciated or sheared adjacent to the low-angle faults, and it is correspondingly more permeable and susceptible to alteration than the thin-bedded limestones above the shale member. Cross-breaking faults in the Herkimer commonly are the sites of such intense alteration that it is difficult to assess the degree of brecciation that attended the original movement. However, the pervasive character of the alteration in the Herkimer limestone suggests that the cross breaks originally were accompanied by a substantial amount of brecciation.

The limestone in both the upper and lower members of the Herkimer is sufficiently strong to stand well in underground openings, except where it has been broken by faults. The shale member of the Herkimer and the associated shaly limestones, however, quite commonly make heavy ground, and should be avoided if possible.

TOPOGRAPHIC EXPRESSION

The Herkimer limestone is moderately resistant to erosion, and the more massive lower part of the formation commonly crops out in low cliffs beneath a marked bench that coincides with the shale member. The thin-bedded limestones in the upper member of the Herkimer form slopes more gentle than those formed from the lower member, and usually stand in contrast to the steeper slopes of the overlying massive Bluebird dolomite.

CHEMICAL AND PHYSICAL PROPERTIES

The only chemical analysis of the Herkimer limestone available is the one given in table 6, which represents a sample collected by G. W. Crane; the locality from which this sample was obtained is unknown, but it apparently was a composite of hydrothermal dolomite and normal limestone with little if any shale. The strong megascopic resemblance of much of the Herkimer limestone to the Teutonic limestone suggests that where it is unaltered, more than 90 percent of the formation, exclusive of the shaly zone in the middle part, is calcium carbonate. The shale member of the Herkimer strongly resembles the middle shales of the Ophir formation, analyses of which are given in table 3.

TABLE 6.—*Chemical analysis of composite sample of dolomitic Herkimer limestone*

[Analysis courtesy Chief Consolidated Mining Co. Sample collected by G. W. Crane]

	Percent
Acid insoluble	1.6
Al_2O_3 and Fe_2O_3	2.4
MgO	14.96
CaO	36.03
CO_2 [1]	44.91
Total	99.9

[1] Calculated.

ALTERATION

The lower member of the Herkimer limestone has been extensively dolomitized, but the beds above the shale member of the Herkimer escaped alteration in many places where the lower limestone was completely changed to a dusky blue-gray hydrothermal dolomite. Many of the beds of hydrothermal dolomite display the white twig-shaped or rodlike bodies which are especially abundant in the Bluebird dolomite, and which were formerly believed to be diagnostic of it. Where hydrothermal solutions have had access to it, the Herkimer limestone behaves in all respects like the Teutonic. The successive changes to dolomite, sandy-textured leached dolomite, argillized dolomite, jasperoid, and replacement ore simulate those in the Teutonic, and it is impossible to distinguish between the altered facies of the two formations except by reference to such marker beds as the Dagmar dolomite or the shale member of the Herkimer.

ECONOMIC IMPORTANCE

An appreciable part of the ore mined above the 700 level in the Tintic Standard mine probably came from the Herkimer limestone. The amount of ore found was small, however, as compared to that in the limestone of the Ophir formation, although the physical and chemical characteristics of the rock suggest that it should be as readily replaced by ore as the Ophir under favorable structural conditions.

BLUEBIRD DOLOMITE

In the ore-producing areas of the East Tintic Mountains, the Bluebird dolomite is principally a massive-bedded dusky-blue medium to finely granular oolitic dolomite that contains many white vermicular or twig-like dolomite bodies that average 10 mm in length and 1–2 mm in width (fig. 15). These organic-looking bodies suggest the descriptive term "twiggy," "spangled," or "wormy" dolomite, and beds containing them, which are widespread in the Cambrian of the eastern Great Basin, are commonly referred to as Bluebird type (Gilluly, 1932, p. 16). However, in areas remote from ore, dark-blue limestone in which the twiggy bodies are not readily apparent makes up a considerable part of the formation.

The contact of the Bluebird with the underlying Herkimer limestone is conformable but sharp, except where the Herkimer has been dolomitized. In such areas the Herkimer closely resembles the Bluebird and may be mistaken for it, especially in isolated exposures. Where the contact is gradational, the boundary is arbitrarily placed at the bottom of the lowest "twiggy" bed; a contact so selected, however, may be tens of feet stratigraphically above or below the contact selected in adjacent areas.

Many of the dusky-blue dolomite beds in the Cole Canyon dolomite closely resemble the Bluebird, and the upper contact of the Blubird is therefore placed at the bottom of the lowest white- to buff-weathering, finely banded bed of the Cole Canyon. These white-weathering beds are lenticular and therefore this contact is not precisely at the same stratigraphic position throughout the district. However, the stratigraphic positions of both the upper and low contacts of the Bluebird probably do not vary by more than 10–20 feet in most of the central East Tintic Mountains.

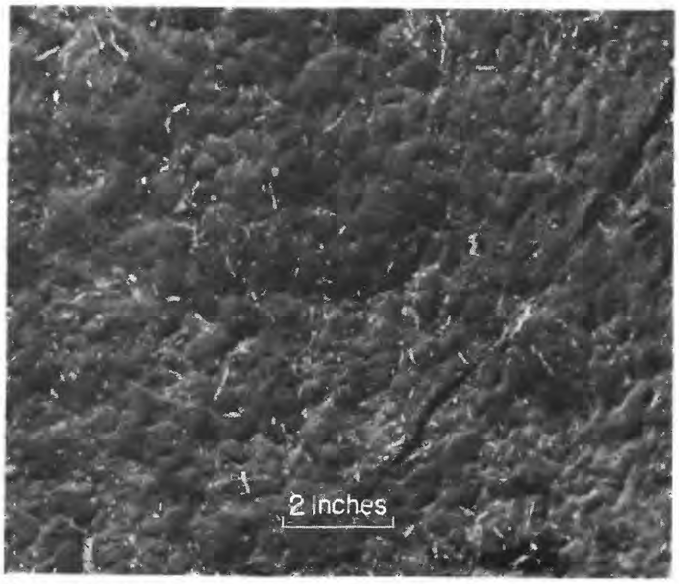

FIGURE 15.—Twig-shaped bodies of white dolomite in massive dark dolomite; characteristic lithology of Bluebird dolomite. × ⅓. Specimen from Eureka Ridge, Eureka quadrangle.

DISTRIBUTION

The Bluebird crops out prominently in nearly vertical beds on both sides of Eureka Ridge between Mammoth and Eureka Gulches, but it is perhaps best exposed about three-fourths of a mile west of Eureka on Bluebird Spur, the locality from which the formation was named. In this area it is relatively unfaulted and little altered, but it contains less limestone than is characteristic of the formation farther to the north. Near the Dagmar prospect the Bluebird is offset to the east along the Paxman and other faults, beyond which it is again well exposed in a continuous, unfaulted outcrop to Jenny Lind Canyon, on the north side of which it is concealed by the Packard quartz latite.

North of the lava cover in the North Tintic district the Bluebird follows first the west side and then the east side of the crest of County Line Ridge nearly to the Tintic Prince fault, a short distance south of which it is displaced and locally concealed by a strike fault. North of the Tintic Prince fault, along which it is shifted to the east approximately 6,000 feet, the Bluebird forms the crest of Gardison Ridge as far north as the Gardison Ridge fault, which again displaces it some 2,500 feet to the east. North of the Gardison Ridge fault the Bluebird trends northwesterly across the ridge crest, and as it approaches the axis of the North Tintic anticline it is concealed by the alluvial fill of Broad Canyon. West of Broad Canyon the Bluebird is exposed in a number of fault blocks extending from a point about one-fourth of a mile southeast of the Hot Stuff prospect southwesterly to the head of Iron Canyon and thence along the northwest side of Iron Canyon to the edge of the range.

In the East Tintic district, unfaulted but more or less hydrothermally altered sections of the Bluebird crop out in the immediate area of the Montana shaft in Burriston Canyon, and on the east side of Silver Pass Canyon 1,500 feet east of the Trixie prospect. Incomplete sections are exposed in a number of places, the most accessible being (a) adjacent to U.S. Route 6 in Homansville Canyon, (b) on the hill between the North Lily and Tintic Standard No. 2 shafts, and (c) adjacent to the Silver Pass road 1,400 feet south of the Eureka Standard shaft.

THICKNESS AND LITHOLOGIC CHARACTER

The dolomitic phase of the Bluebird is found chiefly near the productive mines and the areas of intrusive rocks in Tintic, East Tintic, and North Tintic districts, and the limestone phase is virtually restricted to areas that are beyond the limits of ore production. On Bluebird Spur west of Eureka, the middle part of the formation is somewhat calcitic; on County Line Ridge, 3½ miles north-northwest of Eureka, the Bluebird is mostly limestone. Gilluly (1932, p. 17) also reports that in the Stockton and Fairfield quadrangles, 30 miles north of Eureka, possibly equivalent beds comprising the lower 216 feet of the Lynch formation are limestone over wide areas remote from mineralization. Nolan (1935, p. 10–11) has described beds of similar lithology in the Middle Cambrian Young Peak formation of the Deep Creek Mountains, 100 miles west of the Tintic district. The Young Peak formation there changes within the space of 4 miles from a dolomite with the characteristic twiglike markings to a similarly marked limestone.

The limestone beds of the Bluebird dolomite are medium gray to dusky blue and fine grained, and only rarely contain the "twiggy" bodies that are characteristic of the dolomite beds. On casual inspection they resemble the dolomite layers, but they are lighter colored and finer grained.

The following section is representative of the Bluebird dolomite in the mining districts:

Stratigraphic section of Bluebird dolomite measured on south slope of Eureka Ridge, 1¼ miles south-southwest of Eureka, main Tintic district, in the SE¼ sec. 24, T. 10 S., R. 3 W. (loc. 6, pl. 3)

	Thickness (feet)	Distance above base (feet)
Cole Canyon dolomite (lowest bed only):		
Dolomite, light-gray; scattered chert nodules in lower part	-----	204.5
Contact conformable.		
Bluebird dolomite:		
10. Dolomite, dusky-blue, studded with stubby branching "twigs;" bedding massive; contains scattered grains of clear quartz 1–2 mm in diameter	36	168.5
9. Dolomite, medium dusky-blue, faintly mottled; medium to massively bedded	13.5	155
8. Dolomite, medium- to light-gray; coarsely oolitic, crossbedded	2	153
7. Dolomite, oolitic, massive, with 1- to 2-in. alternating bands which weather medium gray and very dusky blue; the medium-gray bands are argillaceous. Abundant "twigs" subparallel to bedding	14	139
Bluebird dolomite—Continued		
6. Dolomite, dusky-blue, faintly mottled with lighter bluish-gray splotches; bedding indistinct. "Twigs" are abundant in lower 50 ft but become sparse in upper part	63	76
5. Dolomite, dusky blue-gray, massive bedded, finely oolitic. Moderately numerous stubby, branching, and vermiform "twigs" 1–15 in. long	22.5	53.5
4. Dolomite, very dusky blue mottled with irregular dark brownish gray splotches; "twigs" abundant	3	50.5
3. Dolomite, uniformly dusky-blue, medium to massively bedded; oolites abundant, "twigs" sparse	22	28.5
2. Dolomite, dusky-blue, well-bedded. Bedding marked by irregular brownish-gray argillaceous zones resembling bands in Herkimer. Many layers contain abundant oolites and are locally crossbedded Entire unit studded with small white rodlike branching and vermiform bodies about 10 mm long and 1–2 mm thick. These bodies resemble organic remains but are now composed of crystals of white dolomite and, rarely, calcite	26	2.5
1. Dolomite, dusky-blue, studded with white twig-shaped bodies; interbedded with medium blue-gray oolitic and conglomeratic limestone. Contact placed arbitrarily at bottom of lowest twiggy dolomite bed	2.5	
Total Bluebird dolomite	204.5	
Contact conformable.		
Herkimer limestone (upper bed only):		
Light blue-gray, argillaceous limestone.		

No distinctive beds that can be used as horizon markers are present within the Bluebird, but its dusky blue color and oolitic and "twiggy" beds make it one of the more easily recognized stratigraphic units. This characteristic lithology contrasts markedly with that of the fine-grained light blue-gray mudstone-streaked limestones beneath it.

The thickness of the Bluebird dolomite where measured across excellent exposures on Bluebird Spur and Eureka Ridge is close to 200 feet. The formation is probably thinner than this in the East Tintic district, where it is generally considered to be 180–190 feet thick. In the North Tintic district it is estimated to be about 150 feet thick. As mentioned above, however, the true thickness of the Bluebird may be difficult to estimate with accuracy because of the local gradations of lithology from dolomite to limestone at the base and the lenticular habit of the lowermost white-weathering bed of the Cole Canyon dolomite.

AGE AND CORRELATION

A single collection of Middle Cambrian fossils was made in July 1953 from the Bluebird dolomite by A. R. Palmer of the U.S. Geological Survey, who reports on it as follows:

Collection No. USGS 1388–CO Bluebird dolomite within 10 feet of top of formation on south slope of Eureka Ridge, Eureka quadrangle.

Brachyaspidon (?) sp.

"*Ehmania*" sp.

The collection from the top of the Bluebird contains trilobites similar to forms that have been collected from the upper part of the Abercrombie formation in the Gold Hill district of the Deep Creek range and from the upper member of the Maxfield limestone in the central Wasatch Mountains.

Lithologically, the Abercrombie formation (Nolan, 1935, p. 8–10) is unlike the Bluebird dolomite but in general resembles the Teutonic, Dagmar, and Herkimer formations. However, the overlying Young Peak dolomite, which has a gradational contact with the Abercrombie, is closely similar to the Bluebird dolomite, and is overlain by the Trippe limestone, which is almost identical to much of the Cole Canyon dolomite. In consideration of these relations the writers concur with Nolan (1935, p. 11) and correlate the Bluebird dolomite with the Young Peak dolomite.

Beds similar to the Bluebird in general stratigraphic position and lithologic character were recognized by Gilluly (1932, p. 16–17) in the Lynch dolomite in the Ophir district, but because of the scarcity of fossils and the changes from dolomite to limestone along the strike in the basal beds of the Lynch, he was hesitant to make other than tentative correlations. However, the lithologic similarity of the lower part of the Lynch to the Bluebird and the similarity of the fossils from the two units make it quite possible that the Bluebird dolomite of the East Tintic Mountains is equivalent to the lower 216 feet or more of the Lynch dolomite of the Oquirrh Mountains.

Eardley (1944, p. 828–830) has described dolomites and limestones of the Bluebird type in the north-central Wasatch Range, 100 miles north of the East Tintic Mountains, and suggests a correlation with the Middle Cambrian rocks of the Ophir and Tintic districts. However, because of "discrepancies" in the reconstructed stratigraphic columns of the two areas, which Eardley (1944, p. 830) does not further describe, he believes that these units cannot be directly correlated with dolomites and limestones of about the same age in the Blacksmith Fork area, which is only 25–30 miles north of the area he studied (see Walcott, 1908, p. 190–200; and Deiss, 1938, p. 1105–1124). Nevertheless, the fossils collected from the Bluebird and the stratigraphic position of the formation suggest that it correlates with the lower part of the Bloomington formation of the Bear River Range (Williams, 1948, p. 1133–1134), the lower part of the Marjum limestone of the House Range (Deiss, 1938, p. 1147), and the lower part of the Highland Peak limestone near Pioche, Nevada (Westgate and Knopf, 1932, p. 11–13). The Bluebird and Cole Canyon dolomites together probably correlate with the Geddes limestone and the Secret Canyon shale of the Eureka, Nev., area (Nolan, Merriam, and Williams, 1956, p. 11–16).

UNDERGROUND EXPRESSION

The Bluebird dolomite is recognized in underground openings by its irregular fracture, faint bedding, and granular texture, in addition to its dusky blue color and characteristic white twig-shaped bodies. In the absence of these twig-shaped bodies, the formation is difficult to distinguish from other dolomites. In areas where dolomitization is intense and widespread, it is hard to fix the relative positions of the Bluebird and Herkimer formations except where the Dagmar or the lowermost finely laminated creamy-white beds of the Cole Canyon dolomite can be identified nearby.

Where it is not broken by faults, the Bluebird stands well without support in mine openings.

STRUCTURAL HABIT AND GENESIS

Like most of the dolomites similar to it in appearance and composition in the East Tintic Mountains, the Bluebird is brecciated over wide distances adjacent to crosscutting faults and favors the development of bedding-plane breccias near thrust faults and other low-angle faults.

The recrystallized appearance of the Bluebird and the fact that it appears to have been extensively dolomitized in areas of deformation and intrusion, as contrasted with the nondolomitic character of the formation in areas remote from hydrothermal activity, suggest that the Bluebird was highly susceptible to bedding-plane movement and microfracturing, which allowed pervasive dolomitizing solutions to alter it throughly over areas that may be many square miles in extent. Specific evidence for this origin of the dolomite of the Bluebird admittedly is obscure, but it is significant to note that the Bluebird type dolomite is described as occurring chiefly in mining districts of the eastern part of the Great Basin and in bordering regions of strong compressional deformation, whereas it is rare in well-studied areas of Cambrian sedimentary rocks that are remote from centers of tectonic and hydrothermal activity.

The origin of the twiggy bodies is unknown; they may be the replaced excreta of soft-bodied creatures that have not been preserved, or the remains of tubes constructed by small organisms similar to the protective tubes built by caddis fly larvae. In any event, the twig-shaped bodies appear to be of organic origin, but they do not appear to be the fossilized remains of either a plant or an animal.

ECONOMIC IMPORTANCE

The Bluebird dolomite is the country rock of ore bodies in the Lower Mammoth and Empire mines in the main Tintic district, but the ores produced from this formation probably did not exceed more than a few thousand tons.

COLE CANYON DOLOMITE

DEFINITION

The Cole Canyon dolomite as here defined includes all the Cole Canyon as originally described by Loughlin (Lindgren and Loughlin, 1919, p. 28–29), together with the lower unit of dusky-blue dolomite of the original Opex formation, a section that has a total thickness of 830–900 feet but averaging about 850 feet. The contact of the Cole Canyon and Opex formations was placed by Loughlin (Lindgren and Loughlin, 1919, p. 29–30) at the uppermost light colored bed in the Cole Canyon dolomite. This choice was made necessary in part by the obscure stratigraphic position of the Upper Cambrian fossils found by Weeks "* * * about 300 feet above the Middle Cambrian fossiliferous beds in the Cole Canyon dolomite" (Lindgren and Loughlin, 1919, p. 30); and in part by the convenience of making the Cole Canyon a distinct unit restricted to a zone of alternating light- and dark-weathering dolomites. This arbitrary choice of the dividing line between the Upper Cambrian and Middle Cambrian strata unfortunately combined in the Opex formation 150–250 feet of dusky-blue dolomites, lithologically identical with many strata of the Cole Canyon, and 245 feet of entirely dissimilar limestones, shales, and sandstones containing an Upper Cambrian fauna (Lindgren and Loughlin, 1919, p. 30). It was recognized during the present study that the interval between the uppermost light-gray bed of the Cole Canyon and the lowermost limestone of the Opex formation was not of uniform thickness but decreased in general northward, whereas the thin-bedded limestone, mudstone, and shale section of the Opex was comparatively constant in thickness throughout the area mapped. Principally for this reason, but also to include within the boundaries of the Cole Canyon dolomite all the Middle Cambrian rocks above the Bluebird dolomite—a section that is lithologically quite similar throughout—the Opex formation was restricted to the sandstone, limestone, dolomite, and shale series, but the Cole Canyon dolomite was redefined as described above.

The lower three-fourth of the Cole Canyon consists of alternating light and dark layers of laminated to medium-bedded limestone and dolomite, which weather creamy white and dusky blue-gray (fig. 16). The creamy white laminated beds individually are 2–45 feet thick, but one light-gray bed that is unlaminated attains a thickness of 80 feet. Dark-gray or nearly black laminated beds 2–10 feet thick are common, and the massive unlaminated dusky-blue beds range in thickness from 2 to 100 feet or more.

The upper one-fourth of the Cole Canyon, formerly assigned to the Opex, is chiefly dusky-blue dolomite; some beds are mottled and some are studded with the short white twig-shaped bodies that characterize the Bluebird-type dolomite, and some beds consist of light-gray unlaminated dolomite. Some layers are partly oolitic and crossbedded, and some display surface concentrations of carbonaceous material centered about fragments of poorly preserved fossils.

The upper boundary of the Cole Canyon dolomite is placed at the bottom of the lowest calcareous shale or shaly limestone of the Opex formation, which is the first bed of this type of rock that occurs above more than 1,000 feet of dense, dominantly dark-colored, medium-bedded dolomite and limestone.

DISTRIBUTION

The Cole Canyon dolomite is prominently exposed in the main Tintic district on both sides of Eureka Ridge, and extends south and north from the first main summit west of Eureka Peak to the edge of the alluvial fill of Mammoth and Eureka Gulches. A small ex-

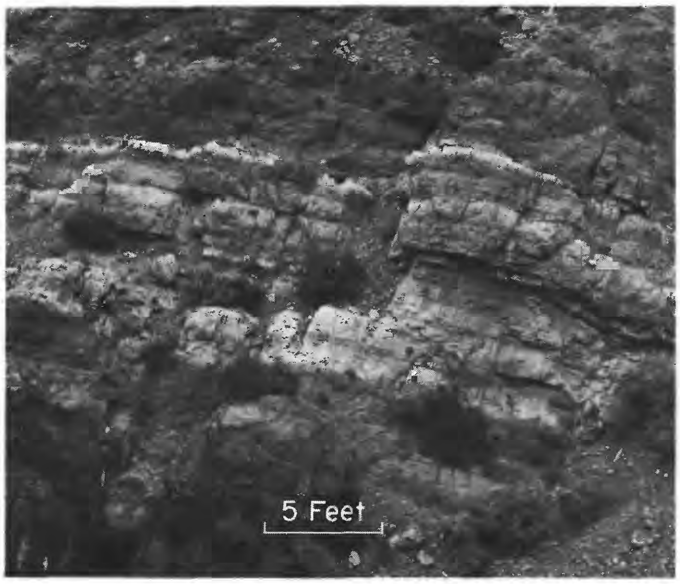

FIGURE 16.—Characteristic outcrop of Cole Canyon dolomite. Note alternating light and dark beds. Outcrop in Homansville Canyon, Eureka quadrangle.

posure is also present on the south side of Mammoth Gulch, in contact with Swansea quartz monzonite, and some of the masses of pyrometasomatized rock surrounded by monzonite of the Silver City stock north of the Cleveland mine are probably Cole Canyon also. Between Eureka Gulch and Jenny Lind Canyon to the north, the Cole Canyon dolomite is well exposed in vertical beds along the west side of the lower part of Cole Canyon, the topographic feature for which the formation was named.

In the North Tintic district the Cole Canyon crops out conspicuously on both flanks of the North Tintic anticline but is partly concealed near the anticlinal axis in Broad Canyon by lava and alluvium. Perhaps the best exposures of the formation in the East Tintic Mountains are on Gardison Ridge. Incomplete sections also crop out at the north base of Pinyon Peak east of the Selma mine, and on the lower eastern slopes of Pinyon Peak one-fourth of a mile west-southwest of the North Standard shaft.

In the East Tintic district, the Cole Canyon dolomite is partly exposed along both sides of Homansville Canyon and in several isolated exposures in Burriston and Silver Pass Canyons, but nowhere in these areas is it so completely exposed that a full section can be measured. A fairly extensive exposure of the Cole Canyon makes up most of the hill north of the Iron King No. 2 shaft and southwest of Mineral Hill; both the top and bottom of the formation are exposed but intense hydrothermal alteration has obscured many of the primary stratigraphic features. Smaller exposures occur 1,000 feet south-southwest of the North Lily mine and in the general vicinity of the Montana shaft.

The Cole Canyon is also extensively exposed in the extreme southeastern part of the East Tintic Mountains in isolated exposures surrounded by lava and agglomerate in secs. 15, 16, 17, and 22 of T. 12 S., R. 2 W. In this area it is chiefly limestone, but many of the light-gray beds, which are common in this area, consist of dolomite.

LITHOLOGIC CHARACTER

The Cole Canyon is easily distinguished from other formations in the East Tintic district by its alternating light and dark strata, thinly laminated beds, and well-stratified appearance. The beds that weather creamy white to light gray are normally medium gray on fresh fracture; many are fine grained and finely banded and resemble the Dagmar (fig. 17), whereas others are granular and massive and resemble the Emerald member of the Ajax formation. The dense, finely banded beds yield a residue of fine white clay and silt when dissolved in hot hydrochloric acid, but the granular variety is almost pure dolomite.

FIGURE 17.—Wavy laminated dolomite in Cole Canyon dolomite. Note channeled contacts and contorted laminae. Laminae are 1–5 mm thick; distance between prominent bedding-plane partings is 5 inches. Outcrop on Eureka Ridge, Eureka quadrangle.

The beds that weather dusky blue and dark bluish gray are still darker on fresh fracture, and range in texture from medium and finely crystalline to subcrystalline and dense. Some beds show fine banding and others mottling or clouding, but most are of uniform color and texture. The more massive, finely granular, dusky-blue beds are commonly studded with small white twig-shaped rods identical with those of the underlying Bluebird dolomite as shown in figure 18; this resemblance makes it virtually impossible to distinguish these beds from the Bluebird in small exposures.

The creamy-white bed at the base of the Cole Canyon commonly carries nodules of light-gray chert 3–6 inches in diameter, but chert is not everywhere present in this unit. The most prominent Bluebird type bed in the Cole Canyon, which occurs from 67 to 135 feet above the base of the formation, is also chert-bearing and is marked at the top by a 5-foot zone carrying nodules of dark-gray chert 1 inch in diameter and 4 inches long. This chert-bearing zone is fairly widespread and may be used to distinguish this part of the Cole Canyon from the chert-free Bluebird dolomite.

Lenses of intraformational conglomerate are common in the lower part of the Cole Canyon, and many of them grade laterally into laminated dolomites. The conspicuous white-weathering, finely banded dolomite units also pinch out along the strike or grade imperceptibly into dusky-blue thin-layered beds. The discontinuity of these distinctive beds prevents their use as horizon

FIGURE 18.—Twiggy dolomite bed of Bluebird type in white-weathering dolomite near top of Cole Canyon dolomite. Note gradational contacts. Outcrop on Gardison Ridge, NE¼NW¼ sec. 12, T. 9 S., R. 3 W., Boulter Peak quadrangle.

markers, except locally, but the zone of cherty dolomite 5 feet thick lying 130 feet above the base of the formation is so persistent within the Tintic and East Tintic mining districts that it can there be used as a marker horizon.

Although the Cole Canyon is preponderantly dolomite in the mining districts of the East Tintic Mountains, much of the formation is limestone in areas remote from the centers of hydrothermal activity (fig. 19). On County Line Ridge 3½ miles north-

FIGURE 19.—Mottled limestone in lower part of Cole Canyon dolomite. Outcrop on Gardison Ridge, NE¼NW¼ sec. 12, T. 9 S., R. 3 W., Boulter Peak quadrangle.

northwest of Eureka, and locally on Gardison Ridge, much of the Cole Canyon consists of mottled and banded limestone interlayered with light-colored laminated dolomite beds. As the formation is followed to the south from about the 40th parallel of latitude the limy layers between the laminated beds can be seen to grade into dolomite, and a mile south-southeast of the point where the 40th parallel crosses County Line Ridge the formation is entirely dolomite. Part of the formation is also limy near the manganese pits on the ridge south of Homansville Canyon, and some beds are true limestone on the north slope of Mammoth Gulch. The local gradation of limestone to dolomite near the centers of ore deposition suggests that some of the dolomite beds may owe their origin, at least in part, to hydrothermal alteration related to the general period of intrusive activity and mineralization.

The following composite section, which was measured on the west side of Cole Canyon 1,500 feet due west of the Sacramento shaft and on Eureka Ridge south-southwest of the Centennial Eureka mine, is typical of the formation throughout the mining districts, but it includes only one bed that we recognized as limestone.

Stratigraphic section of Cole Canyon dolomite. Units 1–28 measured in Cole Canyon 1,800 feet west of Sacramento mine, main Tintic district, in the W½ sec. 13, T. 10 S., R. 3 W. (loc. 7a, pl. 3). Units 29–39 measured on Eureka Ridge, main Tintic district, 600 feet south-southwest of Centennial Eureka shaft, in the E½ sec. 24, T. 10 S., R. 3 W. (loc. 7b, pl. 3)

	Thickness (feet)	*Distance above base (feet)*
Opex formation (lowest bed only):		
Limestone, light blue-gray, shaly, interbedded with shale		852.5
Fault(?) contact; elsewhere contact is apparently conformable but may be disconformable.		
Cole Canyon dolomite:		
39. Dolomite, light-gray, thick-bedded, coarsely crystaline. Six-inch bed of shaly, thin-layered dolomite at top	33	819.5
38. Dolomite, light yellowish-gray, locally conglomeratic. Zone of small white chert nodules at top	11	808.5
37. Dolomite, yellowish-gray, thin-bedded; locally conglomeratic	15	793.5
36. Dolomite, dusky blue-gray, medium-grained, thick-bedded; contains scattered nodules of brown chert ¼–1 in. diameter	4	789.5
35. Dolomite, light blue-gray; mottled with irregular patches of light-gray argillaceous dolomite	16	773.5
34. Dolomite, Bluebird type	5	768.5
33. Dolomite, light blue-gray, finely granular	7	761.5

	Thickness (feet)	Distance above base (feet)
Cole Canyon dolomite—Continued		
32. Dolomite, dark-gray mottled with irregular lighter gray splotches. Finely banded and crossbedded; some thinly banded beds show syngenetic(?) folding	28	733.5
31. Dolomite, lead-gray, medium-grained, medium-bedded	17	716.5
30. Dolomite, dusky blue-gray strongly mottled with light-gray splotches. Conglomeratic bed with yellowish matrix at base	77	639.5
29. Dolomite, dusky blue-gray strongly mottled with white; thin to medium bedded. Many layers contain Bluebird-type white twiggy bodies surrounded by irregular zones of dark dolomite ½–1½ in. wide that weather in slight relief. Lower 2 ft of unit marked by wavy lines of (secondary?) quartz. This bed is the first dusky blue-gray dolomite above the uppermost white-weathering bed that marks the top of the Cole Canyon, as defined by Loughlin, on Eureka Ridge	38	601.5
28. Dolomite, medium- to light-gray, finely banded; weathers creamy white	2	599.5
27. Dolomite, dark blue-gray	4.5	595
26. Dolomite, weathers creamy-white, finely banded	2	493
25. Dolomite, dark blue-gray	35.5	557.5
24. Dolomite, dark- to medium-gray, faintly mottled, well bedded; many 6- to 18-in. beds of Bluebird-type dolomite	56.5	501
23. Dolomite, weathers creamy-white to light-gray; massive, sugary textured	80	421
22. Dolomite, grayish-black, finely-banded	5	416
21. Dolomite, weathers white to very light gray; finely banded	12	404
20. Dolomite, dark-gray, faintly mottled, upper 2 ft finely banded	10	394
19. Dolomite, white to light-gray, finely banded	45	349
18. Dolomite, dark-gray, mottled with lighter gray. Interlayered thin beds of intraformational conglomerate and a few beds of Bluebird-type dolomite. One-foot bed of limestone 48 ft above base	77.5	271.5
17. Dolomite, weathers creamy-white, finely banded	11	260.5
16. Dolomite, medium-gray, finely banded	6	254.5
15. Dolomite, weathers white, finely banded	1.5	253
14. Dolomite, light-gray, well-bedded	2.5	250.5
13. Dolomite, dark-gray with scattered white twiggy bodies. Many 6-in.–1-ft. beds of intraformational conglomerate (pebbles rounded and less than 1 inch in diameter)	58.5	192
12. Dolomite, dark-gray, well-bedded. Individual beds banded with 1–2-in. lighter gray stripes	34	158
Cole Canyon dolomite—Continued		
11. Dolomite, white to light-gray alternating in bands 2–6 in. wide; intraformational conglomerate in upper 2 ft	11	147
10. Dolomite, dull-white to gray, well-bedded and coarsely crystalline	2	145
9. Dolomite, 1–6-in. beds alternately white and light-gray	10	135
8. Dolomite, alternating beds of light-gray and dark blue-gray finely granular dolomite. Light beds weather creamy white; they are finely banded and 3–8 ft thick. Dark beds are of Bluebird type, dense, mottled, and 2–15 ft thick. Top of unit marked by 5-ft zone containing sparse chert nodules 1 in. thick and 3 in. long, dark-gray on fresh fracture, but weathering black. Chert zone 132 ft above base	67.5	67.5
7. Intraformational conglomerate	1	66.5
6. Dolomite, dark-gray, mottled	5	61.5
5. Intraformational conglomerate	1	60.5
4. Limy dolomite, dark-gray, thin-bedded. Beds locally conglomeratic	15.5	45
3. Intraformational conglomerate. Pebbles 1–4 in. long, slightly more limy than matrix	6	39
2. Dolomite, dusky-blue, dense, well-bedded	27	12
1. Dolomite, light-gray on fresh fracture but weathers to creamy-white or very light gray, dense, thinly laminated. Typical of all white-weathering beds of Cole Canyon; resembles Dagmar but much thinner. Rare cherty zones	12	
Total Cole Canyon dolomite	852.5	

Contact conformable.

Bluebird dolomite:

Dolomite, dusky blue-gray twiggy.

DISTINGUISHING FEATURES

The Cole Canyon dolomite is recognized underground and at the surface by its alternating light and dark beds, and by the numerous lenses of intraformational conglomerate in the lower and middle parts of the formation. The creamy-white, finely banded beds may be confused in small outcrops with the Dagmar, but in few places are they more than 25 feet thick. The more massive, finely granular light beds are similar to the Emerald member of the Ajax dolomite, but the abundant chert in the dark dolomites above and below the Emerald member serves to distinguish it except where hydrothermal solutions have removed the chert as, for example, near the Eureka Hill and Centennial Eureka mines. Substantial parts of the Fish Haven and Bluebell formations are similar to parts of the dolomitized mottled limestone of the Cole Canyon, and in small exposures it may be difficult to distinguish the two formations. These limestones, where they are not dolomitized, resemble many of the mottled limestone beds of the Teutonic and Herkimer, but the Cole Canyon includes interbedded light-colored dolomites. Crinoid fragments, which are common in the dark dolomites of the Bluebell, immediately distinguish such beds from the dark dolomites of the Cole Canyon; the laminae of the light-weathering beds of the Cole Canyon are mostly straight, whereas those of the Bluebell are commonly curved and wavy; most of the light-colored beds of the Cole Canyon are also thinner and much more laminated than those of the Bluebell. The dusky-blue beds within the Cole Canyon that resemble the Bluebird dolomite are generally much thinner than the Bluebird, and the only thick twiggy bed in the Cole Canyon contains chert in the upper part, a feature that immediately distinguishes it from the Bluebird.

AGE AND CORRELATION

In 1905 Weeks (cited in Lindgren and Loughlin, 1919, p. 29), found the fossil *Obolus mcconnelli* 1,700 feet above the Tintic quartzite on Eureka Ridge. A similar fossil (*Obolus* sp.) was found at the same horizon by Loughlin (Lindgren and Loughlin, 1919, p. 29) in 1913. Weeks' locality is described more accurately by Walcott (1912, p. 197) as being "* * * in the saddle above and a little east of the Centennial Eureka mine near the summit [of Eureka Ridge]* * * *" Loughlin's map of the main Tintic area (Lindgren and Loughlin, 1919, pl. IV) shows this locality to be near the top of the Cole Canyon dolomite as here defined. Walcott's somewhat more precise definition of the fossiliferous bed of the Cole Canyon also accurately locates the Upper Cambrian horizon of Weeks (which was reported to be 300 feet stratigraphically above the Middle Cambrian fossiliferous beds in the Cole Canyon) as being within the Opex formation as defined in this report.

Walcott (1908, p. 156, 197) correlates the *Obolus* beds of the Cole Canyon provisionally with the "C" member of the Middle Cambrian Marjum limestone between 2,225 and 2,475 feet above the Prospect Mountain quartzite in the House Range section (see also Deiss, 1938, p. 1147).

During the present study, A. R. Palmer made a single small collection of fossils (Colln. No. USGS 1389-CO) from the upper part of the Cole Canyon formation, on the south slope of Eureka Ridge, which included several specimens of *Eldoradia* cf. *E. prospectensis* (Walcott). Concerning this fossil Palmer reports (letter of September 5, 1953):

A collection from the upper part of the Cole Canyon dolomite, in the section exposed on the ridge south of Eureka, contains species of *Eldoradia*. This trilobite was also collected from the Trippe limestone in the Gold Hill district. *Eldoradia* is characteristic of rocks of late Middle Cambrian age, and the Middle-Upper Cambrian boundary, therefore, is probably at or near the Opex-Cole Canyon contact as you have redefined it.

According to Gilluly (1932, p. 17) the Lynch dolomite in the Ophir district resembles the Cole Canyon of Tintic throughout, and he suggests that the two formations are in part equivalent but that the Lynch probably also includes the equivalents of the Bluebird and perhaps the Opex (of Lindgren and Loughlin). The lithologic character of the lower 106 feet of the Lynch dolomite is typical of the Bluebird dolomite, and that of the upper 611 feet is like that of typical Cole Canyon dolomite; the intervening 110 feet of section is less distinctive, but as noted earlier (p. 38) the writers believe it is equivalent in large part to the upper half of the Bluebird dolomite. The upper member of the Maxfield limestone in the central Wasatch Range (Calkins and Butler, 1943, p. 18) is probably equivalent to the Bluebird dolomite; and, as the Maxfield is overlain by the Fitchville formation (the Jefferson(?) dolomite of U.S. Geol. Survey Prof. Paper 201), the beds equivalent to the Cole Canyon are probably missing in this area.

Beds lithologically resembling the Cole Canyon also crop out in the south-central Wasatch Range south of American Fork Canyon (Baker, 1947), and similar units have been observed by the writers in the southern Wasatch Range in North Canyon east of Mona. Eardley (1944, p. 828-830) describes dolomites and limestones lithologically resembling the Cole Canyon dolomite in the Durst Peak area of the north-central Wasatch Range, and the writers have observed similar beds in Ogden Canyon, east of Ogden, in the same general area; the beds in Ogden Canyon have also been described by Eardley (op. cit.).

In northeastern Utah and southeastern Idaho the greater part of the Bloomington formation is proably equivalent to the Cole Canyon (Deiss, 1938, p. 1121-1122), and in the Pioche area, Nevada, the Cole Canyon is probably represented by at least a part of the Highland Peak limestone (Westgate and Knopf, 1932, p. 11-13).

STRUCTURAL HABIT

The Cole Canyon dolomite is structurally competent, and it fails by fracturing rather than by folding. Where cut by faults the formation as a rule is highly shattered and produces a medium- to fine-grained angular breccia, which is most prominent along the fine-banded layers, especially where the fault makes an acute angle with the bedding. However, some of the acute-angle faults turn and follow the finely banded beds, becoming inconspicuous bedding faults.

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TOPOGRAPHIC EXPRESSION

The uniform composition of the Cole Canyon and Bluebird dolomites makes them more resistant to erosion than the somewhat shaly formations above and below. Where the dip is steep, both formations commonly weather in relief and crop out in ridges rising above the adjacent Herkimer and Opex formations. On steep-sided hills, the alternating thin-bedded and medium-bedded strata tend to weather into a succession of steplike outcrops.

CHEMICAL AND PHYSICAL CHARACTER

Near the areas of ore production the Cole Canyon dolomite is a relatively pure dolomite, but some beds have a slight excess of calcium carbonate and small amounts of silica, clay, iron, and carbonaceous material. (See table 7.) The physical constants for this formation are not known.

TABLE 7.—*Chemical analyses of Cole Canyon dolomite*

	1	2	3
Acid insoluble	.	2.8	1.6
SiO_2	8.77		
Al_2O_3		1.2 (Al₂O₃ + Fe₂O₃)	1.8 (Al₂O₃ + Fe₂O₃)
Fe_2O_3	.49		
CaO	27.22	31.2	31.8
MgO	18.53	19.2	19.0
CO_2[1]	41.77	45.5	45.7
Total	96.78	99.9	99.9

[1] Calculated

1. Partial analysis of one of the typical dark dolomite beds of the Cole Canyon; yields H_2S, and carbonaceous residue in acid. (Tower and Smith, 1899, p. 623.)
2. Composite sample of the lower 600 ft. of the Cole Canyon dolomite on Eureka Ridge, collected by G. W. Crane. Analysis courtesy Chief Consolidated Mining Co.
3. Composite sample of 215 ft. of lower Opex dolomite of former usage, classed as upper part of Cole Canyon in this report. Collected by G. W. Crane on Eureka Ridge. Analysis courtesy Chief Consolidated Mining Co.

ECONOMIC IMPORTANCE

The Cole Canyon dolomite has not been recognized as an ore-producing formation in the East Tintic district; in the main Tintic district, however, it has produced much ore in the Centennial Eureka mine, where selective replacement of lithologically different beds has been noted. No information is available, however, concerning the relative susceptibility of the light and dark beds to mineralization.

At the Keigley quarries at the southern extremity of West Mountain, 17 miles east-northeast of Eureka, the Bluebird and Cole Canyon dolomites are quarried for the production of dolomite rock used as flux in the iron blast furnaces at Geneva, Utah. These formations have not been so utilized in the East Tintic Mountains, but they constitute a potential source of raw dolomite.

OPEX FORMATION

The Opex formation is here redefined to include only the beds of limestone and shale, with minor dolomite and sandstone, that lie between the thick series of massive light and dark dolomites and limestones of the Cole Canyon dolomite and the well-bedded cherty dolomites of the Ajax dolomite. This definition restricts the Opex formation to the stratigraphic unit, 140–250 feet thick, defined by Loughlin (Lindgren and Loughlin 1919, p. 29–30) as upper Opex.

DISTRIBUTION

Throughout the East Tintic Mountains as a whole the Opex is poorly exposed. In the main Tintic district it crops out along a line of nearly vertical beds extending from Mammoth Gulch near the Emerald mine northward across Eureka Ridge to the Centennial Eureka mine, where it is offset to the west by the Centennial fault and concealed by mine dumps and surface debris. North of Eureka Gulch the Opex is concealed by the colluvium that fills Cole Canyon, but north of the Paxman fault it is fairly well exposed for 1,700 feet to Porphyry Flat, north of which it is covered for some distance by the Packard quartz latite.

Highly altered Opex is also exposed in the main Tintic district for one-half mile due south of the Lower Mammoth mine at the western edge of the block of pyrometasomatized sedimentary rocks that lies between the main mass of the Silver City monzonite stock and the Sioux-Ajax fault. Other partly digested pendants and xenoliths of limestone of the Opex formation engulfed by the monzonite doubtless occur in this area but they are nearly unrecognizable because of bleaching and recrystallization.

In the North Tintic district the Opex crops out on County Line Ridge from the north edge of the Packard quartz latite, 2,500 feet northeast of the Victoria Manganese prospect, to the Tintic Prince fault, by which it is offset to the east. It then follows the west side of Gardison Ridge to the structural block north of the Gardison Ridge fault, where it swings to the west toward the axial area of the North Tintic anticline and is concealed under the fill of Broad Canyon. On the west limb of the North Tintic anticline it is moderately well exposed on the northwest side of the west fork of Broad Canyon to the pass to Black Rock Canyon, and in a series of fault blocks extending from this area south to the head of Tintic Valley. It also crops out on the main north spur of Pinyon Peak a short distance east of the Selma mine, and in the upper plate of the Pinyon Peak thrust fault a short distance west of the North Standard shaft. An incomplete section is also present in the upper plate of the Allens Ranch thrust fault, in the SW¼ sec. 22, T. 9 S., R. 2 S.

The Opex is not well exposed in the East Tintic district; nearly complete but somewhat contact-metamorphosed sections crop out on the low ridge between the Iron King No. 1 and No. 2 shafts, but these exposures are not suited for a detailed study of the formation.

LITHOLOGIC CHARACTER AND THICKNESS

The Opex formation is quite different lithologically from the more massive, chiefly dolomitic, rocks above and below it. In the main Tintic district, where the Opex is reasonably well exposed at the surface and in mine workings, it is principally a light grayish-blue, thin-bedded limestone interlayered with thin lenses of dolomite, shale, and sandstone. The limestone layers are locally shaly, oolitic, and conglomeratic, and they intergrade with clay shales along the strike and dip. These limestones weather to a litter of thin plates. The shales are greenish gray on fresh fracture but weather buff, yellow, and pink. A persistent thin bed of purple sandstone marks the base of the formation on Pinyon Peak in the North Tintic district, and sandstone also occurs about 28 feet below the top of the formation in both the East Tintic and the main Tintic districts. Layers composed almost wholly of trilobite fragments commonly occur in the oolitic beds of the Opex northwest of Eureka townsite but have not been observed in the East Tintic district.

The Opex varies widely in composition within relatively small areas, and for this reason beds at the same horizon in separate outcrops are difficult to correlate. The limestone layers strongly resemble those in the upper member of the Herkimer limestone, but the interbedded sandy strata, the more numerous thin shale beds, the distinctive yellow and pinkish-red color of the limy shales, and the abundance of flat-pebble conglomerate, especially where it is streaked with sand (fig. 20), all help to distinguish them as Opex.

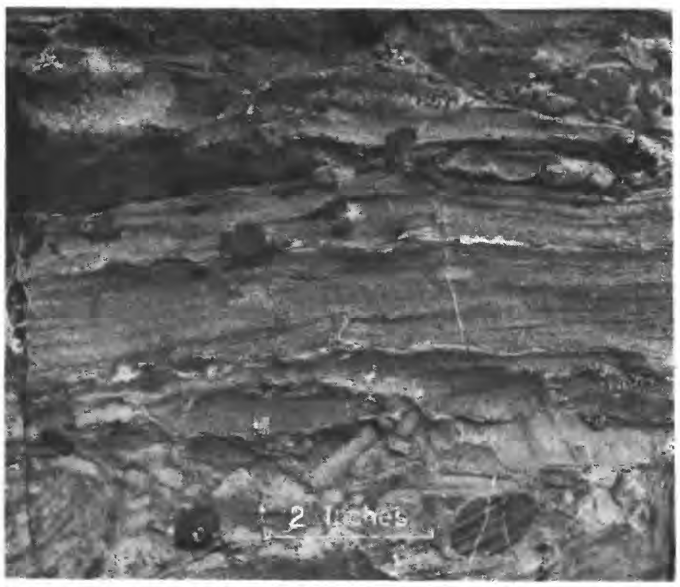


FIGURE 20.—Flat-pebble conglomerate in Opex formation. Sand abundant in matrix and streaking overlying bed. Outcrop near Opex shaft, Eureka quadrangle. × ½.

The Opex differs from the Opohonga limestone chiefly by the presence of dolomite, clay shale, and sandstone; the great thickness and uniform lithologic character of the Opohonga limestone also prevents confusion where a substantial thickness of strata is exposed.

Heavy soil and talus, and many faults, make it extremely difficult to measure complete and undisturbed sections of the Opex in the East Tintic Mountains. The sections presented below, however, are believed to be typical of the formation in the mining areas.

Stratigraphic section of Opex formation measured near Opex shaft, main Tintic district, in SE¼ sec. 24, T. 10 S. R. 3 W. (loc. 8A, pl. 3)

	Thickness (feet)	*Distance above base (feet)*
Ajax dolomite (lowest bed only):		
Dolomite, dusky-blue, mottled, cherty		245
Contact conformable.		
Opex formation:		
12. Shale, gray-green, limy	2	243
11. Limestone, light grayish-blue, thin-bedded; banded with yellowish-gray argillaceous layers 2 in. thick	25	218
10. Sandstone, medium- to light-brown, medium- to fine-grained, thin-bedded. Sandy flat-pebble conglomerate at base	5	213
9. Limestone, dark blue-gray, fine-grained; contains irregular buff-colored sandy and argillaceous partings	10	203
8. Dolomite, light blue-gray, medium-grained; flecked with small white markings; becomes conspicuously mottled with irregular dark-blue splotches in lower 10 ft	26	117
7. Limestone, light blue-gray, thin-bedded; somewhat sandy and finely fragmental	7	170
6. Limestone, light blue-gray and medium blue-gray, in thin irregular bands. Rounded mottles that suggest algal structures scattered through rock	3	167
5. Limestone, dark grayish-blue, thin- to medium-bedded. Unit contains several medium- to light-gray laminated or finely banded beds, ¼–3 in. thick	15	152
4. Dolomite, light blue-gray, finely granular; small nodules of white chert at base	3	149
3. Limestone, medium blue-gray; with thin, irregular argillaceous partings	1	148
2. Covered area. Scattered small outcrops of medium blue-gray massive limestone and dolomite. Float indicates some shale layers	105	43
1. Limestone, medium blue-gray; with buff to pinkish-brown clayey partings. Several shaly limestone layers interbedded	43	
Total Opex formation	245	
Contact with Cole Canyon dolomite, strike fault of small displacement with dolomitized hanging wall.		

The following section was measured on Pinyon Peak and demonstrates the northward thinning of the formation. Much of the dolomite is probably of hydrothermal origin.

Stratigraphic section of Opex formation measured on east spur of Pinyon Peak 3,500 feet east-northeast of crest; North Tintic district, W½ sec. 34, T. 9 S., R. 2 W. (loc. 8B, pl. 3)

	Thickness (feet)	Distance above base (feet)
Ajax dolomite (lowest bed only):		
Dolomite, medium-gray, medium-granular, with light-gray dolomitic layers. Chert nodules and stringers abundant		143.5
Contact conformable.		
Opex formation:		
10. Dolomite, medium-gray; mottled with pink- and yellow-weathering argillaceous material	18.5	125
9. Limestone, light-blue, medium-grained, thin-bedded; Opohonga type. Sandstone bed about 10 ft below top	18.5	106.5
8. Dolomite, purplish-gray, medium-grained; weathers brown. Flat-pebble conglomerate bed 6 ft above base	12.5	94
7. Dolomite, blue-gray, medium- to fine-grained. Bottom 2 ft coarsely mottled with patches of black dolomite	10	84
6. Dolomite, blue-gray, fine- to medium-grained	38	46
5. Dolomite, light-gray, laminated; weathers creamy-white	6	40
4. Dolomite, medium-gray mottled with light gray	2	38
3. Dolomite, light-gray, laminated	1	37
2. Dolomite, shaly, medium blue-gray to purplish-gray; weathers purplish brown; contains 1-in. buff-colored shale layers	36	1
1. Quartzite, dolomitic; weathers light purplish-brown	1	
Total Opex formation	143.5	
Contact conformable.		
Cole Canyon dolomite (upper bed only):		
Dolomite dusky-blue, medium-bedded.		

The section measured near the Opex shaft is much better exposed than the average, but parts of it are totally concealed; it probably contains more shale than is indicated, however, and part of the lower part may be repeated by strike reverse faults. The contact of the Opex with the Ajax dolomite in this area is marked by two feet of green shale, but the writers have not found the obscure erosion surface noted by Loughlin (Lindgren and Loughlin, 1919, p. 30).

The section measured on the east spur of Pinyon Peak is also well exposed, but is much thinner than average. This may indicate a wedging out of the formation northward, but it is also possible that some beds may have been cut out by faults that are concealed in the bedding. The basal sandstone found on Pinyon Peak may also mark a slight disconformity between the dark dolomites of the Cole Canyon and the overlying limy, shaly, and sandy rocks of the Opex.

AGE AND CORRELATION

Upper Cambrian fossils, not identified by name, were collected from the upper part of Loughlin's Opex formation by Weeks in 1905 (cited in Lindgren and Loughlin, 1919, p. 30). These fossils were collected from beds on Eureka Ridge described by Loughlin (Lindgren and Loughlin, 1919, p. 30) as being "about 2,000 feet above the [Tintic] quartzite" and "about 300 feet above the Middle Cambrian fossiliferous bed in the Cole Canyon dolomite." In view of this somewhat indefinite locality description and lack of faunal lists, the writers requested A. R. Palmer to make additional collections from the Opex. He reports as follows:

Collections were made on July 15 and 16, 1954 from the upper part of the Opex formation in the main Tintic district.

1. Collection No. USGS 1384–CO. Upper part of Opex formation: center NW¼NE¼NW¼, sec. 34, T. 9 S., R. 2 W.; northwest part of Eureka quadrangle.
   Kinbladia? sp.
   Burnetia? sp.
   Dellea sp.
   Homagnostus sp.
   Iddingsia sp.
   Pseudagnostus cf. *P. prolongus* (Hall and Whitfield)
   Pterocephalia sp.
2. Collection No. USGS 1381–CO. Upper part of Opex formation above sandy zone; SE¼NE¼SE¼, sec. 24, T. 10 S., R. 3 W.; on east side of gulch above Opex shaft.
   Kinbladia? sp.
   Burnetia? sp.
   Bynumia sp.
   Dellea sp.
   Elvinia sp.
   Homagnostus cf. *H. tumidosus* (Hall and Whitfield)
   Pseudagnostus cf. *P. prolongus* (Hall and Whitfield)
   Pterocephalia sp.
3. Collection No. USGS 1382–CO. Upper part of Opex formation, same locality as (2) above, but below sandy zone. (This sandy zone may be the western equivalent of the Worm Creek quartzite member of the St. Charles limestone of the northern Wasatch and Bear River Ranges.)
   Aphelaspis (?) sp.
4. Collection No. USGS 1385–CO, lower part of Opex formation, NE¼SE¼ sec. 12, T. 10 S., R. 3 W. on west side of peak 6881 about 20 feet topographically below top.
   Coosella sp.

The collections from the top of the Opex contain representatives of the *Elvinia* zone, the most widespread faunal zone in the Upper Cambrian. This zone characterizes the basal part of the middle division of the Upper Cambrian series. Trilobites similar to those from the upper part of the Opex formation have been collected from the Upper Cambrian Hicks formation of the Gold Hill district in the Deep Creek range. The trilobites from the lower part of the Opex formation are apparently not represented in the Gold Hill district.

Lithologically the Opex and Hicks formations resemble each other in only a general way. However, the upper 150 feet of the Lamb dolomite, which directly underlies the Hicks formation and which is believed by Nolan (1935, p. 13) to be of Late Cambrian age, is closely similar in general composition and appearance to the Opex and may be its counterpart in the Gold Hill district.

Upper Cambrian beds equivalent to the Opex are not present in the Oquirrh Mountains and central Wasatch Range, but they probably occur in the upper part of the Nounan limestone and the lower part of the St. Charles limestone of northeastern Utah and southeastern Idaho (Deiss, 1938, p. 1122–1124), and in the Weeks and Orr formations of the House Range in central Utah (Deiss, 1938, p. 1147–1148). Nolan (1935, p. 13) has suggested that the Opex is of the same age as the lower 800 feet of the Mendha formation at Pioche, about 200 miles southeast of Tintic, which it resembles lithologically (See also Westgate and Knopf, 1932, p. 13–14). Nolan, Merriam, and Williams (1956, p. 19) correlate the Dunderberg of Eureka, Nev., with the upper part of the Opex, and Rigby (1958, p. 23–25) has described both the Opex and Dunderberg in the Stansbury Mountains. The Dunderberg of the Stansbury Mountains is chiefly olive- to brownish-green shale interbedded with argillaceous limestone and dolomite, and is not unlike the uppermost part of the Opex in the East Tintic Mountains.

STRUCTURAL HABIT AND TOPOGRAPHIC EXPRESSION

Throughout the East Tintic Mountains the Opex formation is structurally incompetent and is the site of much bedding-plane slippage and thrust faulting. At the crest of Eureka Ridge 120 feet of the formation may be cut out by strike faults, and many of the exposed beds are brecciated along subsidiary fractures. Exposures of the Opex formation in the Opex mine show a much greater thickness than the surface exposures in the same area, and it is probable that the section there is repeated by faulting. The beds underground, according to Lindgren and Loughlin (1919, p. 30), "are partly bulged by local contortions and flexing and probably also by the presence of a down-faulted wedge * * *."

In areas close to strong faults, the shale beds of the Opex are crumpled and sheared and the limestone and dolomite beds are crushed to fine breccias. In these areas the Opex disintegrates readily and is covered by thick accumulations of talus and colluvium. Even where it is undisturbed the Opex is easily eroded and is the site of gulches and draws, and in areas of considerable relief the formation is marked by its tendency to form slopes, saddles, and strike valleys.

ECONOMIC IMPORTANCE

The Opex formation is an ore horizon of considerable importance in the main Tintic district, but no ores have been produced from it in the East Tintic and North Tintic districts. Mines in which ore bodies have been found in the Opex include the Lower Mammoth, Gold Chain (Ajax), Centennial Eureka, Eureka Hill, and Bullion Beck. However, much of the ore credited to the Opex formation in other reports came from ore bodies localized in the part of the formation here included in the Cole Canyon dolomite.

AJAX DOLOMITE

DISTRIBUTION

The Ajax dolomite is composed principally of prominently beeded medium to dark blue-gray cherty dolomite, but it includes a bed of creamy-white dolomite about 30 feet thick, approximately 180 feet above the base. This bed, which was named the Emerald dolomite member by Loughlin (Lindgren and Loughlin, 1919, p. 31–32), is an excellent horizon marker throughout the East Tintic Mountains and is an invaluable mapping aid in areas of complex structural deformation and small exposures.

The most accessible complete exposures of the Ajax are in the Tintic mining district, where it is exposed in steeply dipping beds from Mammoth Gulch near the Emerald mine across Eureka Ridge to Eureka Gulch near the Eureka Hill mine. South of Mammoth Gulch the Ajax crops out in the footwall block of the Sioux-Ajax fault, in a zone extending south-southeastward from the vicinity of the Gold Chain (Ajax) mine to the Great Eastern mine, near the head of Dragon Canyon. Except near Mammoth Gulch, this exposure of the Ajax is close to the Silver City monzonite stock and the dolomite beds are considerably bleached and pyrometasomatized.

North of Eureka Gulch the upper part of the formation crops out prominently along the east side of Cole Canyon. North of Cole Canyon the Ajax is displaced along the Paxman fault, but it is well exposed from near the Black Warrior prospect to the edge of the Packard quartz latite near Porphyry Flat, at the head of Jenny Lind Canyon.

In the North Tintic district the Ajax crops out on the conspicuous saddle about one-half mile northwest of Packard Peak, and extends northward in a nearly vertical attitude to the Tintic Prince fault. North of the Tintic Prince fault it is exposed on both limbs of the North Tintic anticline in a large inverted U-shaped outcrop, only a small part of which is concealed by colluvium in Broad Canyon. In the eastern part of the North Tintic district, the Ajax is exposed in the upper plates of the Allens Ranch and Pinyon Peak thrust faults in the Selma Hills east of the Selma, Tintic Paymaster, and Tintic Empire mines, and on the lower east and southeast slopes of Pinyon Peak west of the North Standard shaft.

In the East Tintic district, the Ajax is partly exposed in several areas, the principal exposures being near the portal of the Iron King tunnel, in the zone of contact-metamorphosed sedimentary rocks a few hundred feet east and northeast of the Iron King No. 1 shaft, and in the general vicinity of the Big Hill and East Tintic Coalition shafts. None of these exposures is suitable for a detailed study of the formation.

THICKNESS

To facilitate mapping and description the Ajax dolomite is divided into three members: the lower and the Emerald members (dolomite), and the upper member (dolomite and limestone). The lower member averages about 180 feet in thickness, but locally it measures as little as 90 feet, possibly because of concealed strike faults. The Emerald member averages just under 30 feet in thickness but is a few feet thicker or thinner in some places. The upper member has a greater range in thickness than the other two members; it averages about 350 feet but is as little as 265 feet thick in some places and as much as 520 feet thick in others. The entire formation ranges from about 500 to 730 feet in thickness.

LITHOLOGIC CHARACTER

The lower member of the Ajax is dominantly medium- to thin-bedded, light to dark blue-gray dolomite. Beds containing small pods of black, brown, and white chert are common, but are not as abundant as in the upper member. Many of the noncherty, lighter colored dolomite beds are mottled or striped with ribbonlike layers of dusky-blue dolomite, but the overall color of the rock is a uniform somber blue or gray. Several of the units are crossbedded and a few are conglomeratic, indicating a shallow environment of deposition.

The following section of the lower member of the Ajax, which was measured on the south slope of Eureka Ridge a short distance east of the Opex shaft, is fairly typical of the member in most of the East Tintic Mountains.

Stratigraphic section of lower member of Ajax dolomite measured on ridge between Opex and Grand Central shafts, main Tintic district, in the SE¼SE¼ sec. 24, T. 10 S., R. 3 W. (loc. 9a, pl. 3)

	Thickness (feet)	Distance above base (feet)
Emerald member of Ajax dolomite:		
Dolomite, creamy white, mottled coarse- and fine-grained		180
Contact conformable.		
Lower member of Ajax dolomite:		
13. Dolomite, light blue-gray, thin-bedded; some layers crossbedded. Five-foot mottled zone near base	26	154
12. Dolomite, dark blue-gray striped with lighter blue-gray in 1-in. bands. Small irregular nodules of brown chert	6	148
11. Dolomite, light blue-gray, finely banded. White chert abundant	7	141
10. Dolomite, dark blue-gray, faintly banded, fine-grained	11	130
9. Dolomite, dusky blue, twiggy Bluebird type	2	128
8. Dolomite, alternating light- and dark-blue bands 1 in. thick	6	122
7. Dolomite, dark blue-gray, with strongly contrasting light bluish-gray mottles	17	105
6. Dolomite, medium blue-gray, medium-bedded	7	98
5. Dolomite, light blue-gray, dense, finely banded. Abundant white chert nodules, 1 by 10 in. in size, in bedding planes	3	95
4. Dolomite, medium to dark blue-gray, thin-bedded; abundant white chert in lower part	30	65
3. Dolomite, medium blue-gray, faintly mottled; thin-bedded	27	38
2. Dolomite, light blue-gray, finely granular. Small dark chert seams and nodules abundant	12	26
1. Dolomite, mottled in medium to light gray, thin-bedded	26	0
Total lower member of Ajax dolomite	180	
Contact conformable.		
Opex formation (uppermost bed only):		
Shale, gray-green, fissile.		

The Emerald member of the Ajax dolomite is a massive bed of creamy or grayish-white medium- to coarse-grained dolomite, which weathers to a mottled surface that is the result of differences in grain size rather than color or composition (fig. 21). It crops out conspicuously between thick units of dark-gray well-bedded dolomites, and it is easily recognized except where the rocks have been hydrothermally altered or contact-metamorphosed. In limited outcrops or underground the Emerald member may be confused with the Dagmar dolomite, but it is less thick and is not laminated and striped but has a granular texture

FIGURE 21.—Mottled coarse- and fine-grained dolomite in Emerald member of Ajax dolomite. Outcrop on west side of Keystone Ridge, one-half mile southwest of Eureka, Eureka quadrangle.

and is massive. It is distinguished from the massive white-weathering beds of the Cole Canyon dolomite, however, only by the distinctive dark abundantly cherty dolomites above and below it. The Emerald is relatively uniform in thickness and appearance, and the section presented below is characteristic. It was measured at the type locality, near the Emerald mine in the main Tintic district.

Stratigraphic section of Emerald member of Ajax dolomite measured 900 feet north of Emerald mine, main Tintic district, in SE¼SE¼ sec. 24, T. 10 S., R. 3 W. (loc. 9b, pl. 3)

	Thickness (feet)	Distance above base (feet)
Upper member of Ajax dolomite (lowest bed only):		
Dolomite, dark blue-gray, Bluebird type		209
Contact conformable.		
Emerald member of Ajax dolomite:		
1. Dolomite, white to grayish-white, even-grained, finely granular. Beds near upper and lower contacts slightly darker gray and faintly mottled with 1-in. by 2-in. irregular dark-gray splotches of slightly coarser grained dolomite	29	180
Contact conformable.		
Lower member of Ajax dolomite.		

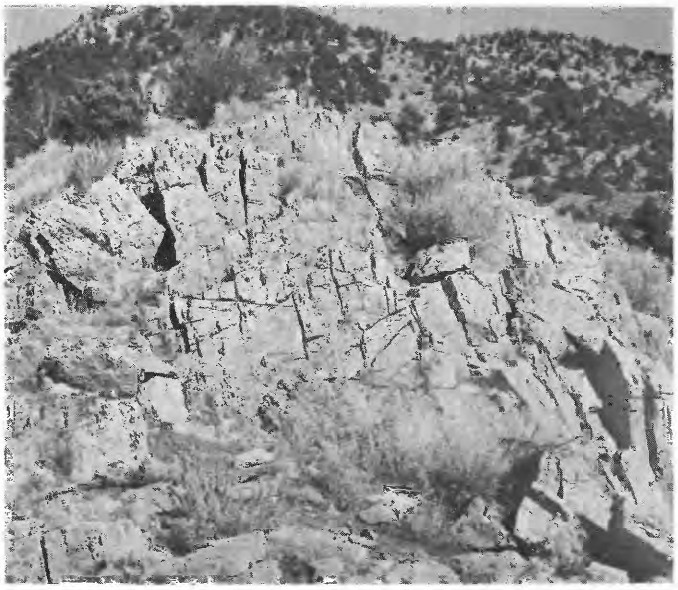


FIGURE 22.—Characteristic outcrop of upper member of Ajax dolomite. Note abundant pods of chert. Beds are 6 inches to several feet thick; top to right of photograph. Exposure on ridge 1,000 feet north of Emerald mine, Eureka quadrangle.

The upper member of the Ajax dolomite is mostly fine-grained well-bedded dark bluish-gray dolomite containing white, gray, brown, and black chert lenses that range in size from the merest seams to nodules several inches thick and several feet long. (see fig. 22.) No other dolomite in the East Tintic Mountains shows such a profusion of white chert nodules, and this is the most distinctive feature of the member. In small outcrops the cherty dark dolomites of the Fish Haven dolomite may be mistaken for some beds in the Ajax, but white cherts are rarely present in the Fish Haven, and dark-colored cherts are chiefly confined in the Fish Haven to a narrow zone of light and dark striped and mottled dolomite quite unlike any in the upper member of the Ajax.

No shale has been found in the upper member of the Ajax dolomite, and sandy beds are absent from all but the topmost units. Local lenses of quartzite mark the upper contact, but we regard these beds as basal units of the Opohonga limestone. Near the Emerald and Opex mines in the main Tintic district, and throughout most of the North Tintic district, the upper third of the upper member of the Ajax is limestone that is similar in color and bedding characteristics to the limestones of the Opohonga. Near the productive mines and larger mineralized faults, however, the upper member is entirely dolomite.

The quartzite beds at the base of the Opohonga limestone are the only satisfactory mapping datum that can be used to define the contact between the two formations. These beds also represent the time line between Upper Cambrian and Lower Ordovician rocks; the Upper Cambrian trilobite *Eurekia* sp. was collected from the limy zone just below the basal sandy zone of the Opohonga, and the limestone just above this zone contains trilobites of the *Symphysurina* zone, at present the lowest recognized faunal zone in the Lower Ordovician.

The measured section presented below is representative of the upper member of the Ajax dolomite throughout the mining areas of the East Tintic Mountains, but it does not contain the limestones that are characteristic of the upper part of the member in areas more remote from ore deposition.

Stratigraphic section of upper member of Ajax dolomite measured on west slope of Keystone Ridge 2,000 feet southwest of Gemini shaft, main Tintic district, in the S½ sec. 13, T. 10 W., R. 3 W. (loc. 9b, pl. 3)

	Thickness (feet)	Distance above base (feet)
Opohonga limestone:		
Limestone, argillaceous, thin-bedded		351
Contact conformable.		
Upper member of Ajax dolomite:		
17. Covered area. Float indicates medium-gray medium-grained limy dolomite; some quartzite fragments. Contact placed at base of quartzitic sandstone, assumed to be 20 ft above bottom of covered beds	20	331
16. Dolomite, light brownish-gray, coarse-grained, sandy. Many lenses of white chert	3	328
15. Dolomite, medium blue-gray, coarse-grained. Many small chert nodules and seams	15	313
14. Dolomite, light pinkish-gray, faintly mottled	2	311
13. Dolomite, medium blue-gray, medium-grained, prominently bedded	28	283
12. Dolomite, medium brownish-gray, banded, somewhat argillaceous; thin lenses of brown chert in lower part	22	261
11. Dolomite, medium blue-gray; faintly banded and mottled. Seamed and flecked with calcite	16	245
10. Dolomite, medium to dark blue-gray, medium-grained. Scattered 1- by 3-in. nodules of black chert	34	211
9. Dolomite, medium- to light-gray, thin-bedded. Many ½- by 1-in. nodules of black and light-gray chert	29	182
8. Dolomite, medium blue-gray, prominently-bedded. Large brown chert nodules abundant at base, sparse in upper part	34	148
7. Dolomite, medium blue-gray; mottled with lighter gray. Thin irregular seams and small nodules of white and brown chert	14	134
Upper member of Ajax dolomite—Continued		
6. Dolomite, light bluish-gray, medium-grained. Thin lenses of white chert as much as 2 ft. long	6	128
5. Dolomite, light bluish-gray; banded and mottled with brownish-gray argillaceous dolomite	19	109
4. Dolomite, medium to dusky blue-gray; mottled and banded with irregular zones of coarsely crystalline dolomite. Numerous lenses of white and brown chert	31	78
3. Dolomite, medium blue-gray; faintly banded and mottled. Small scattered lenses of chert in upper part	40	38
2. Dolomite, dusky-blue, fine-grained. Many lenses of flat-pebble conglomerate	10	28
1. Dolomite, dusky blue-gray, Bluebird type	28	0
Total upper member of Ajax dolomite	351	
Contact conformable.		
Emerald member.		
Total Ajax dolomite	560	

AGE AND CORRELATION

The Late Cambrian age of the Ajax dolomite is based on collections of fossils made from two widely separated exposures of the formation. These fossils were identified by A. R. Palmer (written communications, 1952 and 1953) who reports as follows:

Report of December 5, 1952:

This report concerns silicified brachiopods from approximately 30 feet below the Emerald member of the Ajax dolomite that were collected by Jean Berdan, Helen Duncan, and others, on the lower east slope of Pinyon Peak west of the North Standard shaft. (NW¼ sec. 34, T. 9 S., R. 2 W.)

The brachiopods represent a species of *Eoorthis*, a distinctive Upper Cambrian form. This genus is most common in rocks of Franconia age (middle Upper Cambrian) and the bed from which they were obtained is certainly no older than that. *Eoorthis* is not known from post-Cambrian rocks and definitely dates that portion of the Ajax dolomite as Upper Cambrian.

Report of September 30, 1953:

Collection No. USGS 1383–CO:

(1) Limy zone just below sandy horizon that marks base of Opohonga limestone: SW¼ SW¼ sec. 19, T. 10 S., R. 2 W; east slope of spur that contains Emerald shaft.

Eurekia sp.

(2) Lower member of Ajax dolomite in lower east slope of Pinyon Peak. (NW¼NE¼NW¼ sec. 34, T. 9 S., R. 2 W.)

Eoorthis sp.

Two collections from the Ajax, two from the Opex and one from the base of the Opohonga provide evidence to indicate that the Ajax dolomite is the highest Cambrian unit in the East Tintic Mountains. The collections from the top of the Opex contain representatives of the *Elvina* zone. Silicified specimens of the middle Upper Cambrian brachiopod genus *Eoorthis*, [fig. 23], which were reported in December 5, 1952, have been re-collected from the lower member of Ajax dolomite below the Emerald member, and a single collection from limestone just below the quartzitic zone that marks the base of the Opohonga near the Emerald mine contains trilobite fragments referable to the upper Upper Cambrian genus *Eurekia*. . . . The evidence indicates strongly that the Ajax dolomite is wholly Upper Cambrian in age. It probably correlates with the lower part of the Chokecherry dolomite of the Gold Hill district and with the Windfall formation of the Eureka area, Nevada.

FIGURE 23.—Silicified brachiopods of the genus *Eoorthis* from lower member of Ajax dolomite. Specimen collected near Opex shaft, Eureka quadrangle. ×1½.

Beds equivalent in age to the Ajax dolomite, but composed chiefly of thin-bedded shaly limestone, crop out in the northern part of the Sheeprock Mountains, 20 miles west of the East Tintic Mountains. Fossils collected from these beds by Robert Cohenour were submitted to A. R. Palmer for identification. His report (written communication, Dec. 13, 1955) follows:

The collections of Late Cambrian age from the Sheeprock Mountains are of particular interest because, in addition to the presence of silicified specimens of *Billingsella*, a characteristic middle Upper Cambrian brachiopod, it contains examples of Cambrian conodonts, and a specimen of a peculiar three-pronged problematicum that has been described only from Upper Cambrian beds in Sweden. Cambrian conodonts have been recognized in collections from the Dugway Range in rocks that seem to resemble those from which these collections were obtained. They are also known from Wyoming and central Texas. At all known localities they have occurred only in horizons equivalent to the *Conaspis* zone of middle Franconia age in the standard Upper Cambrian section.

The Ajax dolomite probably correlates also with the lower part of the Notch Peak limestone of the House Range (Walcott, 1908, p. 9), the upper part of the Mendha formation of the Pioche area (Westgate and Knopf, 1932, p. 13–14), and with at least part of the St. Charles limestone of northern Utah and southern Idaho (Deiss, 1938, p. 1123–1124; Williams, J. S., 1948, p. 1134–1135).

STRUCTURAL HABIT AND UNDERGROUND EXPRESSION

The Ajax dolomite is structurally competent, and in areas of strong deformation it has either failed along breccia-filled faults or bent into large folds accompanied by few of the minor crenelations that are common in the underlying and overlying Opex and Opohonga formations. North of Mammoth Gulch in the main Tintic district it is the locus of at least one major strike fault—the "East Limit break"—and many minor bedding-plane faults; as is common with the steep faults that crosscut the formation, these bedding slips are accompanied by wide breccia zones.

Underground the unaltered lower and upper members of the Ajax may be distinguished by their granular texture, well-bedded habit, and abundant chert nodules. The Emerald member is easily recognized by its creamy-white color, granular texture, lack of fine banding, and blocky fracture habit.

TOPOGRAPHIC EXPRESSION

The Ajax dolomite as a whole is resistant to erosion, and in areas of steep dips it forms long ridges that separate gulches developed in the less resistant underlying Opex formation and overlying Opohonga limestone. Small gullies are not uncommon within Ajax terranes, but the control is normally structural rather than lithologic. The more massive dolomite of the Emerald member and the dense, poorly bedded dolomites immediately above it typically form the crests of ridges or spurs.

Where the Ajax dips gently or is flat, it is a cliff and ledge former that is readily distinguished from the slope-forming Opex and Opohonga formations. The Ajax is commonly well exposed even in areas of simple structure but locally may be partly covered by talus debris contributed by adjacent formations.

CHEMICAL AND PHYSICAL CHARACTER

The dolomite of the Ajax contains small amounts of silica, clay, and carbon, and from 5 to 9 percent $CaCO_3$ in excess of that required for theoretically pure dolomite. The analyses of the formation members presented in table 8 obviously do not include the cherts of the Ajax, but are believed to be representative of the matrix of the average Ajax dolomite.

TABLE 8.—*Chemical analyses of composite samples of Ajax dolomite*

	1	2	3	4
Acid insoluble		5.9	3.6	2.2
SiO_2	2.27			
Al_2O_3	.26	2.2	1.5	2.2
Fe_2O_3	.17			
FeO	.13			
MgO	19.96	18.6	19.5	18.9
CaO	32.10	29.4	30.0	31.2
Na_2O	.05			
K_2O	.08			
H_2O-	.04			
H_2O+	.02			
TiO_2	.02			
CO_2	45.09	[1]43.3	[1]44.8	[1]45.1
P_2O_5	.04			
SO_3	.00			
Cl	.04			
F	.01			
S	.02			
MnO	.04			
BaO	.00			
Total	100.34	99.4	99.4	99.6
Less O	.02			
Total	100.32			

[1] Calculated.

1. Chemical analysis of composite sample of Ajax dolomite from ridge between Opex and Grand Central shafts. Bulk density of light-colored beds is 2.65 and of dark-colored beds is 2.84. Density of powdered composite sample is 2.85. Analyst: L. N. Tarrant, Oct. 25, 1954.
2. Composite sample of upper member of Ajax dolomite, analysis courtesy of Chief Consolidated Mining Co. Collected by G. W. Crane.
3. Composite sample of Emerald member, Ajax dolomite, analysis courtesy of Chief Consolidated Mining Co. Collected by G. W. Crane.
4. Composite sample of lower member of Ajax dolomite, analysis courtesy of Chief Consolidated Mining Co. Collected by G. W. Crane.

ALTERATION

CONTACT METAMORPHISM

The Ajax dolomite is contact metamorphosed in several areas within and adjacent to the Tintic and East Tintic districts. The most intensely metamorphosed variety has been described by Loughlin (Lindgren and Loughlin, 1919, p. 95) as a dark greenish-gray, brown-weathering chert-free rock minutely fractured and cut by innumerable veinlets of calcite and quartz. As seen in thin section the unweathered rock is composed of calcite, enstatite, and spinel, with a few small grains of zoisite, garnet, and magnetite, and is cut by veinlets composed of tridymite(?) and calcite. The enstatite in the weathered rock is almost wholly converted to feathery aggregates of penninite (?) that enclose unaltered enstatite and minerals relict from the unaltered dolomite. The spinel forms isolated roughly euhedral grains that approach octahedral and possibly dodecahedral outlines. Some of the spinel crystals, which probably are near hercynite or pleonaste in composition, appear to be partially altered at their borders to clay minerals and limonite.

Contact metamorphism of the Ajax dolomite near its contacts with the shaly Opohonga and Opex formations lccally resulted in the formation of andradite garnet and wollastonite, but these minerals as a rule are rare.

A less severe degree of metamorphism is characterized by a general replacement of the cherts by coarse-grained calcite or dolomite and the recrystallization and bleaching of the rock, which may contain minor amounts of zoisite.

Hydrothermal metamorphism of the Ajax in the area a few hundred feet east and northeast of the Iron King No. 1 shaft has desilicated and dedolomitized the rock, leaving a granular, highly porous calcic rock that has been considerably enriched in iron by the introduction of hematite and limonite. This "sawdust" rock—to use its descriptive field name—is associated with deposits of manganiferous limonite and halloysite at the contact of the Packard quartz latite close to intrusive stocks and pipes. The replacement by halloysite at the Dragon mine is described below.

SILICIFICATION

The Ajax dolomite has been extensively silicified in the productive areas of the main Tintic district. The resulting jasperoid is gray or bluish gray to black in color and fine grained. Near copper-ore bodies it is coarser, somewhat resembling a fine- to medium-grained quartzite, with which it may be confused, but in the areas producing lead ores, the jasperiod is flinty or cherty in appearance. The rock commonly contains a few microscopic prisms of barite, crystals of various sulfide minerals, and unreplaced residual grains of calcite or dolomite. Where it is exposed at the surface, the jasperoid is commonly stained brown, red-brown, or red from the oxidation of disseminated pyrite.

ECONOMIC IMPORTANCE

In the main Tintic district, the Ajax dolomite is a host rock for metallic ores of considerable economic importance in the Bullion Beck, Eureka Hill, Centennial Eureka, Dragon, and Gold Chain (Ajax) mines. The gross value of the ore produced from the Ajax dolomite in these mines probably exceeds $60 million (Cook, 1957, p. 65). Small amounts of limonite have been mined for fluxing purposes from the Ajax dolomite in the East Tintic district, but otherwise the Ajax is unimportant as an ore-producing formation there.

At the Dragon mine in the main Tintic district the greater part of the high-grade deposit of halloysite clay, which is mined and chemically activated for use as a filter catalyst used in the refining of certain types of crude oils, occurs as a hydrothermal replacement body in the Ajax dolomite. This deposit is as yet not fully developed, but is believed to be the largest known massive concentration of nearly pure halloysite. It has the further distinction of being the basic raw material of a new mineral product that was developed commercially as a result of a coordinated program of chemical and geological research.

ORDOVICIAN SYSTEM

OPOHONGA LIMESTONE

The Opohonga limestone is a uniform sequence of light blue-gray thin-bedded limestones and calcareous flat-pebble conglomerates, whose weathered outcrops are characteristically flaggy. The limestone beds are separated by thin layers of argillaceous and siliceous limestone that weather brown, buff, yellow, and light red. The Opohonga is conformable with the Ajax dolomite below it, and the contact is in part gradational, suggesting continuous deposition from Late Cambrian to Early Ordovician time in the area of the East Tintic Mountains. Throughout the greater part of its exposures in the East Tintic Mountains, the base of the Opohonga is marked by a bed of sandstone or quartzite 2–6 feet thick, but this unit is found only locally in the East Tintic district. The lowermost limestone beds of the Opohonga are commonly dolomitized close to ore and resemble the Ajax dolomite, but they are characterized by moderately abundant smooth lenticular nodules of milky-white chert, 1 or 2 feet long and several inches thick, that lie parallel to the bedding. These beds on Eureka Ridge yield fossils of Early Ordovican age. As noted elsewhere, the uppermost beds of the Ajax dolomite immediately below the basal quartzite of the Opohonga are limestone in areas remote from ore and may be confused with the Opohonga, but they contain relatively little argillaceous material and yield fossils of Late Cambrian age.

The contact of the Opohonga limestone with coarse-grained dusky-blue dolomites of the overlying Fish Haven dolomite is abrupt and clean, but the contact shows no angular discordance over hundreds of feet of outcrop. However, stratigraphic studies in the Sheeprock Mountains and in the Bear River, northern Wasatch, and Thomas Ranges (pl. 1) have shown that an important unit of Middle Ordovician age, the Swan Peak formation or Eureka quartzite, is normally present between these formations, or between units stratigraphically equivalent to them.

DISTRIBUTION

In the main Tintic district, outcrops of the Opohonga limestone extend northward in a faulted band from the edge of the Silver City monzonite stock near the head of Dragon Canyon to the edge of the Packard quartz latite at the south base of Packard Peak, interrupted only by the alluvium of Mammoth and Eureka Gulches. The resistant central part of the formation forms spurs where it crosses Eureka Ridge and also underlies the highest summit of the ridge, Eureka Peak.

North of Packard Peak in the North Tintic district, the Opohonga extends north-northwestward from the edge of the quartz latite at the divide between Hatfield and Fremont Canyons to the Tintic Prince fault at the head of the east fork of Broad Canyon. North of the Tintic Prince fault, it is widely exposed on both limbs of the North Tintic anticline in a large faulted horseshoe-shaped outcrop, only a small part of which is concealed under the alluvium of Broad Canyon.

In the eastern part of the North Tintic district, the Opohonga is exposed in several large areas in the Selma Hills, east and north of the Tintic Empire mine, and it also extends southeastward as a partly concealed line of outcrops, from the Selma mine around the north and east sides of Pinyon Peak to the volcanic rocks near the railroad tunnel in the canyon of Pinyon Creek.

In the East Tintic district, most of the exposures of Opohonga limestone are in areas of complex structure and intense alteration. The best-exposed outcrops are on the east and west slopes of the hill between the Iron King No. 1 shaft and the Iron King tunnel. On the eastern slope of the hill both the upper and lower contacts are well exposed, but locally the limestone adjacent to monzonite plugs and dikes is bleached and contains contact-metamorphic minerals. The outcrops of Opohonga that extend across Burriston Canyon from the west side of Iron King hill to the area of the Zuma shaft are at the crest of a tightly folded anticline, which is faulted along its eastern limb near the axial plane and intruded by monzonite plugs. These exposures likewise are valueless for a detailed stratigraphic study of the formation.

A partial section of the Opohonga is exposed in a window in the Packard quartz latite west of the East Tintic Coalition shaft, but some of the beds in this area have been altered to a finely granular jasperoid that closely resembles the tuffs at the base of the Packard in areas where they are silicified.

The upper part of the Opohonga is exposed in the southern part of the East Tintic Mountains in the first canyon south of the Tintic Chief prospect, in the W½ sec. 24, T. 12 S., R. 2½ W., and the E½ sec. 24, T. 12 S., R. 3 W., and also at the crest of the 6,576-foot hill in the SE¼ sec. 15 and NE¼ sec. 22, T. 12 S., R. 2 W.

THICKNESS

The Opohonga varies considerably in thickness in the East Tintic Mountains; it thins considerably northward and eastward, and is not present in either the Oquirrh Mountains or the Wasatch Range. On Eureka Ridge it is about 850 feet thick, but near the Paxman shaft it is probably as thin as 700 feet. In most of the western part of the North Tintic district the Opohonga is between 700 and 800 feet thick, but in the SE¼NE¼ sec. 28, T. 9 S., R. 2 W., which is near the Selma mine in the eastern part of the North Tintic district, it is only about 450 feet thick. In the East Tintic district it is about 850 feet thick in the E½ sec. 21, T. 10 S., R. 2 W. about 1,000 feet south of the Iron King No. 2 shaft, but it thins northward to about 300 feet on the east slope of Pinyon Peak in the hanging wall of the Pinyon Peak thrust fault. In this area some beds may be cut out along low-angle faults, but most of the decrease in thickness is the result of erosion of the Opohonga before the Fish Haven dolomite was deposited.

In the Currant Creek canyon, which cuts through Long Ridge 14 miles east southeast of Eureka, the Opohonga is about 250 feet thick where observed by the writers and is all dolomite. Some 5 miles farther east, in Santaquin and North Canyons of the south-central Wasatch, the formation is absent along an unconformity between the Ajax(?) dolomite and the Pinyon Peak limestone.

LITHOLOGIC CHARACTER

The Opohonga limestone is one of the most distinctive and easily recognized formations in the East Tintic Mountains. It is thin bedded from top to bottom and contains virtually no marker horizons except the sandstone bed at the base and the cherty layers in the lower part. The weathered surfaces display short lenses and bands of light blue-gray limestone alternating with seams and beds of pinkish-red and yellow argillaceous material that give it a striped, mottled, or mosaic appearance. In exposures normal to the bedding the shaly material forms ramifying seams, which divide and rejoin in a flattened hexagon pattern that suggests the descriptive term "chicken-wire structure" (see fig. 24). This distinctive pattern is retained when the rock is dolomitized or thermally metamorphosed and is a useful feature in recognizing the formation in areas of alteration and recrystallization.

Thin beds of intraformational flat-pebble conglomerate are especially characteristic of the Opohonga. These beds consist of subparallel tabular to blocky fragments of blue-gray limestone enclosed in a matrix of slightly darker limestone of nearly identical texture and composition (see fig. 25). Beds that may be termed "edgewise conglomerates" occur locally but are not common. The flat-pebble beds are probably the result of desiccation and cracking of limy sediments during temporary shoal conditions with subsequent flooding of the mud-cracked layer. The individual chips apparently did not move far and were imbedded in limy muds of similar composition in rather quiet water. Mud-cracked layers are not common in the Opohonga, but this may be due to the slabby character of the individual beds, which could have been completely desiccated and fragmented without retention of deep cracks.

FIGURE 24.—Close-up view of Opohonga limestone. Note ramifying partings of argillaceous material (dark-gray) isolating small pods of limestone (light-gray). Outcrop on Keystone Ridge, Eureka quadrangle.

FIGURE 25.—Flat-pebble limestone conglomerate in Opohonga limestone. Note similarity to flat-pebble conglomerates in Herkimer limestone and Opex formation. Outcrop on south end of Keystone Ridge, Eureka quadrangle.

The flat-pebble beds are uniformly limy, but the bedding-planes between them are commonly marked by laminae of shale. Not any of the conglomerate beds are useful as marker horizons, for all of them pinch out within a short distance along the strike.

The local prominence of red and yellow argillaceous material in the thin beds of light-blue limestone may cause the Opohonga to be mistaken for limestone beds in the Opex, Herkimer, or Teutonic formations, but in areas of good outcrop the Opohonga is readily distinguished by its many beds of flat-pebble conglomerate.

AGE AND CORRELATION

Loughlin (Lindgren and Loughlin, 1919, p. 33–34) assigned the Opohonga limestone to the Lower Ordovician on the strength of a few poorly preserved fossils that he found on the east slope of Eureka Peak, about 100 feet below the top of the formation. These were identified by Edwin Kirk as *Dalmanella* cf. *D hamburgensis* (Walcott), *Cyrtolites* sp., *Ophileta* sp., and *Asaphus* sp. (fragments), with this comment (Lindgren and Loughlin, 1919, p. 35):

> Although the fossils are poor they show that these faunas are undoubtedly of Beekmantown (Lower Ordovician) age. In the west they can be correlated with the Pogonip of Nevada, the Garden City limestone of northeastern Utah, and the El Paso limestone of Texas.

During the present study several additional collections of fossils were made from the Opohonga, which also indicate an Early Ordovician age. Two collections made from exposures in the main Tintic district were reported on by R. J. Ross, Jr. (written communication, Dec. 22, 1955) as follows:

> Collection No. USGS 67–CO.—In a 1-inch lens, 10 feet above quartzite at base of Opohonga; center S½ sec. 13, T. 10 S., R. 3 W.; southwest slope of Keystone Ridge, east of Cole Canyon road.
>
> *Xenostegium* cf. *X. franklinense* Ross
> *Bellefontia*? sp.
> *Symphysurina* sp. (cf. *S. globocapitella* Hintze)
> *Hystricurus genalatus* Ross
>
> This fauna correlates with faunal zone "B" of the Garden City formation (Ross, 1951, and Hintze, 1952). The "A" zone as I considered it in 1951 probably does not exist as a separate entity and should be grouped with the "B" zone; L. F. Hintze's investigations (1952, p. 5.) strongly indicate this to be the proper procedure.
>
> In all known sections in Utah the lower beds of the Garden City formation, containing the above listed fauna, rest on dolomite from which no fossils have ever been collected; this unfossiliferous unit has generally been considered as the top of the St. Charles limestone, of which the underlying fossiliferous beds are known to be of Late Cambrian age.
>
> Collection No. USGS 68–CO.—About 30 feet below top of Opohonga limestone; east slope of Keystone Ridge at elevation 6,625 feet, S. 81° W. of junction of Church and Main Streets, Eureka, Utah; at center of line between SE¼ and SW¼, NW¼, SE¼ sec. 13, T. 10 S., R. 3 W.
>
> *Pseudocybele* sp.
> *Kirkella* sp.
> *Paranileus* sp.
>
> This fauna indicates equivalence to the upper part of the Garden City formation, zones "H–J" of Ross (1951) and Hintze (1952).

L. F. Hintze (1951, p. 87–89) collected and identified the following fossils from the upper-middle part of the Opohonga about 800 feet southwest of the Bullion Beck shaft, on the north side of Eureka Gulch in the main Tintic district:

Brachiopod:
- *Syntrophina* cf. *S. carinifera* Ulrich and Cooper (slightly larger than *S. carinifera*).

Trilobites:
- *Protopliomerops superciliosa* Ross
- *Hystricurus oculilunatus* Ross
- *Goniophrys prima* Ross
- *Pachycranium faciclunis* Ross
- *Asaphellus*? sp.

Cystid stem fragments

Concerning this collection L. F. Hintze (1951, p. 88) states in part: "* * * the trilobites are distinctive of Ross's (1949, 1951) faunal zone F, which is found in northeastern Utah from 300 to 400 feet above the base of the Garden City formation."

A. E. Disbrow collected several specimens of sponge-like fossils within 100 to 200 feet of the top of the Opohonga in Black Rock Canyon (SW¼ sec. 16, T. 9 S., R. 3 W.). R. J. Ross, Jr. (written communication, Dec. 10, 1954) reported on them as follows:

> The specimens belong to "*Receptaculities*," a problematical sponge. A species of similar form is common in faunal zone "H" (Ross, 1951) of the Garden City formation of northeastern Utah. Other similar forms are reported in the upper part of the Pogonip by Kirk and Hintze. How much zonal value they have, other than a general equivalence to "Upper Pogonip," is not certain.

The Opohonga is probably equivalent not only to the Garden City formation and Pogonip group of Nevada, but to the Yellow Hill limestone of Pioche (Westgate and Knopf, 1932, p. 14) and part of the Grampian limestone in the San Francisco mining region of west-central Utah (Butler, 1913, p. 30). Nolan (1935, p. 15) suggests that the Chokecherry dolomite of the Deep Creek Mountains may be of the same age as the Ajax and Opohonga at Tintic; lithologically, however, the Chokecherry is quite unlike the Opohonga and closely resembles the nonfossiliferous dolomites of the Upper Cambrian of the Tintic district and northeastern Utah. If any part of the Chokecherry dolomite is equivalent to the Opohonga, it is most probable that the uppermost beds are equivalent to beds in the lower part of the Opohonga, but even this seems doubtful.

L. F. Hintze (1951, p. 38–58) also notes the presence of lower Ordovician rocks probably correlative with the Garden City and Opohonga formations in the Lakeside Mountains, the Silver Island Range (pl. 1; formerly called the Desert Range), the Fish Springs Range, the south end of the Confusion Range, the San Francisco mining district, and the Canyon Mountains. In Oak Creek canyon in the central part of the Canyon Range, beds lithologically identical with the Opohonga were observed to overlie a thick cherty unfossiliferous dolomite that closely resembles the Ajax dolomite of the East Tintic Mountains. The Opohonga in the Canyon Range is in the footwall of a large thrust fault whose hanging wall is quartzite.

In the West Tintic mining district, which is located in the southern end of the Sheeprock Mountains about 18 miles southwest of Eureka, a metamorphosed limestone unit closely resembling the Opohonga limestone, underlies a sequence of shale and quartzite with a combined thickness of 265 feet that is probably correlative with the Kanosh shale of Hintze (1951) and the Eureka quartzite in western Utah and eastern Nevada. These units were also observed by the writers in the northern part of the Sheeprock Mountains.

STRUCTURAL HABIT

Major faults transect the Opohonga limestone as simple, clean breaks with little subsidiary fracturing and virtually no development of breccia. Minor faults die out or, if their trend is acute with the bedding, turn and follow the shale partings, especially near the top and bottom of the formation. Inasmuch as the Opohonga is overlain by massive brittle dolomites, its contacts are commonly the loci of thrust and bedding-plane faults. Adjacent to thrust faults, as in the Burgin mine, the Opohonga is complexly drag folded and cut by minor thrusts and tear faults.

TOPOGRAPHIC AND UNDERGROUND EXPRESSION

Prominent bedding-plane faults near the top and bottom of the Opohonga, and the accompanying brecciation of the adjacent dolomite stratigraphically above and below the formation, create structurally weak zones that erode easily and, in areas of steep dip, form saddles and gulches. However, as stated earlier, the main mass of the formation is comparatively resistant to erosion, chiefly because of its uniform lithologic character and the absence of wide breccia and shear zones within it.

Although comparatively large amounts of ore have been produced from it, the Opohonga limestone is regarded as an unfavorable host rock for ore by many mine operators in the Tintic district, who therefore wish to recognize and avoid it underground. In mine openings, the Opohonga is characteristically lighter gray and more thinly banded than adjoining rocks and includes partings of shale as much as 2 inches thick spaced every few feet. The light color and shaly character of the rock has caused it to be called the white lime shale, a name formerly used in the central Tintic district by Crane (written communication, 1943). The feature most readily recognized underground is the presence of many beds of flat-pebble conglomerate. The individual chips are commonly about 1½ inches long and ½ inch thick. As they are slightly curved and resemble peanuts in outline, the miners call the beds containing them peanut beds. Since these peanut beds occur throughout the Opohonga, they are a reliable clue to its identification where observed in association with the abundant shale partings and thin limestone layers.

CHEMICAL AND PHYSICAL PROPERTIES

The chemical and physical properties of the Opohonga limestone are not well known, partly because of the general disfavor with which it is regarded by the mine operators. Loughlin (Lindgren and Loughlin, 1919, p. 33) notes that the limestone when dissolved in hydrochloric acid leaves a large residue of light-brown to dark-gray clay. The high clay content of the rock is also reflected in the large value for "Acid insoluble" in the chemical analyses (see table 9).

TABLE 9.—*Chemical analyses of Opohonga limestone*

[Samples collected by G. W. Crane; analyses courtesy of Chief Consolidated Mining Co.]

Sample	Acid insoluble	Al_2O_3 and Fe_2O_3	CaO	MgO	CO_2[1]	Total
1	24.0	3.7	37.6	2.5	32.2	100.0
2	9.6	2.4	28.0	17.7	41.5	99.2

[1] Calculated.

1. Composite sample of Opohonga limestone (white lime shale).
2. Composite sample of upper 125 ft of hydrothermally dolomitized Opohonga limestone (white lime shale).

ALTERATION

Despite its common lack of preparation by closely spaced fracturing and brecciation, the Opohonga in some places is strongly altered. In areas of pervasive dolomitization of adjacent beds it is dolomitized at its contacts and immediately adjacent to large crosscutting faults; one-half mile east-northeast of Pinyon Peak, for example, an entire wedgelike fault block of Opohonga has been completely dolomitized. A substantial mass of Opohonga limestone about a mile east-southeast of Pinyon Peak and just south of the North Standard shaft is also completely dolomitized, probably because it is near the intersection of the Pinyon

Peak thrust fault with the contact of the Packard quartz latite. Where it is dolomitized, the normally fine-grained light blue-gray limestone becomes medium grained and darkens to a somber tone of medium to dark gray with no trace of a bluish tint. Locally the dolomitized rock is cut by short, narrow veinlets of a lighter gray or cream-colored dolomite, assuming a striped appearance that causes the miners to call it zebra rock. The argillaceous seams and partings appear little changed except perhaps for the addition of iron; they help to identify the formation in areas of complex structure and hydrothermally altered rocks.

Near intrusive rocks the Opohonga is strongly altered and pyrometasomatized. In the wide zone of contact metasomatism next to the Silver City stock a mile or more southeast of Mammoth in the main Tintic district, the Opohonga is partly dolomitized, strongly bleached, and recrystallized. This rock was examined in thin section by Loughlin (Lindgren and Loughlin, 1919, p. 96) who described it as follows:

> One specimen of the Opohonga limestone, taken about 800 feet northwest of Diamond Pass and 100 feet south of the spur crest, is of light-gray color, striped only where the weathering has left fine powdery material along the more soluble layers. In thin section the rock consists mainly of calcite, relatively coarse-grained (0.25 to 0.5 millimeter in diameter) and pure in some layers and relatively fine-grained and crowded with minute crystals of diopside and possibly of mica in others * * *. The same limestone farther north, close by United States mineral monument No. 1 and farther from the contact, is recrystallized into a very fine-grained to dense rock of light-gray to pale yellowish or buff color * * *. In thin section fine carbonate grains make up the entire rock with the exception of a few limonite grains which appear to be pseudomorphs after pyrite crystals. No mineral containing alumina was noted, and any of the clay of the original rock must be uniformly scattered and hidden in the carbonate grains. Recrystallized carbonate with no visible silicates occurs also in the beds of coarse-grained limestone or dolomite found in the workings of the Lower Mammoth and the Dragon iron mines and along the railroad cut northeast of the Dragon open cut.

In the East Tintic district near the Iron King and Zuma mines, the Opohonga is invaded by monzonite and considerably metasomatized. Small zones near fingerlike projections of monzonite are wholly replaced by coarse granular calcite which is studded with pale green-gray zoisite and a few scattered crystals of adularia. In thin section the bleached limestone exposed in a road cut just north of the Zuma shaft shows small interlocking calcite crystals that are veined and replaced by adularia, the zeolite okenite, and a chlorite(?) mineral that is visible in the hand specimen as celadon-green veinlets and fracture fillings.

ECONOMIC IMPORTANCE

As noted above, the Opohonga limestone is not considered by the mine operators in the Tintic district to be an especially favorable host rock for ore, because of its shaly character and lack of breccia zones adjacent to faults. However, substantial amounts of ore have been mined in the Opohonga close to its contacts, and along cross-cutting faults and fissures near which the rock has been dolomitized and silicified. Billingsley and Crane (1933, p. 110) estimated the total value of ores produced from the Opohonga in the main Tintic district at $25 million. This figure seems to be at least 60 percent too high but serves to show the relative importance of the formation as an ore host rock. The principal mines producing base- and precious-metal ores in small part or wholly from the Opohonga are the Centennial Eureka, Grand Central, Mammoth, Gold Chain (Ajax), Opohonga, North Star, Dragon, Red Rose, Victor, and Iron Blossom No. 1 mines. In the Dragon mine, part of the large body of commercially important halloysite clay occurs in the lower part of the Opohonga limestone.

In the East Tintic district the Opohonga was the host rock of some small lead-silver ore bodies in the Zuma mine, and a few relatively unimportant deposits of manganese and iron ore on the Iron King property.

UNCONFORMITY AT THE TOP OF THE OPOHONGA LIMESTONE

The unconformity between the Opohonga limestone and the overlying Fish Haven dolomite, as noted above, is not marked by a measurable angular discordance between the beds of the two formations. It is recognized chiefly by the absence in the East Tintic Mountains of either the Swan Peak formation or the Eureka quartzite, both of Middle Ordovician age, which occur between formations equivalent to the Opohonga and Fish Haven in northern and west-central Utah and eastern Nevada. A hiatus representing a large part of Middle and early Late Ordovician time is also indicated by a faunal gap between the fossils collected from the topmost beds of the Opohonga limestone and those from the lowermost dolomites of the Fish Haven. It is not surprising, then, to find that a considerable thickness of the upper part of the Opohonga limestone and equivalent rocks in nearby areas to the north and northwest was eroded before the Fish Haven dolomite was deposited. (Hintze, 1951, p. 88–89; Webb, 1956, and Rigby, 1958, p. 80–83).

Much of the evidence of the original extent of the Middle Ordovician positive area was lost during the planation of the zone uplifted during the Late Devonian epoch (see p. 78–81); however, the distribution and thickness variations of the Middle Ordovician Swan Peak formation and Eureka quartzite indicate that the positive area extended approximately from the area of Salt Lake City and Provo, Utah, on the east, to a point not far northeast of Eureka, Nev., on the west, and from the general region of the southern Lakeside Mountains on the north to the southern East Tintic Mountains on the south. The precise limits of this area are unknown, however, because of the lack of exposures, irregularities in the original boundaries of the uplifted area, and the effects of Cretaceous thrust faulting.

The axis of the Middle Ordovician positive area apparently trended westerly and plunged to the west. The actual position of the axis is not definitely known, although the northward wedging-out of the Opohonga beneath the Fish Haven dolomite in the northeastern part of the East Tintic Mountains, and the occurrence of about 265 feet of Kanosh shale of Hintze, 1951, overlying a complete section of the Garden City formation in the southern part of the Stansbury Mountains (Rigby, 1958, p. 80) indicates that the axis probably lies between these two areas. This position and trend is not greatly different from the position and trend of the axis of the zone of Late Devonian uplift, and may be essentially coincident with it.

Nolan, Merriam, and Williams (1956, p. 32) comment on the westward extension of Middle Ordovican positive area to the vicinity of Eureka, Nev., where it apparently terminated. In this area the uplift was low, but it is marked by the erosion of Pogonip rocks that are probably correlative with beds in the upper part of the Opohonga and Garden City formations. The depth to which the Pogonip rocks beneath the unconformity were eroded also approximates that to which the Lower Ordovician limestones were eroded in the East Tintic Mountains, indicating that the positive area was a broad, almost flat-topped upwarp that frequently may have been awash by the sea. A second Middle Ordovician positive area is recognized by Nolan, Merriam, and Williams (1956, p. 32) northwest of Eureka, Nev. This uplifted zone was somewhat higher and steeper than the eastern, flat-topped upwarp but apparently was not connected with it, since the western uplift is older and probably separate geographically.

Stratigraphic relations in the Stansbury and East Tintic Mountains definitely fix the age of the Ordovician uplift as younger than the Kanosh shale of Hintze, 1951, (Chazy) and older than the Fish Haven dolomite (Richmond). The occurrence of the Swan Peak formation and Eureka quartzite in a zone peripheral to the uplift suggests that the positive area may have supplied at least part of the arenaceous and argillaceous sediments found in these formations. Continuing detailed studies of the Swan Peak formation, Eureka quartzite, and the rocks above and below them will no doubt reveal further information concerning the source areas of the clastic sediments, and give some idea of the crustial movements that took place during the Middle Ordovician epoch.

FISH HAVEN DOLOMITE

The Fish Haven dolomite which ranges from 270 to 350 feet in thickness, consists of a series of dark-, medium-, and light-gray locally cherty dolomites, which formerly constituted the lower third of the Blubell dolomite as originally defined by Lindgren and Loughlin (1919, p. 34–36). It comprises all of the Eagle member and the lower half of the Beecher member of the original Bluebell dolomite as subdivided by Crane (written communication 1943). As noted above, the Fish Haven disconformably overlies the Opohonga limestone and is in turn conformably overlain by the Bluebell dolomite, which in this paper is restricted to the upper two-thirds or so of the Bluebell dolomite of Loughlin (Lindgren and Loughlin 1919, p. 34–36). The Fish Haven–Opohonga contact is sharp and one of the most readily recognized in the sedimentary series. The contact of the Fish Haven with the Bluebell dolomite is less easily recognized, because both formations are chiefly dark-gray dolomite; the topmost bed of the Fish Haven, however, is a massive unit of prominently mottled dark- and light-gray dolomite, known locally as the Leopard Skin marker bed (fig. 26), whereas the basal beds of the overlying Bluebell are fine-grained dolomites weathering light gray, which were named the No. 21 beds by Crane (written communication, 1943). These beds are similar to other light-gray to white, well-bedded units in the Fish Haven and Bluebell dolomites but are

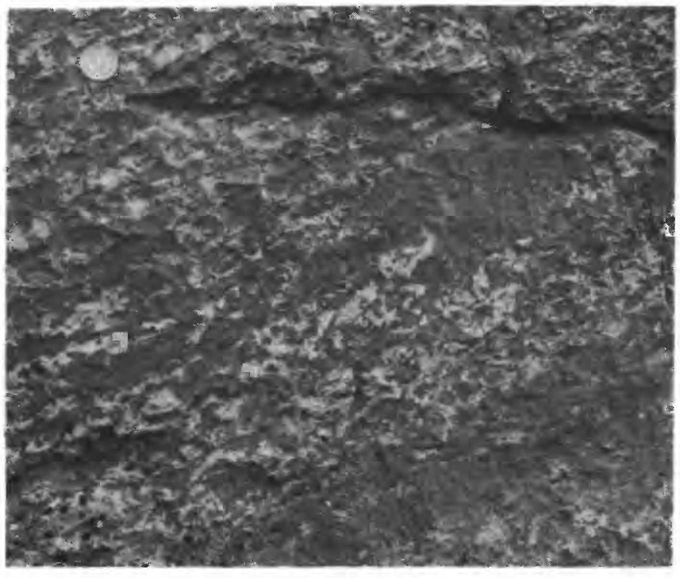


FIGURE 26.—Mottled dolomite in Leopard Skin marker bed of Fish Haven dolomite. Outcrop on main northeast spur of Pinyon Peak, Eureka quadrangle. Silver dollar, 1.5 inches in diameter, gives scale.

readily identified by their position above the Leopard Skin marker.

The Fish Haven of the East Tintic Mountains contains a fauna of Late Ordovician (Richmond) age and appears to correspond in age and lithologically with the greater part of the type Fish Haven dolomite in the Randolph quadrangle in northeastern Utah (Richardson, 1913, p. 409–410).

DISTRIBUTION

In the Tintic district the Fish Haven is well exposed in a much faulted, slightly curving band extending northward from the edge of the Silver City monzonite stock near the Iron Blossom No. 1 shaft to a point between the Eagle and Bluebell and Chief No. 1 shafts, where it is concealed by the alluvium of Eureka Gulch. North of Eureka Gulch it is displaced to the west along the Beck fault, beyond which its outcrops extend north-northeastward from the south end of Keystone Ridge near the Gemini shaft to the edge of the Packard quartz latite a short distance north of the Paxman shaft. The exposures on Keystone Ridge and in the central part of Cole Canyon near the Raymond-Illinois shaft (Raymond shaft on Eureka quadrangle map) are perhaps the best in the main Tintic district, but they may contain several small strike faults that locally cut out a few feet of the beds.

In the western part of the North Tintic district the outcrop of the Fish Haven extends northward from the edge of the lava cover in Fremont Canyon to a point near the head of the east fork of Broad Canyon, where it is offset to the east along the Tintic Prince fault. Between the Tintic Prince and Gardison Ridge faults it is locally cut out or thinned by thrust faults and the section exposed is not useful for a detailed study of the formation. North of the Gardison Ridge fault the Fish Haven is well exposed on both sides of the North Tintic anticline in an inverted U-shaped band of outcrops that extend southward on the west limb to the vicinity of Dry Lake.

In the eastern part of the North Tintic district, the Fish Haven crops out prominently on the north and east slopes of Pinyon Peak, in a broad curving band extending generally southeastward from the Selma fault near the Selma mine to a point near the craggy jasperoid outcrop 2,700 feet west-northwest of the Water Lily shaft, where it is displaced and complexly broken by the Pinyon Peak thrust fault and partly covered by alluvium and lava. It is also exposed in the lower plate of the Pinyon Peak thrust fault a few hundred feet north and west of the North Standard shaft. North of Pinyon Peak it is well exposed along the western front of the Selma Hills, in both the lower and upper plates of the Pinyon Peak thrust fault, from the vicinity of the Tintic Empire shaft northward nearly to Chimney Rock Pass, where it disappears beneath lava and alluvium. Less continuous outcrops occur also in the SW¼ sec. 16, T. 9 S., R. 2 W.; in the SE¼ sec. 35, T. 8 S., R. 2 W., about 2 miles south of Allens Ranch; in the E½ sec. 26, T. 8 S., R. 2 W., on the southeast side of Wanlass Hill; and in the E½ of sec. 23, T. 8 S., R. 2 W., on the southwest side of Greeley Hill.

In the East Tintic district the Fish Haven crops out on both sides of Burriston Canyon near the Zuma and Iron King Nos. 1 and 2 shafts, but the rocks in this area are intruded by many small dikes and plugs of monzonite and are bleached and recrystallized.

The Fish Haven was also observed in the south-central part of the East Tintic Mountains, in the first main gulch south of the Tintic Chief prospect adit, in the SW¼ sec. 24, T. 12 S., R. 2½ W.; and in the extreme southeastern part of the range, in the NE¼ sec. 22, T. 12 S., R. 2 W., there is an inlier of Fish Haven surrounded by lava and unconsolidated deposits.

THICKNESS

The Fish Haven is relatively uniform in thickness throughout the areas studied. On Pinyon Peak, 2,000 feet east-southeast of the crest, it is about 345 feet thick, and nearly 4 miles west-southwest, on the low ridge between the Raymond-Illinois and the Paxman shafts, it is about 290 feet thick. On Eureka Ridge, Crane (written communication, 1943) found equivalent beds to be 268 feet thick. The latter figure was more or less confirmed by H. G. Peacock (written communication, 1952) who measured 256 feet of beds between the Opohonga limestone and the No. 21 marker beds underground in the Eagle and Bluebell mine. On Eureka Ridge, however, the Fish Haven and the Bluebell dolomites are the host rocks of extensive ore bodies which may be localized by strike faults.

LITHOLOGIC CHARACTER

The Fish Haven is chiefly medium- to light-gray dolomite, in beds that range in thickness from a few inches to several tens of feet. Crinoid fragments are common in some beds, and chert nodules are abundant in the upper third of the formation. Some of the more massive medium-gray beds are conspicuously mottled with irregular cream-colored spots an inch or more in diameter, and these beds weather with a rough surface covered by sharp projections joined by narrow curving ribs. The thin-layered beds are mostly fine grained, and light gray or buff to light gray-blue in color; many are banded and striped with coarser textured and darker colored dolomite. Several of these beds are finely laminated and resemble certain of the buff to grayish-white beds of the Dagmar and Cole Canyon dolomites.

The chert-bearing section, which extends from 170 feet above the base to the lower part of the Leopard Skin marker bed at the top of the formation, a zone about 50–100 feet thick, is an identifying feature that distinguishes this part of the Fish Haven from the Bluebell dolomite. The cherts are enclosed in lead-gray medium-bedded to massive dolomite. The nodules are ovoid and mostly range from ½ to 8 inches in length, but nodules as much as 12 or 14 inches long occur locally in the base of the dolomite unit below the Leopard Skin marker bed. The chert nodules are chiefly black or brown and are elongated parallel to the bedding. On Eureka Ridge and near the Raymond-Illinois shaft, the middle part of the chert-bearing zone is virtually free from chert, so that there are two chert-bearing zones, the lower of which Crane (written communication, 1943) named the Geode bed and the upper of which is termed the Football marker bed by Peacock (oral communication, 1952) and other mining geologists. The name Geode bed is derived from the appearance of the lower chert zone near ore in the Chief No. 1 and Eagle and Bluebell mines, where the chert nodules are partly replaced by crystalline calcite and dolomite, thus resembling true geodes. On the 1450 level of the Eagle and Bluebell mines, also, the chert nodules of the Football marker are partly leached, leaving loose masses of corroded chert in some of the cavities, which are locally lined with a narrow rim of powdery or finely crystalline calcite.

The Leopard Skin marker bed at the top of the Fish Haven is a massive, ledge-forming dolomite unit. It is a medium- to dark-gray granular rock mottled with irregular light- to medium-gray patches of coarser-grained dolomite. Locally the upper part of this unit is a healed sedimentary breccia, containing fragments ranging from about 1 inch to 3 or 4 inches in diameter. The lower part is also mottled, but the rock does not appear to have been a breccia; this zone contains moderately well preserved Upper Ordovician fossils.

Stratigraphic sections of the Fish Haven were measured on Pinyon Peak in the North Tintic district, and near the Raymond-Illinois shaft in the main Tintic district. These sections are similar in many respects and are presented for comparison:

Stratigraphic section of Fish Haven dolomite measured on spur 2,000 feet east-northeast of crest of Pinyon Peak, North Tintic district, in the W½ sec. 34, T. 9 S., R. 2 W. (loc. 10A, pl. 3)

	Thickness (feet)	Distance above base (feet)
Bluebell dolomite:		
Basal beds are fine-grained, medium-blue dolomite that weathers light gray; prominently bedded in units 3 in. to 2 ft thick. No. 21 marker beds of Crane (written communication, 1943)		344.4
Contact conformable.		
Fish Haven dolomite:		
17. Dolomite, medium blue-gray, mottled with light-blue-gray; coarsely crystalline; massive, cliff-forming. Beds in lower part fossiliferous, beds in upper part resemble a healed breccia. Paleontological collection USGS 3106–SD from lower part of this unit. Leopard Skin marker bed	96	248.4
16. Dolomite, medium- to light-gray, fine to medium-grained; weathers medium- and dark-gray. Contains brown, black, and white ½- by 4-in. chert nodules	11	237.4
15. Dolomite, creamy-white, very fine-grained	2	235.4
14. Dolomite, blue-gray, medium- to fine-grained, thin-banded, medium-bedded	26	209.4
13. Dolomite, medium-gray, faintly banded, medium-grained	8	201.4
12. Dolomite, medium-gray, laminated	2	199.4
11. Dolomite, lead-gray, medium- to coarse-grained	7	192.4
10. Dolomite, lead-gray, laminated. Bedding-plane fault at base	1	191.4
9. Dolomite, light-gray, thin-banded, fine-grained, contains scattered black chert nodules. Geode bed zone	5	186.4
8. Dolomite, light-gray, banded, fine-grained, thin-bedded; medium-gray bands at base	51.2	135.2
7. Dolomite; layers of strongly mottled medium-gray dolomite alternating with layers of light-gray, uniformly colored dolomite; both types of rock weather with rough texture. Cliff former	12.2	123
6. Dolomite, medium light-gray, thin-banded, thin-bedded	15	108
5. Dolomite, mottled and banded, light- and medium-gray; darker and more strongly mottled at base	37	71
4. Dolomite, medium-gray, medium-grained. Silicified corals, poorly preserved crinoid columnals, and sparse calcite and dolomite nodules weather in relief	17	54
3. Dolomite, arenaceous, buff-weathering	15	39
2. Dolomite, argillaceous, brown-weathering. Sand streaks at base. Paleontologic collection USGS 3279–SD from this unit	38	1
1. Sandstone, dolomitic, brown-weathering	1	
Total Fish Haven dolomite	344.4	
Disconformity.		
Opohonga limestone:		
Limestone, light blue-gray, thin-bedded.		

Stratigraphic section of Fish Haven dolomite measured 75 feet south of Raymond-Illinois shaft, main Tintic district, in N½NE¼ sec. 13, T. 10 S., R. 3 W. (loc. 10B, pl. 3)

	Thickness (feet)	Distance above base (feet)
Bluebell dolomite (lowest bed only):		
Dolomite; medium- to dark-gray, fine-grained, weathers with a light-gray surface; well bedded in units 3 to 12 in. thick. No. 21 marker beds of Crane (written communication, 1943)		285.5
Contact conformable.		
Fish Haven dolomite:		
20. Dolomite, dusky blue-gray strongly mottled with medium blue gray, banded at top. Rare *Catenipora* near base. Leopard skin marker beds	11	274.5
19. Dolomite, medium blue-gray, mottled with lighter gray irregular patches. Contains 1- by 6-in. chert lenses, which are white near the base of the unit and black with brown borders in upper part. Football marker bed horizon	5.5	269
18. Dolomite, medium-gray mottled with light blue-gray; scattered pisolitic bands	18.5	250.5
17. Dolomite, light blue-gray, fine-grained; contains scattered ½- by 10-in. chert lenses	16.5	234
16. Dolomite, alternating light blue-gray and medium blue-gray in thin, laminated beds	15	219
15. Dolomite, medium to light blue-gray; contains many 3-in. black chert nodules with white centers	27	192
14. Dolomite, dusky blue-gray, fine-grained, with 3- to 8-in. lenses of black chert parallel to bedding. Geode bed zone	8.5	183.5
13. Dolomite, medium blue-gray, medium-grained	7.5	176
12. Dolomite, light-gray, fine-grained	14	162
11. Dolomite, medium blue-gray, dense	9.5	152.5
10. Dolomite, medium-gray, fine grained, abundant coral and crinoid fragments. Unit weathers yellowish-gray. Paleontologic collections USGS 3061-SD and USGS 3074-SD from this unit	8	144.5
9. Covered zone	15	129.5
8. Dolomite, chalky-gray, medium-grained, faintly crossbedded, possibly clastic	14	115.5
7. Dolomite, dusky-gray, fine-grained, fragmented crinoid columnals abundant	13	102.5
6. Dolomite, light-gray, dense, medium-bedded. Some beds near top are laminated	33	69.5
5. Dolomite, blue-gray mottled with light-gray, finely granular	13.5	56
4. Dolomite, light-gray, fine-grained. Cup corals abundant	19	37
3. Dolomite, medium-gray, massive. Discontinuous chert layers 2 in. thick	2	35
Fish Haven dolomite—Continued		
2. Dolomite, blue-gray, fine-grained, massive. Abundant crinoids and corals. Paleontological collection USGS 3278-SD from this unit	33	2
1. Dolomite, dark-gray, subcrystalline, with small agal(?) structures	2	
Total Fish Haven dolomite	285.5	
Disconformity.		
Opohonga limestone (upper beds only):		
Limestone, light blue-gray, thin-bedded, argillaceous.		

AGE AND CORRELATION

Loughlin (Lindgren and Loughlin, 1919, p. 34–36) designated the age of the original Bluebell dolomite, the lower part of which is the Fish Haven of this report, as Lower to Upper Ordovician. He did so on the basis of *Maclurea annulata* Walcott and *Helicotoma* sp., collected "from the bottom bed"; *Solenopora* sp., collected from the middle part of the dolomite; one specimen of *Orthis* found on the north side of Homansville Canyon just below the basal Mississippian beds; and a specimen of *Streptelasma* sp., found at zones 400 feet below the top of the dolomite on the southeast slope of Pinyon Peak. Edwin Kirk identified the fossils and stated that the *Maclurea annulata* and *Helicotoma* sp. are "* * * undoubtedly of Beekmantown (Lower Ordovician) age," that the *Solenopora* "is typically post-Beekmantown, and the *Orthis* finds its closest ally in rocks of Stones River age," and that "* * * the *Streptelasma* points clearly to the Richmond age of the containing beds." Loughlin (Lindgren and Loughlin, 1919, p. 35) therefore concluded that "* * * the Bluebell dolomite * * * ranges from Lower to Upper Ordovician and it is possible that the upper 400 feet at Pinyon Peak may include Silurian or Devonian strata."

Collections of fossils made from the original Bluebell dolomite during the present geologic study of the East Tintic Mountains confirmed the view that the Bluebell as originally defined contains rocks of Late Ordovician, Silurian, and Devonian age. The fossils of Beekmantown age reported by Loughlin from the bottom bed on Eureka Peak were not found during the present study, and it is believed that they were collected from the upper part of the Opohonga limestone, which is hydrothermal dolomite in the area where Loughlin collected the *Maclurea* and *Helicotoma*.

Additional collections of fossils were made from the Fish Haven dolomite by members of the Geological Survey during the recent survey. The corals in these collections were identified by Helen Duncan and Jean Berdan and the brachiopods by Josiah Bridge. The fossils found include the following, according to Berdan:

A. Raymond-Illinois mine section, Eureka quadrangle, NW¼NE¼ sec. 13, T. 10 S., R. 3 W.; north side of Cole Canyon between Raymond-Illinois and Colorado Chief shafts.

Collection No. USGS 3278–SD. From 4 to 10 feet above base of Fish Haven dolomite.
Favosites sp.
Lepidocyclus perlamellosus (Whitfield)
Strophomena sp.

Collection No. USGS 3074–SD. Lower part of Fish Haven dolomite.
Favosites sp.

Collection No. USGS 3276–SD. Float from stratigraphically below Leopard Skin marker bed.
Calapoecia sp.

Collection No. USGS 3061–SD, Fish Haven dolomite 145 feet above base.
Favosites sp.
phacelloid coral, undetermined.

Collection No. USGS 3280–SD, Fish Haven dolomite 285 feet above base.
Catenipora sp.

B. Pinyon Peak section, NW¼ sec. 34, T. 9 S., R. 2 W., Eureka quadrangle. Collections made on main easterly trending spur of peak 2000 feet east-northeast of crest.

Collection No. USGS 3279–SD, Fish Haven dolomite 10–25 feet above base.
Palaeophyllum sp.
Catenipora sp. of *C. rubra* Sinclair and Bolton
Streptelasmatid corals
Bryozoan(?)

Collection No. USGS 3275–SD, from float 100 feet above base of Fish Haven dolomite.
Catenipora rubra Sinclair and Bolton

Collection No. USGS 3106–SD, Fish Haven dolomite 256 feet above base.
Cephalopod siphuncle
Streptelasmatid coral

C. Rattlesnake Spur, Gardison Ridge section, NW¼ sec. 1, T. 9 S., R. 3 W., Boulter Peak quadrangle.

Collection No. USGS 3274–SD, Fish Haven dolomite 15–20 feet above base.
Catenipora rubra Sinclair and Bolton
Palaeophyllum sp.
Calapoecia sp.

Collection No. USGS 3112–SD, Fish Haven dolomite 210–230 feet above base.
Calapoecia sp.
Saffordophyllum sp.
Palaeophyllum? sp.
Streptelasma trilobatum Whiteaves

D. Collections from the Fish Haven dolomite in the Allens Ranch quadrangle: W½ sec. 22, T. 9 S., R. 2 W:

Collections Nos. USGS 3014–SD and 3016–SD. From 20 to 70 feet above base of formation.
Catenipora rubra Sinclair and Bolton
Palaeophyllum sp. indet.
Streptelasmatid coral
Trepostomatous bryozoan, probably one of the Trematoporidae

Collection USGS 3020–SD. Center sec. 13, T. 9 S., R. 3 W.
Catenipora rubra Sinclair and Bolton
Aulacera cf. *A. undulata* (Billings)
Streptelasmatid corals
Cephalopod, indeterminate

Collection No. USGS 3113–SD. SE¼SE¼ sec. 9, T. 9 S., R. 2 W.; near Greeley shaft. Distance above base not known.
Streptelasma trilobatum Whiteaves
Halysites (*Catenipora*) cf. *C. rubra* Sinclair and Bolton
Saffordophyllum? sp.
Lepidocyclus cf. *L. perlamellosus* (*Whitfield*)
Lepidocyclus rectangularis (Wang)

Duncan and Berdan (written communication, 1957) state—

The fauna represented by the above lists is typical of the Upper Ordovician of the western States, and is distributed from Montana to Texas and California. One of the most characteristic and abundant elements of this fauna is *Catenipora rubra* Sinclair and Bolton, which is listed as *Catenipora gracilis* Hall, in reports made before 1956. Commonly associated with this species are *Calapoecia* sp., *Palaeophyllum* sp., *Favosites* sp., and the distinctive solitary coral *Streptelasma trilobatum* Whiteaves. The occurrence of the Richmond brachiopod *Lepidocyclus perlamellosus* (Whitfield) at the base of the Fish Haven in the East Tintic Mountains suggests that all of the formation in this area is of Richmond age, and that the unconformity between the Opohonga and the Fish Haven includes Eden and Maysville as well as Middle Ordovician time.

The Fish Haven dolomite is correlated with at least part of the Fish Haven dolomite at the type locality in the Randolph quadrangle (Richardson, 1913, p. 407, 409) and also with units of the same name in the Gold Hill quadrangle (Nolan, 1935, p. 16–17) and in the Thomas Range, Utah (Staatz, oral communication, 1954). It is equivalent to the greater part of the Ely Springs dolomite of the Pioche region, Nevada (Westgate and Knopf, 1932, p. 16), all or part of the Hanson Creek formation of the Roberts Mountain quadrangle (Merriam, 1940, p. 10–11), and the Bighorn dolomite of Wyoming and Montana (Miller, 1930, p. 195–209). The Fish Haven is absent in the Oquirrh Mountains and central Wasatch Range; it was either destroyed during one or more pre-Mississippian erosion intervals or was not deposited in this area.

TOPOGRAPHIC EXPRESSION

Because of the alternation of massive and thin-layered beds, the Fish Haven dolomite and the lithologically similar Bluebell dolomite above it weather with distinctive ledgy outcrops. The base of the Fish Haven may easily be followed on Pinyon Peak, where it rises abruptly as a low cliff above the slope-forming shaly limestone of the Opohonga. In areas of gentle dips the massive mottled beds from 50 to 100 feet above the base also crop out as nearly vertical cliffs standing 30–80 feet high in many places. The thin-bedded layers almost invariably form slopes rather than cliffs, but are commonly well exposed in steplike outcrops in narrow gulches.

The cherty dolomite of the Geode bed zone in the upper part of the formation is locally a cliff former, but on the east ridge of Pinyon Peak this unit forms a slope that occurs at the base of an abrupt cliff, 80–100 feet high, formed by the Leopard Skin marker bed.

STRUCTURAL HABIT

The Fish Haven consists of relatively brittle dolomite, and in areas of severe deformation it is complexly shattered and faulted. The increase in porosity attendant on this breaking has facilitated alteration and ore deposition, especially in the main Tintic district, where the Fish Haven is an important host rock for ore.

UNDERGROUND EXPRESSION

Underground the Fish Haven is most likely to be confused with the Ajax and Cole Canyon dolomites; however, it differs from the dark magnesian rocks of the Ajax in containing somewhat less chert and many more light-colored and laminated beds, and from the Cole Canyon by the presence of chert in the upper third of the formation; crinoid stems and other post-Cambrian fossils, also, are sparsely present in some places.

CHEMICAL AND PHYSICAL PROPERTIES

Exclusive of the chert fraction, the Fish Haven is a remarkably pure dolomite averaging about 1 percent each of insoluble residue (probably silica and alumina) and ferric oxide plus alumina. The MgO : CaO ratio is nearly identical with that of pure dolomite. An analysis is given in table 10.

TABLE 10.—*Chemical analysis of Fish Haven dolomite*

Formation	Acid insoluble	Al_2O_3 and Fe_2O_3	CaO	MgO	CO_2[1]	Total
Fish Haven[2] dolomite (lower 180 ft)	1.1	1.0	29.9	20.8	46.2	99.0

[1] Calculated.
[2] Collected (as Eagle member of Bluebell dolomite) by G. W. Crane; analysis, courtesy Chief Consolidated Mining Co.

The physical properties of the formation are not known but are probably similar to those of other comparatively pure dolomites.

ECONOMIC IMPORTANCE

The Fish Haven dolomite is an ore bearing formation of major importance in the main Tintic district, but it has produced only small amounts of base- and precious-metal ores in the East Tintic district, chiefly from the Zuma mine. Many of the ore bodies in the Mammoth-Chief ore zone and in the Gemini–Centennial Eureka ore zone north of the Beck fault are in the Fish Haven, and the gross value of the ores produced from these ore bodies probably amounts to about $10 million (Cook, 1957, p. 65). In the East Tintic district, also, relatively small tonnages of oxidized manganese and iron fluxing ores have been mined from the Fish Haven near the Iron King and Zuma shafts.

ORDOVICIAN, SILURIAN, AND DEVONIAN SYSTEMS

BLUEBELL DOLOMITE

The term Bluebell dolomite is here restricted to the Upper Ordovician, Silurian, and Devonian rocks that constituted the upper two-thirds of the Bluebell dolomite as defined by Loughlin (Lindgren and Loughlin, 1919, p. 34–36). The revised Bluebell comprises the upper half of the Beecher member and all of the Dora and Noah members of the Bluebell as defined by Crane (written communication, 1943).

The base of the Bluebell dolomite is here placed at the base of the light-gray-weathering thin-bedded fine-grained dolomite unit, about 20 feet thick, that was named the No. 21 marker beds by Crane (written communication, 1943). This unit is readily recognized in mine workings, but it may be locally concealed at the surface, where it tends to weather into subdued outcrops. However, the No. 21 beds directly overlie the prominent Leopard Skin marker bed which forms the top of the Fish Haven dolomite; this association allows the basal unit of the Bluebell to be identified with confidence, and the contact to be located with some accuracy even in areas of poor exposures.

The top of the Bluebell is placed at the base of the first quartzite or sandstone bed of the Victoria formation. Throughout the northern half of the East Tintic Mountains, the lowest quartzite bed of the Victoria is a few feet below a highly distinctive bed of medium-gray medium-grained dolomite, 1–3 feet thick, that is crowded with well-formed white dolomite crystals and crystal aggregates a centimeter or two in diameter. The latter characteristic has prompted the names speckled bed and porphyry bed for this marker. The bed is readily recognized in outcrop, or in float where the lowest quartizite beds of the Victoria are concealed by surface debris, and is an excellent mapping datum in the mines.

CHARACTER AND DISTRIBUTION

The Bluebell dolomite is principally medium grained and fine grained, buff to dusky blue-gray, well-bedded dolomite that contains scattered poorly preserved fossils of latest Ordovician, Middle Silurian, and Devonian age. It is somewhat similar in appearance to the Cole Canyon dolomite but is readily distinguished from it by the abundant fragments of crinoid columnals, as well as by honeycomb and chain corals, and pentameriod brachiopods that are present in some beds. The Bluebell also has fewer well laminated light-gray-weathering dolomite beds than the Cole Canyon dolomite, and the dusky-blue dolomites of the Bluebell do not contain the abundant twig-shaped bodies that are diagnostic of the Bluebird-type dolomite of the Cole Canyon and Bluebird formations.

The Bluebell dolomite also closely resembles the Fish Haven dolomite, which underlies it, but the Bluebell has comparatively little chert and is more banded than mottled in general appearance.

Surface exposures of the Bluebell dolomite closely follow those of the Fish Haven dolomite. The most accessible outcrops are found on both sides of Eureka Ridge from the Mammoth mine north to Fitchville, on Keystone Ridge north of the Gemini mine, on the ridge east of the Raymond-Illinois shaft, on Gardison Ridge north of the Gardison Ridge fault, and on the north and east slopes of Pinyon Peak from the Selma fault across the broad north spur and along the east slopes to the southeast base of the peak. In the East Tintic district it is partly exposed on the hill between the Iron King Nos. 1 and 2 shafts and the Burriston Canyon road (Eureka quadrangle), but at this locality it is intruded by monzonite and somewhat bleached.

The Bluebell is also exposed in the extreme southeastern part of the East Tintic Mountains southeast of Little Dog Valley in the E½ sec. 22, T. 12 S., R. 2 W., and along the western edge of the south-central part of the range south of Riley Canyon in the SW¼ sec. 24, T. 12 S., R. 2½ W. and the NE¼ sec. 25, T. 12 S., R. 3 W. Part of the formation is also exposed one mile north of Jericho Pass between large faults, but the beds are highly broken and much altered in this area.

THICKNESS

In the East Tintic Mountains the Bluebell dolomite is from about 330 feet to more than 600 feet thick. In the central and western parts of Long Ridge, 14 miles east of Eureka, equivalent rocks are less than 300 feet thick, and the formation is entirely absent in the central Wasatch Range and in the Oquirrh Mountains. West and southwest of the East Tintic Mountains equivalent strata of Silurian and Devonian age are much thicker, and more than 1200 feet of Silurian beds alone are found in the Thomas Range (Staatz, written communication, 1954).

LITHOLOGIC CHARACTER

The Bluebell is entirely dolomite—both the thick and the thin beds. The thick beds are chiefly medium to coarse grained and range in color from lead gray and medium blue gray to dusky blue gray and nearly black. Locally they are mottled with irregular patches of medium- to light-gray dolomite and are sparsely cherty and fossiliferous. The thin-bedded and laminated strata are mostly fine to medium grained and are medium gray, light gray or yellowish gray. Some of the lighter colored dolomite beds are extremely dense and have been termed lithographic limestones by the mining geologists in the Tintic district.

Except in the Pinyon Peak area, the Bluebell has a distinctive marker bed of laminated dolomite near the middle, which separates the formation into two members. This bed, the upper curly bed of Crane (written communication, 1943), is here named the Colorado Chief marker bed (fig. 27). The dolomite unit is about 10 feet thick and is characterized by medium dark-gray and medium light-gray laminae, a few millimeters to a centimeter or more in thickness, which are wavy and contorted. The lighter colored laminae are calcareous and react slowly with dilute hydrochloric acid, whereas the somewhat carbonaceous darker layers are entirely dolomite. The crenulated laminae suggest an algal origin for this distinctive marker bed.

On Pinyon Peak the Colorado Chief marker bed is absent, having been eroded prior to the deposition of the upper half or more of the formation; in this area

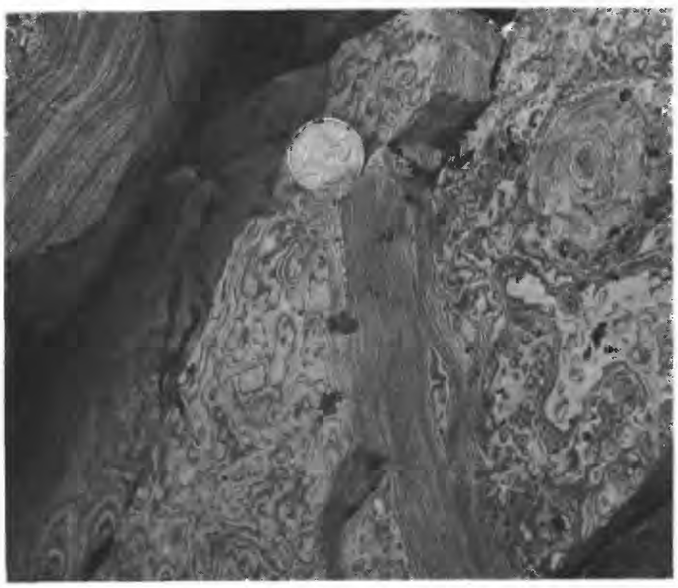


FIGURE 27.—Colorado Chief marker bed of Bluebell dolomite. Note wavy light- and dark-gray laminae. Silver dollar, 1.5 inches in diameter, gives scale. Outcrop on Fitchville Ridge, three-fourths mile southeast of Eureka, Eureka quadrangle.

the contact between the upper and lower members of the Bluebell is placed at the base of the dolomite unit that contains fossilized fish plates (see p. 69). The lower member of the Bluebell contains much fine- to medium-grained, thin- to medium-bedded dolomite that weathers light to medium gray; in contrast, the upper member of the Bluebell is largely medium- to coarse-grained, thick-bedded dolomite that weathers medium to dark gray. The lower member has yielded Ordovician and Silurian fossils, and the upper member has produced the only Devonian fossils collected from the formation.

The following detailed section, which was measured near the Raymond-Illinois shaft in the main Tintic district, is characteristic of the Bluebell dolomite throughout the greater part of the East Tintic Mountains.

Stratigraphic section of Bluebell dolomite measured between Raymond-Illinois and Colorado Chief shafts, main Tintic district, in the N½NE¼ sec. 13, T. 10 S., R. 3 W. (loc. 11A, pl. 3)

	Thickness (feet)	Distance above base (feet)
Victoria formation:		
Alternating dolomite and dolomitic and calcitic quartzite in units 2–10 ft thick. Contact placed at base of lowest quartzite bed. In this locality the basal quartzite bed is overlain by a medium-gray dolomite unit crowded with crystals and irregular blebs of grayish-white dolomite near the top, which is the speckled-bed marker of local usage		491.0
Contact conformable.		
Bluebell dolomite:		
Upper member (Eyebeds zone of local usage):		
23. Dolomite, medium- to light-gray on both fresh and weathered surfaces, medium- to coarse-grained, massive	3.2	487.8
22. Dolomite, medium light-gray on fresh surface, light-gray on weathered surface, medium- to fine-grained. Contains many 1- by 1½-in. pods of coarsely crystalline dolomite; weathers with a rough surface	27.0	460.8
21. Dolomite, medium dark-gray on fresh surface, medium light-gray on weathered surface, medium-grained. Weathers with a smooth surface	2.8	458.0
20. Dolomite, medium dark-gray on fresh surface, weathers medium dark-gray mottled with patches of medium light-gray dolomite; contains scattered ½- to 1-in. oval pods of coarse crystalline white dolomite. Weathers with a rough surface	7.9	450.1
19. Dolomite, medium dark-gray on fresh surface, medium light-gray on weathered surface, medium-grained	4.6	445.5
Bluebell dolomite—Continued		
Upper member (Eyebeds zone of local usage)—Continued		
18. Dolomite, medium dark-gray on both fresh and weathered surfaces, medium-grained. Contains a few poorly defined lighter colored bands that appear to be healed bedding-plane breccias	13.0	432.5
17. Dolomite, medium dark-gray, banded and mottled with lighter gray dolomite, coarse-grained; well bedded in units 2 to 5 ft thick. This unit is characterized by many vugs partly filled with coarse-grained creamy-white dolomite. Some vugs are entirely filled and are represented by almond-shaped pods of white dolomite. White dolomite veinlets cut rock and cement local breccia zones. Near middle are a few shaly and sandy beds	68.2	364.3
16. Dolomite, medium light-gray on fresh surface; weathers light gray; medium to fine grained	5.5	358.8
15. Dolomite, medium light-gray on fresh and weathered surfaces, faintly mottled and laminated along strike	21.0	337.8
14. Dolomite, gray to black on fresh fracture, weathering a slightly darker tint; seamed with anastomosing stringers or veinlets of coarse-grained dolomite. Middle part of the unit is faintly mottled and has faint structures resembling oolites. Top is an irregular color line	8.7	329.1
13. Dolomite, medium light-gray on both fresh and weathered surfaces. Base is marked by an 8–10 in. bed of brownish-gray clay shale; a second shale zone also occurs 8 ft above base	33.0	296.1
12. Dolomite, medium dark-gray, medium-grained, well-bedded; bedding planes marked by thin seams of shale. Beds near top contain scattered pods of white dolomite 1 in. in diameter	11.0	285.1
11. Colorado Chief marker bed: dolomite, finely laminated, medium light-gray and medium dark-gray; laminae are most commonly moderately contorted but locally are straight or complexly whorled. The lighter colored laminae are slightly calcareous and react with cold dilute hydrochloric acid	10.6	274.5
Lower member:		
10. Dolomite, medium-gray, slightly darker on fresh fracture; coarse-grained; contains scattered cylindrical nodules of coarse-grained white dolomite 1.4 in. in diameter and 0.5 in. long; zones of these nodules apparently mark bedding	15.0	259.5

	Thickness (feet)	Distance above base (feet)
Bluebell dolomite—Continued		
Lower member—Continued		
9. Covered zone; float indicates a medium light-gray, medium-grained dolomite	16.0	243.5
8. Dolomite, medium dark-gray faintly mottled and banded with lighter gray dolomite; contains scattered irregular pods of coarse-grained dolomite	12.0	231.5
7. Covered zone; float indicates yellowish-brown fine-grained argillaceous dolomite near top and light-gray fine-grained dolomite near base	40.0	191.5
6. Dolomite, medium dark-gray banded and laminated with lighter gray dolomite. At top is a 3-ft zone of limy flat-pebble conglomerate. Along strike this unit becomes as well laminated as the Colorado Chief marker and may be confused with it. Lower curly bed of local usage	16.5	175.0
5. Dolomite, dusky-gray to grayish-black; prominently banded with thin and thick layers that range in color from medium dark-gray to creamy-white. The lighter beds contain lenses of flat-pebble conglomerate; some of the dark beds are finely banded and may be termed curly beds. Base of unit is marked by a prominent bed of flat-pebble conglomerate in which black chiplike fragments are enclosed in a matrix of light-gray to white dolomite. The beds a few feet above the basal conglomerate contain brachiopods, cephalopods, and other fossils. Collections of fossils Nos. USGS 2948-SD, 3062-SD, and 3077-SD from bed 17-19 ft above base. This unit is the Black Panther marker bed of local usage	45.0	130.0
4. Dolomite, medium light-gray on fresh fracture, light-gray to creamy-white on weathered surface; thin- to medium-bedded. Many beds are laminated. This unit is the Beecher beds of local usage	65.0	65.0
3. Dolomite, medium-gray, medium- and coarse-grained, moderately well bedded; contains some thin units of flat-pebble conglomerate and some beds that are speckled with white dolomite crystals. Fossils of uppermost Ordovician age weather in relief on many beds. Collection of fossils No. USGS 3075-SD is from this unit. *Propora* beds of field usage	30.0	35.0
2. Dolomite, medium dark-gray mottled with irregular patches of lighter gray dolomite, medium- to coarse-grained. Collection of fossils No. USGS 3076-SD is from this unit	15.5	19.5
1. Dolomite, medium dark-gray on fresh surface, light-gray to white on weathered surface, well-bedded and very fine-grained. No. 21 marker beds of Crane (written communication, 1943)	19.5	
Total Bluebell dolomite	491.0	
Contact conformable.		
Fish Haven dolomite (upper bed only):		
Dolomite, massive, mottled dusky blue-gray and medium- to light blue-gray; cherty in lower part; Leopard Skin marker bed.		

For comparison, a remarkably well exposed, apparently normal section of the Bluebell dolomite measured on the northeastern side of Pinyon Peak is presented below. Although the two sections are identical or closely similar in their upper and lower parts, the section measured on Pinyon Peak is much thinner and lacks a considerable number of lithic units recognized near the Raymond-Illinois shaft and elsewhere in the Eureka and Boulter Peak quadrangles, including the Colorado Chief marker bed. This suggests the presence of an obscure disconformity within the Bluebell in at least the northeastern part of the East Tintic Mountains. This disconformity is believed to separate Silurian and Devonian strata, but the absence of an angular discordance, and of conglomerate or sandstone beds, makes it difficult to establish the precise positions of the breaks within the Bluebell.

Stratigraphic section of Bluebell dolomite measured on spur 1,700 feet east-northeast of crest of Pinyon Peak, North Tintic district, in W½ sec. 34, T 9 S., R. 2 W. (loc. 11B, pl. 3)

	Thickness (feet)	Distance above base (feet)
Victoria formation (lowest bed only):		
Dolomite breccia, sand-streaked, 12.3 ft thick; speckled dolomite marker bed 5.5 ft above top of this bed		336
Contact conformable.		
Bluebell dolomite:		
22. Dolomite, light blue-gray, weathers medium blue-gray, fine-grained, medium- to thick-bedded. Some beds slightly arenaceous. Secondary chert in joints	20	316
21. Dolomite, medium blue-gray, medium to fine-grained; with abundant white dolomite nodules scatered through it	46.5	269.5

	Thickness (feet)	Distance above base (feet)
Bluebell dolomite—Continued		
20. Shaly dolomite, light- and dark-gray, thin-banded, thin-bedded	23.3	246.2
19. Dolomite, medium to light blue-gray, laminated, fine-grained, thin-bedded	12.7	233.5
18. Dolomite, dusky-blue, banded and locally mottled with light gray. Some layers striped with fine- and medium-grained dolomite crystals that weather in relief	15.3	218.2
17. Dolomite, dusky blue-gray, faintly banded; speckled with secondary white dolomite nodules; fine-grained	10	208.2
16. Dolomite, light yellowish-gray, thin-banded, fine-grained	19.8	188.4
15. Dolomite, dusky blue-gray; contains rough-weathering white calcite nodules	4.5	183.9
14. Dolomite, light yellowish-gray, laminated	2.5	181.4
13. Dolomite, dusky blue-gray, fine-grained; includes minor chert as irregular small- to medium-sized nodules	1	180.4
12. Dolomite, medium blue-gray, even-grained, medium-bedded. Some beds have 1-in. black bands 1 ft apart	9.5	170.9
11. Dolomite, alternating beds yellowish-gray and medium blue-gray	7.6	163.3
10. Dolomite, buff-gray, faintly banded, medium-bedded	14.6	148.7
9. Sandy dolomite, purplish blue-gray; somewhat conglomeratic. Zone of fossilized fish fragments, collection USGS 4435–SD	1	147.7
8. Argillaceous dolomite, banded pinkish-buff and blue-gray, fine-grained, thin-bedded	39.5	108.2
7. Dolomite, medium blue-gray, fine-grained; weathers light blue gray	14	94.2
6. Dolomite, alternating medium blue-gray and light blue-gray contorted laminae. Lower curly bed of Crane (written communication, 1943)	3	91.2
5. Dolomite, medium blue-gray, very fine grained; weathers light blue gray	9.2	82
4. Dolomite, light-gray, fine-grained, laminated; weathers white	26	56
3. Dolomite, light-gray, fine-grained, medium-bedded; banded in lower part, bands medium gray, 1 in. to 1 ft. thick	11	45
2. Dolomite, light- to medium-gray, mottled in lower part, banded in upper part; zone of *Propora* and *Reuschia*?, collections USGS 3069–SD and 3082–SD	30	15
1. Dolomite, medium-gray, weathers light-gray; well bedded in units 3 in. to 2 ft thick; No. 21 marker beds of Crane (written communication, 1943)	15	
Total Bluebell dolomite	336.0	

Contact conformable.

Fish Haven dolomite (upper bed only):

Dolomite, dusky-blue, mottled; Leopard Skin marker bed.

AGE AND CORRELATION

Collections of fossils were made from the sparsely fossiliferous Bluebell dolomite from: (a) the short spur between the Raymond-Illinois and Colorado Chief shafts, (b) the northwestern and northeastern slopes of Pinyon Peak, (c) Rattlesnake Spur near the north end of Gardison Ridge, (d) Black Rock Canyon, and (e) exposures near the Lehi Tintic shaft. These fossils confirm Loughlin's belief that the Bluebell contains strata of Late Ordovician, Silurian, and Devonian ages (Lindgren and Loughlin, 1919, p. 35).

The collections made from zones 33 and 47 feet above the base of the formation while the geologic maps of Eureka, Allens Ranch, and Boulter Peak quadrangles were being prepared were originally thought to indicate a Silurian age for the enclosing beds. Some time later, however, a species of *Tetradium*, previously reported only from the Upper Ordovician of the Arctic and the Baltic States, was recognized in these collections. The genus does not range beyond the Ordovician. Because of the general vagueness of the precise boundary between Upper Ordovician and Silurian rocks in other areas of the Great Basin province, and because no prominent lithologic change could be found that was suitable for a formation boundary between the Ordovician and Silurian faunas, no attempt was made to redefine the upper contact of the Fish Haven dolomite to include these uppermost Ordovician beds or to relocate the boundary as mapped between the Fish Haven and Bluebell formations. This makes the Bluebell dolomite a somewhat unusual "time unit," but does not affect its original designation as a mappable lithologic entity.

Collections of fossils confirm a Silurian age for the upper part of the lower member of the Bluebell, beginning with certainty about 115 feet above the Ordovician coral beds; a few poorly preserved but distinctive fossils suggest a Middle(?) and Late Devonian age for all or the greater part of the upper member—the eyebeds zone of local usage.

Collections made from the Upper Ordovician and Silurian parts of the Bluebell dolomite by Jean M. Berdan, Helen Duncan, and Raymond Lewandowski were described in November 1955 by Berdan as follows:

The Bluebell dolomite contains three faunal associations which appear to hold approximately the same stratigraphic positions in the three sections that have been carefully collected. The lowest of these faunal associations, which comes from two beds, 33 and 47 feet above the base in the Raymond-Illinois area, contains a sparse assemblage of corals that includes *Favosites* sp., heliolitid corals, and a peculiar phacelloid coral. Some 100 feet above this in the section exposed near the Raymond-Illinois shaft, is a bed that contains pentameroid brachiopods tentatively identified as *Virgiana*. These brachiopods definitely date this part of the section as Silurian. The highest faunal association, which consists of gastropods, extremely poorly preserved branching favositid corals, and a very few brachiopods, is believed to be Devonian.

Reexamination of the collections, which include the lowest of the 3 faunal associations, showed that what had been identified as a very small phacelloid coral was actually a species of *Tetradium*, comparable to *T. tubifer* Troeddson, which prior to this discovery has been reported only from the Baltic States and the Arctic. This discovery led to an intensive reexamination of the other specimens from this horizon, with the result that the heliolitid coral can now be identified as *Propora* sp., a genus which ranges from the Ordovician into the Silurian. Other phacelloid corals in these collections appear to be similar to *Reuschia*, a genus also described from the Upper Ordovician of the Baltic region. *Favosites* * * * is known to be found throughout the Upper Ordovician in the west.

In view of the above statements, it now seems probable that the beds containing the small corals should be considered Upper Ordovician, rather than Silurian, on the basis of the occurrence of *Tetradium* and the general similarity of this faunal association to that in the Upper Ordovician Lyckholm beds of the Baltic Province. This means that the Ordovician-Silurian contact is not precisely known but lies somewhere between points 47 feet and 147 feet above the base of the Bluebell dolomite.

The details of several collections are listed below:

A. Raymond-Illinois mine section, NW¼NE¼ sec. 13, T. 10 S., R. 3 W., Eureka quadrangle; north side of Cole Canyon between Raymond-Illinois and Colorado Chief shafts. Fossils identified by Berdan and Duncan.

Collection No. USGS 2949–SD. Near base of Bluebell dolomite probably from the horizon of *Reuschia* and *Propora* faulted against the top of the Fish Haven dolomite.
Favosites sp.
Paleophyllum sp.
Strophomenoid brachiopods
Age: Late Ordovician.

Collection No. USGS 3076–SD. Approximately 33 feet stratigraphically above base of Bluebell dolomite, about 15 feet stratigraphically below collection USGS 3075–SD, and about 100 feet stratigraphically below horizon of *Virgiana* (colln. No. USGS 3077–SD).
Tetradium cf. *T. tubifer* Troedsson.
Age: Late Ordovician.

Collection No. USGS 3075–SD. Approximately 47 feet stratigraphically above base of Bluebell dolomite.
Propora sp.
Age: Probably Late Ordovician.

Collections Nos. USGS 2948–SD, USGS 3062–SD, and USGS 3077–SD.
All from 147 to 149 feet above the base of the Bluebell dolomite in the Black Panther marker bed of local usage.
Virgiana sp.
Favosites sp.
Zelophyllum sp.
Horn corals, unidentified
Age: Silurian

B. Pinyon Peak section, W½ Sec. 34, T. 9 S., R. 2 W., Eureka quadrangle. Collections made on main east-trending spur of peak 2,000 feet east-northeast of crest.

Collections Nos. USGS 3069–SD and 3082–SD, 40–45 feet above the base of the Bluebell dolomite, from a bed lithologically similar to the one from which collection USGS 3075–SD was made in the Raymond-Illinois area.
Propora sp.
Favosites sp.
Reuschia ? sp.
Stromatoporoids
Horn corals, unidentified
Age: Probably Late Ordovician

C. Rattlesnake Spur, Gardison Ridge, near north end of NW¼ sec. 1, T. 9 S., R. 3 W., Boulter Peak quadrangle.

Collection No. USGS 3073–SD. From Bluebell Dolomite, 29 feet above base. Same zone from which collection 3075–SD was made in Raymond-Illinois area and collections 3069–SD and 3082–SD were made in Pinyon Peak area.
Reuschia? sp.
Age: Probably Late Ordovician

Collection No. USGS 3071–SD. From Bluebell dolomite, 40–50 feet above base.
Propora sp.
Favosites sp.
Streptelasma sp.
Stromatoporoids
Age: Probably Late Ordovician.

Collection No. USGS 3072–SD. From Bluebird dolomite, 130–140 feet above base.
small cephalopods, indeterminate.
Age: Probably Silurian.

Collection No. USGS 3067–SD. From Bluebell dolomite, 425 feet above base.
Favosites sp. (small corallites)
sp. (large corallites)
Halysites sp.
Polyorophe (?) sp.
Dissepimented coral, unidentified.
Age: Silurian

Collections of probable Devonian age from the Allens Ranch and Boulter Peak quadrangles have been discussed by Berdan as follows:

The fossils from the upper part of the Bluebell dolomite in the Allens Ranch and Boulter Peak quadrangles are dolomitized and occur as ghosts or outlines in the rock, or as blebs of pinkish dolomite. It is probable that most of the eyes in the eyebeds represent dolomitized fossils which can no longer be recognized as such. Unfortunately, the best-preserved specimens come from areas in which considerable faulting has occurred and these cannot be tied to a complete section. However, a few identifiable forms have been found. The dorsal valve of a *Cyrtospirifer* (*s.l.*), identified by G. A. Cooper, was found approximately 50 feet below the Victoria formation in a gully just west of the road to the Lehi Tintic shaft, NE¼SE¼, sec. 21, T. 9 S., R. 2 W., Allens Ranch quadrangle (USGS 3068–SD), associated with some very poorly preserved and unidentifiable gastropods. This is not the same species of *Cyrtospirifer* that occurs in the Pinyon Peak limestone. On the low spur just north of this gully (USGS 3079–SD) there are beds with dolomitized gastropods, cross sections of brachiopods, and a zone of crudely dolomitized branching favositid corals of the type usually referred to *Thamnopora*. The presence of *Cyrtospirifer* indicates Late Devonian age for the enclosing beds, and the branching favositids are similar to types occurring in lower Upper Devonian rocks of the Great Basin region. Some completely dolomitized gastropods from a locality about three-tenths of a mile north of USGS 3068–SD, S½NE¼NE¼ sec. 21, T. 9 S., R. 2 W., (USGS 3066–SD) were examined by J. Brookes Knight, who stated that they resemble Middle Devonian types but could possibly be Upper Devonian, and who tentatively identified them as *Orecopia*? sp. These specimens were collected from beds less than 20 feet below the Victoria formation, but the section may be faulted. In the Boulter Peak quadrangle, a collection (USGS 4436–SD) was made from the eyebeds zones in the upper part of the Bluebell dolomite in Black Rock Canyon, NW¼SE¼ sec. 17, T. 9 S., R. 3 W. This collection contains objects that are probably the remains of the dendroid stromatoporoid *Amphipora*, which is abundant in the Middle and lower Upper Devonian of the west. However, this material is so recrystallized that positive identifications cannot be made.

The above evidence, although meager, points consistently to a Middle or Early Date Devonian age for the upper part (eyebeds zone) of the Bluebell dolomite, with the probability being that most of the beds are lower Upper Devonian.

The assignment of the upper part of the Bluebell formation to the Devonian was also confirmed by the discovery of the fossil remains of an antiarch fish (USGS 4435–SD) in the middle part of the formation on the northeast and northwest slopes of Pinyon Peak. The original discovery of fish plates was made in a loose block of rock, but some time later the beds containing well-preserved fragments were found in place and followed for a considerable distance along the strike. The fragments were referred to D. H. Dunkle of the U.S. National Museum, who reports as follows:

Of the three fragments at hand, two are recognizable. These are a central dorsal plate from a right pectoral appendage and a left mixilateral element from a body carapace of the antiarch fish *Bothriolepis*. Moreover, all show the recticular ornamentation generally considered characteristic of *B. coloradensis* Eastman, a species known from the Temple Butte limestone of Arizona and the Elbert formation and Parting member of the Chaffee formation of Colorado.

Although a few late Middle Devonian occurrences of *Bothriolepis* are known, the genus is first commonly encountered in rocks of late Devonian age, in which it is found in an almost cosmopolitan distribution. In addition to the occurrences cited above, the genus is frequently found in North America in continental and near-shore facies of the Finger Lakes and Chemung stages of the Upper Devonian.

The dolomite beds containing the fish plates are medium grained to coarse grained, prominently streaked with sand, and locally contain intraformational conglomerate. The plates are considerably broken and scattered, suggesting that the fish were swept onto a tidal flat or into shallow marine waters from freshwater streams flowing from a highland area, probably as a result of a flood or storm. Beds of similar lithologic character were carefully examined in other outcrops of the Bluebell, but no similar fossilized fish fragments were found.

The lower part of the Bluebell dolomite—at least that part below the Colorado Chief marker bed and above the Black Panther marker beds—correlate well with the Laketown dolomite of Richardson in northeastern Utah and central Idaho (Richardson, 1941, p. 18), and with equivalent beds of the same name in the Gold Hill quadrangle (Nolan, 1935, p. 17–18).

Bothriolepis, *Amphipora*?, *Cyrtospirifer* sp., and *Orecopia*? all indicate a Devonian age for the upper part or eyebeds zone of the Bluebell and a probable equivalence to the lower part of the Jefferson dolomite of northeastern Utah, central Idaho, and southwestern Montana (Deiss, 1933, p. 41–44), and perhaps to the uppermost part of the Guilmette formation of Deep Creek Range (Nolan, 1935, p. 20–21). The eyebeds zone also appears to be equivalent to part of the Silverhorn dolomite of the Pioche area, Nevada (Westgate and Knopf, 1932, p 16–19).

The disconformity between the Upper Ordovician and Silurian rocks in the Bluebell is inconspicuous but probably represents all of Early Silurian time. The disconformity between the Silurian and Devonian probably marks a hiatus representing nearly all of Early and Middle Devonian time, since no beds equivalent to the Sevy and Simonson dolomites of the Gold Hill district (Nolan, 1935, p. 18–20), or units correlative with them, are recognized with any degree of certainty in the East Tintic Mountains.

STRUCTURAL HABIT

The Bluebell dolomite is well exposed in the East Tintic Mountains, both in areas of complex deformation and of simple structure. In all localities faults transect it without diminishing in throw and without passing into folds as is common in the shaly limestones that are present in the section not far above and below it. The major faults are almost everywhere accompanied by wide breccia zones, and the walls of nearly every fracture in the Bluebell are brecciated to some degree. The laminated and thin-bedded layers are favorable loci for bedding faults, and most of these low-angle faults show bedded fault breccias composed of 1- to 2-inch blocky fragments of laminated light-colored dolomite. Locally where faults and bedding dip in the same direction, faults that cut the bedding at an acute angle turn and follow the thin-bedded layers, especially where the faults and bedding dip steeply.

CHEMICAL AND PHYSICAL PROPERTIES

In aggregate composition the Bluebell is essentially a true dolomite with minor silica, clay, and iron oxides; it averages 1.2 percent insoluble residue and less than 1 percent combined Fe_2O_3 and Al_2O_3. The MgO-CaO ratio is very close to that of theoretical dolomite, and it is evident that nearly all the $CaCO_3$ present is combined with $MgCO_3$ as dolomite. The fine-grained beds that weather light gray are less pure than the dusky blue-gray beds; they leave a small residue of fine clay when digested in strong hot hydrochloric acid.

Chemical analyses of composite samples of the Bluebell dolomite collected on Eureka and Keystone Ridges in the Tintic district were made available to the writers by the Chief Consolidated Mining Co. and are presented in table 11.

The physical properties of the formation are not known, but are probably similar to those of other comparatively pure dolomites.

TABLE 11.—*Chemical analyses of Bluebell dolomite*

[Analyses courtesy Chief Consolidated Mining Co.; samples collected by G. W. Crane]

Bluebell dolomite	Acid insoluble	Al_2O_3 and Fe_2O_3	CaO	MgO	CO_2[1]	Total
Interval 120 ft. above base to top [2]:						
Lithographic beds	2.1	0.9	30.7	20.0	45.9	99.6
Dusky blue beds	1.0	1.0	26.7	23.9	47.1	99.7
Lower 120 ft.: [3]						
Lithographic beds	.7	1.0	29.1	21.7	46.5	99.0
Dark gray beds	1.0	.9	30.6	20.7	46.7	99.9

[1] Calculated.
[2] Collected as composite samples from Dora and Noah members of Crane (written communication, 1943).
[3] Collected as composite samples from upper part of Beecher member of Crane (written communication, 1943).

ECONOMIC IMPORTANCE

The Bluebell dolomite is an ore host rock of major importance in the main Tintic district, but it has produced only insignificant amounts of ore in the East Tintic district. It is the country rock of most of the ore in the Mammoth-Chief ore zone, the Iron Blossom No. 1 ore zone, and the Gemini-Ridge and Valley ore bodies. Billingsley and Crane (1933, p. 110–112) estimated the net value of ore produced from the Bluebell of Lindgren and Loughlin, which includes the Fish Haven dolomite of this report, at $41½ million, but they did not include that part of the ore localized in the Fish Haven and Bluebell dolomites in the Mammoth mine, which may approach several million dollars in value. In addition to this total value of approximately $45 million, ore valued at several millions of dollars (net) has been mined from the Bluebell and Fish Haven dolomites in the Chief No. 1 mine and other properties since 1933 when the above estimates were published, bringing the grand total to nearly $50 million (net from smelters). Cook (1957, p. 65) has estimated the gross value of ores produced from the Bluebell dolomite as defined in this report, at $110 million.

The fine-grained dolomites of the lower part of the Bluebell are comparatively pure and have commanded some interest as a possible source of high-grade dolomite for the iron and steel industry of Utah. During 1955 the Chief Consolidated and other mining companies were actively exploring and developing the lower half of this formation as a possible source of raw material for high-purity calcined dolomite.

DEVONIAN SYSTEM

VICTORIA FORMATION

The Victoria formation is here redefined to include all the Victoria quartzite as originally proposed (Lindgren and Loughlin, 1919, p. 38–39), together with the mottled, coarse-grained dolomites that constituted the lower 50–75 feet of the Gardner dolomite (op. cit. p. 39–40). The total thickness of the redefined Victoria formation is about 280 feet. The mottled dolomites placed in the top of the Victoria are lithologically identical with the dolomite units interbedded with quartzite in the lower 200 feet of the formation and are likewise locally streaked with sand.

DISTRIBUTION

The Victoria is moderately well exposed in the northern half of the East Tintic Mountains, and it is also exposed locally in the south central part of the range, one-half mile south of the Tintic Chief prospect. In the main Tintic district, outcrops of the Victoria extend northward from the Sioux-Ajax fault near the Mammoth mine across Eureka Ridge to Fitchville, where it is concealed by alluvium. North of Eureka Gulch in the main Tintic district it is exposed across the upper part of Keystone Ridge near the Ridge and Valley shaft, and part of it is exposed also along the east slope of Raymond-Illinois ridge from the Colorado Chief shaft to the Paxman fault near the Paxman shaft. North of the Paxman fault it is offset to the west and concealed by the Packard quartz latite.

In the North Tintic district the Victoria is prominently exposed on both sides of the North Tintic anticline and in the Selma Hills. On the steep eastern limb of the North Tintic anticline it may be followed from the edge of the Packard quartz latite in Fremont Canyon to the Tintic Prince fault at the head of Rattlesnake Canyon. Between the Tintic Prince and Gardison Ridge faults it is thinned and locally cut out along the Tintic-Humboldt thrust fault, but north of the Gardison Ridge fault it crops out prominently along the east side of Gardison Ridge to the mouth of Broad Canyon, where it is concealed by alluvium and cut off by the South Essex fault. On the west limb of the North Tintic anticline it is exposed between faults at the heads of Edwards and Scranton Canyons, and also in a band of faulted outcrops extending southward from near the South Essex mine to the head of Tintic Valley.

In the eastern part of the North Tintic district, outcroppings of the Victoria are found on Greeley Hill and the smaller hill to the south, on all sides of Wanlass Hill, and in a number of fault blocks and thrust fault slices in the Selma Hills. Exposures much better suited to a detailed study of the formation extend from the Selma fault near the Selma mine around the northern, eastern, and southeastern sides of Pinyon Peak to the Denver and Rio Grande Railroad tracks northwest of the Central Standard shaft.

The Victoria formation is poorly exposed in the East Tintic district, but it crops out in the E½SE¼ sec. 20, T. 10 S., R. 2 W., between the Zuma and Crown Point No. 3 shafts. In this area, however, it is intruded by monzonite and is bleached and hydrothermally altered.

The basal beds of the Victoria are also exposed in the extreme southeastern part of the East Tintic Mountains in the SE¼ sec. 22, T. 12 S., R. 2 W.

Underground, the Victoria has been extensively cut by workings in the Mammoth, Grand Central, Victoria, Plutus (Tetro), Chief No. 1, and other mines.

LITHOLOGIC CHARACTER

The Victoria formation is chiefly fine grained to medium grained gray dolomite, interlayered with medium-grained, light-brown, rusty-weathering quartzites and quartizite breccias (fig. 28). The topmost 50–75 feet of the formation is relatively free from sand and quartzite, but is otherwise indistinguishable from the dolomites of the lower part. The base of the Victoria is placed at the lower contact of the lowest prominent quartzite bed. This bed nearly everywhere is only a few feet below a bed of bluish-gray dolomite crowded with crystals and crystal aggregates of dolomite up to one-fourth inch in diameter that is known locally as the speckled dolomite marker bed (fig. 29). The top of the Victoria is placed where the shaly limestones of the Pinyon Peak limestone first appear above the massive dolomite beds. The contact is slightly channeled and is marked by a thin layer of calcareous shale. On Pinyon Peak the uppermost bed of the Victoria is a fine- to medium-grained dolomite that weathers to a sandy texture; it is overlain by the massive cavernous-weathering limestone that forms the basal unit of the Pinyon Peak limestone.

The quartzitic sandstones and dolomitic quartzites that are distinctive of the Victoria are from a few inches to as much as 20 feet thick, but are most commonly 2–5 feet thick. On the unweathered surface the quartzite is light brown or buff with a distinct pinkish tinge. Most of the quartzites are fine grained and thin bedded, with the individual laminae accentuated by narrow darker brown bands that probably contain a high proportion of oxidized detrital iron minerals.

The breccia beds are composed of jumbled tabular blocks of laminated dolomite and quartzite 10–12 inches on a side and 2–5 inches thick, imbedded in a matrix of fine-grained quartzite of buff dolomite sandstone. (See fig. 30.) The breccia lentils are commonly overlain by undisturbed beds of fine-grained laminated dolomite and interfinger along the strike with less conglomeratic quartzites and true quartzite beds. They are not useful as horizon markers, except locally, but are identifying features of the Victoria formation itself.

Dolomite is everywhere far more abundant than quartzite in the Victoria, but the ledgy limonite-stained quartzite outcrops and the resistant debris of quartzite and sandstone give the erroneous impression that the

FIGURE 28.—Quartzite and sandy dolomite in Victoria formation. Note channeled contacts at base of quartzite beds. Outcrop on east slope of Pinyon Peak, Eureka quadrangle.

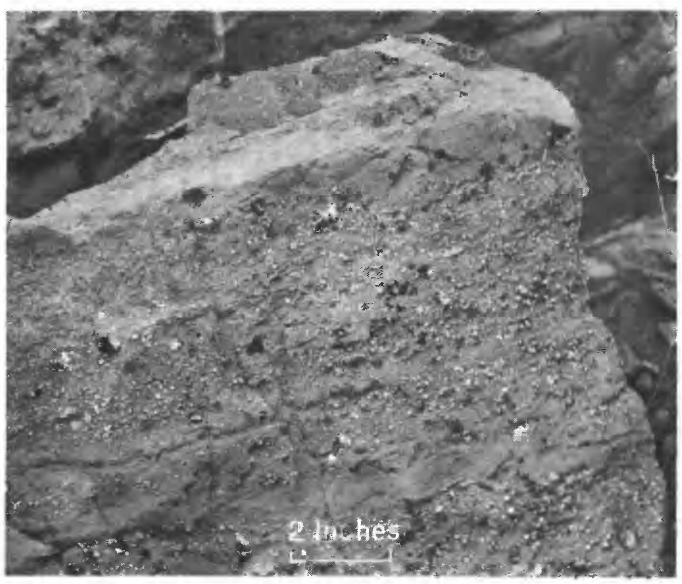


FIGURE 29.—Speckled dolomite marker bed near base of Victoria formation. Outcrop on east slope of Pinyon Peak, Eureka quadrangle.

reverse is true. In areas of poor exposure the formation can readily be mapped by the characteristic rusty-brown quartzite fragments in the colluvium.

Although the Victoria is comparatively uniform in thickness throughout the East Tintic Mountains, the number and thickness of the quartzite beds vary considerably from place to place. The overall lithologic characteristics are distinctive, however, and the following detailed stratigraphic section is typical.

Stratigraphic section of Victoria formation measured on the east slope of Pinyon Peak 3,500 feet N. 53° W. of Water Lily shaft, North Tintic district, in the E½SE¼ sec. 33, T. 9 S., R. 2 W. (loc. 12, pl. 3)

	Thickness (feet)	Distance above base (feet)
Pinyon Peak limestone (lowest bed only):		
Limestone, medium blue-gray, massive; cavernous		278
Disconformity (?).		
Victoria formation:		
34. Dolomite, medium-gray, fine-grained, sandy-weathering. One-inch calcereous shale band at top. Upper contact slightly channeled	2	276
33. Dolomite, light-gray, fine-grained; many small white dolomite nodules	1.5	274.5
32. Dolomite, light-gray, spangled with white dolomite rods; banded with slightly argillaceous layers 4 inches thick	10	264.5
31. Dolomite, light-gray, fine-grained	10.5	254
30. Dolomite, sandy, dark-gray	6	248
29. Dolomite, medium-gray, sandy at base; grades upward into thin-bedded light-gray dolomite that weathers with sugary texture. Scattered white dolomite nodules at top	6	242
28. Dolomite, medium-gray, thin- to medium-bedded	3	239
27. Covered zone	3	236
26. Dolomite, dark-gray, lighter near top	5	231
25. Dolomite, medium-gray, thin-bedded to varved, sand-streaked along bedding	5	226
24. Covered zone	4	222
23. Dolomite, dark-gray mottled with small white dolomite blebs, thin-bedded	8	214
22. Dolomite, sandy, light-gray, laminated	9	205
21. Dolomite, medium light-gray, streaked with brownish weathering sand; 1-ft quartzite conglomerate-breccia bed at top	4	201
20. Covered zone	4.5	196.5
19. Dolomitic sandstone, medium-gray with lavender tinge, thin-bedded	6.5	190
18. Covered zone	3	187
17. Dolomite, sandy, medium light-gray, fine-grained, medium-bedded	9	178
16. Sandstone, buff to grayish-orange, fine-grained	5	173
15. Covered zone. Probably dusky blue-gray dolomite	6.5	166.5
Victoria formation—Continued		
14. Dolomite, medium light gray to light brownish-gray with prominent white dolomite blebs, medium-bedded fine-grained	12.5	154
13. Dolomite, medium gray, streaked with light-gray argillaceous material. Top marked by a dolomite-sandstone sedimentary breccia 1 ft thick	7	147
12. Breccia, sedimentary, medium-gray angular dolomite fragments cemented by brownish-weathering buff sandstone. Dolomite fragments 2 to 10 in. in diameter	27.5	119.5
11. Dolomite, medium light gray, iron-stained, locally sandy and conglomeratic	22.5	97
10. Breccia, sedimentary; medium light-gray laminated angular dolomite fragments in brown-weathering sandstone matrix. Fragments highly jumbled	3.5	93.5
9. Sandstone, quartzitic, buff to pinkish-tan, fine-grained. Interfingers with sandy dolomite along strike	15.5	78
8. Dolomite, sandy, medium light-gray, laminated and thin-bedded. Brown sand streaks throughout	14	64
7. Sandstone, dolomitic, very light brown, medium-grained, quartzitic in part	7	57
6. Dolomite, medium light-gray, massive. Lenses of sandy dolomite and sedimentary breccia interlayered along strike	10	47
5. Dolomite, interlayered medium-gray, thin-bedded dolomite and sedimentary dolomite breccia, sand-streaked throughout. Some of the dolomite beds faintly mottled	30.8	16.2
4. Quartzite, very light brown, thin-layered; interbedded with medium- to light-gray sandy dolomite	4.2	12.0
3. Dolomite, medium light-gray, finely granular; characterized by many ⅛- to ¼-in. white dolomite blebs and small dolomite crystals that weather in relief; speckled dolomite marker bed	3.5	8.5
2. Covered zone	3.5	5
1. Dolomite, sandy, light brownish-gray, thin-layered. Bottom contact irregular and channeled. Sand lenses and sand streaks near base	5	
Total Victoria formation	278	
Contact conformable.		
Bluebell dolomite (upper beds only):		
Dolomite, blue-gray medium-grained rough weathering.		

The sandstones, quartzites, and sedimentary breccias of the Victoria, which appear abruptly within a thick section of carbonate rocks, suggest that there was probably a highland of considerable relief not far

FIGURE 30.—Penecontemporaneous sedimentary breccia in Victoria formation. Abundant sand in matrix. Outcrop on east slope of Pinyon Peak, Eureka quadrangle.

from the Tintic area during part of Devonian time, and that the sea bottom was alternately exposed and submerged at the time the Victoria was deposited. However, the absence of any angular discordance between beds within the Victoria, or with the overlying Pinyon Peak limestone, indicates that the oscillations of the sea floor were not accompanied by tilting or deformation but were broad rhythmic undulations. This highland area is believed to have been a short distance north of the East Tintic Mountains and is discussed in detail in the description of the Pinyon Peak limestone.

AGE AND CORRELATION

Although the Victoria formation has yielded no identifiable fossils, it must be of Late Devonian age, because the top of the Bluebell dolomite, which underlies it, and the lower part of the Pinyon Peak limestone, which overlies it, have both yielded Late Devonian fossils.

The distinctive lithologic character of the Victoria has its counterpart only in Upper Devonian beds in the surrounding region. The Beirdneau sandstone member of the Jefferson formation in the Logan quadrangle (Williams, J. S., 1948, p. 1139–1141) is characterized by many sedimentary sandstone breccias like those of the Victoria, and like the Victoria it is nearly devoid of fossils. The Hyrum dolomite member just below it, however, is similar to the dolomite beds in the Victoria and in the uppermost part of the Bluebell dolomite and locally carries a well-defined Upper Devonian fauna. The Beirdneau member of the Jefferson dolomite in the Logan quadrangle is also overlain by strata carrying upper Upper Devonian fossils, and these beds are very probably equivalent to the Pinyon Peak (Holland, 1952, p. 1718–1723).

The Victoria apparently should be correlated also with part of the Silverhorn dolomite of the Pioche area (Westgate and Knopf, 1932, p. 16–19), and probably with part of the Hayes Canyon member of the Devils Gate limestone (Nolan, Merriam, and Williams, 1956, p. 48–53) of the Eureka area, Nevada.

The Victoria is thinner than any of the formations with which it is correlated, probably because it was deposited on the shallow shelf adjacent to the Late Devonian positive area of central and eastern Utah, whereas the equivalent strata farther west were deposited in basins that attained greater depths in eastern Nevada and western Utah during Devonian time (Osmond, 1954).

STRUCTURAL HABIT

Because of its lithologic dissimilarity to the thick, relatively uniform carbonate sections above and below it, the quartzitic Victoria formation is a locus of low-angle faulting. On the lower southeast slope of Pinyon Peak it is repeated in imbricate slices of the Pinyon Peak thrust zone; the thrust planes are not wholly confined to the Victoria, however, but break at a low angle to the bedding and pass out of the quartzite into the formations above and below.

High-angle faults break cleanly through the formation, and the displacement on such faults is readily determined by the offset of the quartzite beds.

The Victoria generally weathers to steep slopes on which low quartzite cliffs alternate with benches representing the weaker dolomite and sandstone layers. The thicker beds of breccia form cliffs as much as 30 feet high on the east slope of Pinyon Peak.

In areas of low relief, the Victoria is recognized by the litter of rusty-tan quartzite fragments that cover the slope below the outcrop.

CHEMICAL PROPERTIES

Chemical analyses of composite samples of the two rock types that predominate in the Victoria formation show that the quartzite beds are calcitic rather than dolomitic, but that the dolomite layers are virtually free from calcite. The data are given in table 12. As the cement of the quartzitic sandstone beds is probably calcitic in some places and dolomitic in others, the analysis presented below may not be truly representative of the carbonate in the quartzitic layers.

The physical properties of the formation are not known.

TABLE 12.—*Chemical analyses of Victoria formation*

[Analyses courtesy Chief Consolidated Mining Co.; samples collected by G. W. Crane]

	Acid insoluble	Fe_2O_3 and Al_2O_3	CaO	MgO	CO_2 [1]	Total
Dolomite beds above quartzite zone [2]	1.5	1.3	32.2	18.8	45.9	99.7
Dolomite beds interlayered with quartzite beds	3.0	.9	29.1	21.1	45.9	100.0
Quartzite beds	77.5	6.5	8.7	.1	7.0	99.8

[1] Calculated.
[2] Mottled dolomite of Crane (written communication, 1943).

ECONOMIC IMPORTANCE

The Victoria formation is not an ore-producing unit in the North Tintic and East Tintic districts. In the main Tintic district, however, a significant production of silver and base-metal ores has been made from replacement bodies in the Victoria, chiefly in the Plutus (Tetro), Chief No. 1, and Victoria mines.

DEVONIAN AND MISSISSIPPIAN SYSTEMS

PINYON PEAK LIMESTONE

The Pinyon Peak limestone consists of fine-grained thin-bedded medium to light blue-gray argillaceous limestone commonly stained on weathered surfaces by accumulations of silt, clay, and iron oxides. In its northernmost exposures in the East Tintic Mountains, the base is marked by a bed of white quartzite 5–15 feet thick, but in the central part of the range this unit is absent or is represented only by a thin zone of sandy shale.

Although the Pinyon Peak limestone was recognized by Loughlin (Lindgren and Loughlin, 1919, p. 36) only on Pinyon Peak, it is now known to occur throughout the East Tintic Mountains. In limiting it only to its type locality, Loughlin concluded that elsewhere it had been stripped off during an erosion interval represented by an unconformity between the Victoria formation, which he supposed to be the basal Mississippian rocks in the area, and the Bluebell dolomite, which he regarded as being chiefly Early to Late Ordovician in age. His original field notes show that when he mapped the Pinyon Peak limestone on the northern and eastern slopes of Pinyon Peak he failed to recognize the sandstone and quartzite beds of the Victoria formation, which there are partly covered by debris from the overlying Fitchville and Gardison formations, and mistakenly identified the sandstone marker bed at the base of the Fitchville as much-thinned Victoria. He thus concluded that the Pinyon Peak limestone was present only in the area of Pinyon Peak and occurred below the Victoria formation, and that in the main Tintic district the Victoria, which is actually of Devonian age, represented the basal sandy sediments of the Mississippian series. He therefore unknowingly included the Pinyon Peak limestone throughout most of the East Tintic Mountains as part of his Gardner dolomite. Loughlin apparently collected no fossils from the Victoria formation or lower part of the Gardner dolomite in the main Tintic district and did not realize that the Upper Devonian fossils that he collected on Pinyon Peak all occurred above the Victoria.

During the present survey it was found that limestones resembling those assigned by Loughlin to the Pinyon Peak were nowhere present below the Victoria formation in the Tintic and East Tintic districts but did form the lower part of the Gardner dolomite, which is the next unit above the Victoria formation in Loughlin's stratigraphic section. A few specimens of brachiopods determined by Edwin Kirk to be of Late Devonian age were collected from float below the outcrop of these limestones on Pinyon Peak in 1949 by J. Steele Williams, W. R. Record, J. D. Smedley, and the writers. The fossiliferous beds were located in place by Jean Berdan, Helen Duncan, and Raymond Lewandowski when they re-examined the section with us in 1951. This work corroborates Loughlin's report of Devonian limestones but necessitates the following revisions to the stratigraphic section established by him: (a) the Pinyon Peak limestone must be assigned to a position 50–75 or more feet above the uppermost sandy or quartzitic beds of the Victoria; (b) since the overlying Pinyon Peak and the underlying Bluebell both contain Devonian fossils, the Victoria formation must be assigned to the Devonian; and (c) the remaining units in Loughlin's Gardner dolomite must be renamed in conformity with stratigraphic units now recognized and mapped in the adjacent areas.

DISTRIBUTION

In the Tintic district the Pinyon Peak limestone is exposed along a line of steeply dipping outcrops extending northward from the Sioux-Ajax fault near Mammoth Peak along Fitchville Ridge to the alluvium of Eureka Gulch. North of Eureka Gulch the formation is partly exposed in the immediate vicinity of the Ridge and Valley shaft and locally along the edge of the volcanic rocks of the Packard quartz latite from the area of the Colorado Chief shaft northward to the Paxman fault.

In the North Tintic district it crops out on both limbs of the North Tintic anticline and is especially well exposed in Black Rock Canyon in sec. 17, T. 9 S., R 3 W., at the head of the south branch of Edwards Canyon in sec. 4, T. 9 S., R. 3 W., on the northeast side of Gardison

Ridge in sec. 1, T. 9 S., R. 3 W., and in secs. 35 and 36 of T. 8 S., R. 3 W.

In the eastern part of the North Tintic district there are excellent exposures of the formation in the Selma Hills north of Nichol's adit in the NW¼ sec. 22, T. 9 S., R. 2 W., and along the west front of the Selma Hills near the west boundaries of secs. 10 and 15, T. 9 S., R. 2 W. Outcrops of the Pinyon Peak also nearly encircle Wanlass Hill, in sec. 35, T. 8 S., R. 2 W., and are present on the southwest side of Greeley Hill in the NE¼ sec. 23, T. 8 S., R. 2 W.

Near the peak for which it was named, the Pinyon Peak limestone crops out as a continuous line of exposures from the Selma fault at the northwest base of Pinyon Peak, across the northern spur, and along the east slope to the southeast base of the peak, where it is cut off by the Pinyon Peak thrust fault. In the footwall block of the thrust it is exposed only on the lower slopes of the small rounded spur 3,300 feet northwest of the Central Standard shaft; elsewhere in this general area it is concealed by lava and alluvium.

In the East Tintic district exposures of the Pinyon Peak limestone are limited to the N½SE¼ sec. 20, T. 10 S., R. 2 W., a short distance northeast of the Crown Point No. 3 shaft; these exposures are excellent for a detailed study of the formation.

A few beds representing the lower part of the Pinyon Peak are also exposed in the SE¼ sec. 22, T. 12 S., R. 2 W., in the extreme southeastern part of the East Tintic Mountains; but the rest of the formation is concealed in this area by lava and unconsolidated deposits.

THICKNESS AND STRATIGRAPHIC RELATIONS

The Pinyon Peak limestone is from 70 to nearly 300 feet in thickness. The upper and lower contacts of the formation are moderately well defined in the few localities where the unit is prominently exposed; in areas where the basal quartzite or shale bed is absent, the base is placed at the bottom of the first limestone above the interbedded dolomites and quartzites of the Victoria formation, and the top is placed arbitrarily at the bottom of a persistent 1-foot bed of limy sandstone or sand-streaked limestone that is here defined as the base of the Lower Mississippian Fitchville formation. Mississippian fossils locally occur a few feet below this bed, indicating that the Pinyon Peak limestone was deposited without interruption through Late Devonian into Early Mississippian time.

LITHOLOGIC CHARACTER

The limestones of the Pinyon Peak are chiefly fine grained, medium to light gray blue, commonly with a faint pink tinge, and thin to medium bedded; they resemble limestone beds in the Herkimer, Opex, and Opohonga formations, but seldom display as much argillaceous material as is common in these units and contain only a few flat-pebble conglomerate beds. The limestone that forms the lower 25–35 feet of the formation on Pinyon Peak and the area to the north is a mas-

FIGURE 31.—Characteristic cavernous outcrop of Pinyon Peak limestone. Exposure on east slope of Pinyon Peak. Uppermost ledge above slope is Fitchville formation.

FIGURE 32.—Argillaceous limestone in Pinyon Peak limestone. Outcrop near head of south fork of Edwards Canyon, Boulter Peak quadrangle.

sive bed of very fine texture in which large re-entrants and shallow caverns have formed (fig. 31). This bed is overlain by tan-weathering argillaceous and fossiliferous thin-bedded faintly mottled limestones that are locally separated by thin beds of calcareous and ferruginous shale or siltstone (fig. 32).

In the main Tintic and East Tintic districts the argillaceous thin-bedded limestones are subordinate to the dense, pinkish-weathering variety and are entirely absent in some places.

Except where the basal quartzite is prominently developed, as in the Boulter Peak quadrangle, the somewhat shaly base of the formation is commonly concealed by soil and surface debris. In these areas the base of the formation is placed at the bottom of the lowermost limestone bed, which is easily identified because it is the first limestone bed above the Opohonga limestone. This method of placing the contact is not wholly reliable, however, as locally the lower beds of the Pinyon Peak may be hydrothermal dolomite. At greater distances from ore, on the other hand, limestones occur in the top of the Victoria formation, and where that is so and the sandy or shaly zone at the base of the Pinyon Peak is absent, the placing of the contact is also somewhat arbitrary.

The top of the Pinyon Peak limestone is placed at the base of the thin sandstone or sand-streaked limestone that is the lowest unit in the Fitchville formation. This contact was selected chiefly for convenience in mapping, since the upper limestones of the Pinyon Peak are almost indistinguishable from the lower limestones of the Fitchville formation. This sandy zone or bed is widespread and easily recognized. The quartz grains that compose it range from silt-sized particles to small pebbles ¼–⅓ inch in diameter. All of them are well rounded and highly frosted and appear to have been shaped and pitted by wind action. The larger grains obviously could not have been carried through the air for substantial distances, unless by cyclonic wind storms, but may have been blown across dry calcareous mud flats at a time when the sea had receded from shoal areas. On Wanlass Hill and in the East Tintic exposures, 2 and locally 3 sand-streaked beds occur within a stratigraphic interval of 10 feet. In these areas the top of the formation is taken at the base of the lowest well-developed sandstone or sand-streaked zone. However, the occurrence of fragmental Mississippian brachiopods and corals several feet below this bed indicates that the marker bed does not represent a systemic boundary.

In the following section, measured on the east slope of Pinyon Peak, the sequence is nearly identical with that on Eureka Ridge, 4½ miles to the southwest, but does not contain the basal quartzite or sand-streaked zones that are present in the Boulter Peak quadrangle.

Stratigraphic section of Pinyon Peak limestone measured on ridge 1,000 feet east-northeast of crest of Pinyon Peak, North Tintic district, in the SE¼ sec. 33, and the W½W½ sec. 34, T. 9 S., R. 2 W. (loc. 13A, pl. 3)

	Thickness (feet)	Distance above base (feet)
Fitchville formation (lowest bed only):		
Quartzite, buff-weathering, 8 in. to 1 ft thick		70
Contact conformable.		
Pinyon Peak limestone:		
7. Limestone, light blue-gray, granular; interlayered with small irregular lenses of pink-weathering argillaceous limestone; thin-bedded	5.5	64.5
6. Limestone, light-blue mottled with pink, very fine grained. Upper part contains eye-shaped nodules of white dolomite crystals and irregular lenses of gray chert	9	55.5
5. Limestone, light-blue, wavy-bedded; flat-pebble conglomerate 1 ft thick at top. Fossiliferous at base. (Collections USGS 4316–SD and 4317–SD.)	3	52.5
4. Limestone, light-blue, fine-grained	9	43.5
3. Limestone, medium-gray; hackly fracture	5.5	38
2. Limestone, light-blue mottled with pink; beds faintly laminated	12	26
1. Limestone, medium blue-gray, very fine grained, massive; locally is sandy or shaly at base and may be conglomeratic in lower 2–5 ft. Cavernous in many places	26	0
Total of Pinyon Peak limestone	70	
Disconformity (?)		
Victoria formation (uppermost bed only):		
Dolomite, medium-gray, fine-grained, sandy-weathering.		

The fossiliferous beds in the section measured on Pinyon Peak have yielded diagnostic forms that are useful in identifying the formation in areas of limited exposure. The chert is probably secondary and cannot be used either as a horizon marker or as an identifying feature.

The Pinyon Peak limestone in the northwestern part of the East Tintic Mountains differs in several respects from the section exposed on Pinyon Peak, the chief differences being the occurrence of a thick basal sandstone, together with sandstone layers higher in the unit.

The following section was measured in the central part of the Boulter Peak quadrangle.

Stratigraphic section of Pinyon Peak limestone measured by A. E. Disbrow in Black Rock Canyon, North Tintic district, in the NW¼SE¼ sec. 17, T. 9 S., R. 3 W. (loc. 13B, pl. 3)

	Thickness (feet)	Distance above base (feet)
Fitchville formation (lowest bed only):		
Limestone, sand-streaked, 3 ft. thick; sand grains frosted		85
Contact conformable.		
Pinyon Peak limestone:		
5. Limestone, fine-grained, dark-gray; weathers medium-gray; irregularly streaked with faint bands of tan-weathering argillaceous material	22	63
4. Limestone, fine-grained, dark-gray; weathers medium-gray; weathered surface marked with many streaks and splotches of yellowish-pink argillaceous material. Crinoid columnals and other fossil fragments abundant (Collections USGS 4427–SD and 4429–SD)	32	31
3. Limestone, medium- to fine-grained, medium-gray; weathers tan with an accumulation of silt at surface. Weathered surface locally speckled with small clumps of limonite	13	18
2. Dolomite, medium-grained, tan-weathering; encloses scattered lenses of fine-grained quartzite about ½ by 3 in size	5	13
1. Quartzitic sandstone, poorly sorted (grains range in size from silt particles to ¼ in. in diameter, light grayish-tan; weathers tan to brown. Interlayered with dolomite towards top; platy. Basal marker of Pinyon Peak	13	
Total Pinyon Peak limestone	85	
Disconformity(?).		
Victoria formation (uppermost bed only):		
Limestone, dolomitized, medium-blue, fine-grained, dense; underlain by light-gray dolomite.		

AGE AND CORRELATION

Several collections of fossils have been made from the Pinyon Peak limestone and all confirm a Late Devonian age for all but the uppermost few feet of the formation. The fossils collected on Pinyon Peak were identified by A. J. Boucot and Helen Duncan.

Collections Nos. USGS 4316–SD and 4317–SD; from zone about 52 to 53 feet above the base of the Pinyon Peak formation on Pinyon Peak, Eureka quadrangle.

Anastomopora sp.
Bryozoans, branching and incrusting forms.
Paurorhyncha endlichi (Meek)
Paraphorphynchus sp.
Cyrtospirifer sp.
Schuchertella sp.
Dalmanellacean brachiopod
Pelecypods

The following comments about the Pinyon Peak fauna and its age were made by Duncan and Berdan (1957):

Except for the fossils of Carboniferous aspects in the uppermost beds, the fauna of the Pinyon Peak limestone is of late Late Devonian age, and has elements similar to those of the Percha, Ouray, and the upper part of the Three Forks fauna. Beds in the vicinity of Salt Lake City have a comparable fauna and lithology, and the name Pinyon Peak has therefore been extended into this area (see Granger, 1953, p. 2).

Three small collections of fossils were made from the basal part of the Pinyon Peak exposed in Black Rock Canyon in the NW¼SE¼ sec. 17, T. 9 S., R. 3 W., Boulter Peak quadrangle. They were submitted to Jean Berdan, who reported on them as follows:

Collection No. USGS 4427–SD, from 20 feet above the basal quartzite, contains *Cyrtospirifer* sp., and in addition USGS 4429–SD contains *Paurorhyncha* sp. cf. *P. endlichi* (Meek). These Upper Devonian fossils are also present in the type section on Pinyon Peak, but occur there higher in the section. USGS 4428–SD, 12 feet above the basal quartzite, contains only fragments of unidentifiable rhynchonellid brachiopods.

In addition to the correlations noted, the Pinyon Peak limestone may be equivalent to the West Range limestone of the Pioche district, Nevada (Westgate and Knopf, 1932, p. 16–19), part of the Pilot shale of the Eureka district, Nevada (Nolan, Merriam, and Williams, 1956, p. 49–53), and the Mowitza shale of the San Francisco district, Utah (Butler, 1913, p. 34–35).

Reconnaissance study of the rocks immediately above the pre-Mississippian unconformity in the Ophir mining district and in the Cottonwood-American Fork area disclosed dolomitic sandstone and argillaceous limestone, streaked with frosted sand grains, that closely resemble the sandstreaked upper part of the Pinyon Peak limestone. These dolomitic sandstones and argillaceous limestones underlie dolomite units that closely resemble some of the dolomites of the Fitchville formation, but they unfortunately contain only a few very poorly preserved fossils. In the Ophir district, however, less than 35 feet above the unconformity in Dry Canyon, two impressions of brachiopods were found in a fine-grained dolomitic sandstone, together with a small specimen of bryozoa that was not well enough preserved for accurate identification. Concerning the brachiopods, Berdan reports as follows:

The brachiopods collected in the Ophir district in the Oquirrh Mountains are too poorly preserved for accurate identification, but one specimen suggests *Paurorhyncha* of the type of *P. endlichi*, which would indicate a Late Devonian age. * * * A collection (USGS 4430–SD) was made in July 1954 by me and Rudy Kopf from a ledge of dolomitic sandstone about 3 feet thick, approximately 5 feet above the Lynch dolomite and 20 feet below the base of the Fitchville, which crops out on a spur on the north side of Ophir Canyon, about one-half mile west of Bowman Gulch and about 900 feet above the floor of the canyon. This collection contains impressions of *Cyrtospirifer* sp. and *Anastomopora* sp., and suggests that beds equivalent to the Pinyon Peak limestone are present in the Ophir district.

In view of the lithologic similarity of these units to the same beds of Pinyon Peak and of the occurrence in them at Ophir of a *Cyrtospirifer* sp., *Anastomopora*, and a possible *Paurorhyncha*, it seems virtually certain that Upper Devonian rocks equivalent to the Pinyon Peak limestone or part of it occur locally in the Oquirrh Mountains.

Rocks of Late Devonian age lithologically similar to the Pinyon Peak limestone are reported by Granger (1953, p. 2) from City Creek Canyon in the Wasatch Range, and by N. C. Williams (1953, p. 2740–2741) from the extreme eastern end of the Uinta Mountains. According to J. T. Dutro (written communication, 1958) most of the Sappington sandstone member of the Three Forks at the type locality in southwestern Montana is also of late Upper Devonian age and would correlate with the Pinyon Peak.

TOPOGRAPHIC EXPRESSION

The Pinyon Peak limestone is moderately resistant to erosion, and in areas of gentle dip the basal bed of massive limestone or dolomite is prominently marked by a low cliff. As noted above, this cliff is commonly marked by many shallow caverns or re-entrants. The thin-bedded limestones above the cliff-making bed are also well exposed on the higher peaks but are mostly covered in areas of low relief.

CHEMICAL PROPERTIES

The chemical composition of composite samples of the Pinyon Peak limestone in the main Tintic district is that of a nearly pure limestone. The rock taken for analysis (table 13), however, may not have included a proportionate amount of the ferruginous and argillaceous material that is locally abundant in some of the middle and upper beds.

TABLE 13.—*Chemical analysis of Pinyon Peak limestone*

[Data courtesy Chief Consolidated Mining Co. Samples collected by G. W. Crane]

	Percent
Acid insoluble	1. 0
Fe_2O_3 and Al_2O_3	2. 3
CaO	52. 4
MgO	1. 3
CO_2[1]	42. 6
Total	99. 6

[1] Calculated.

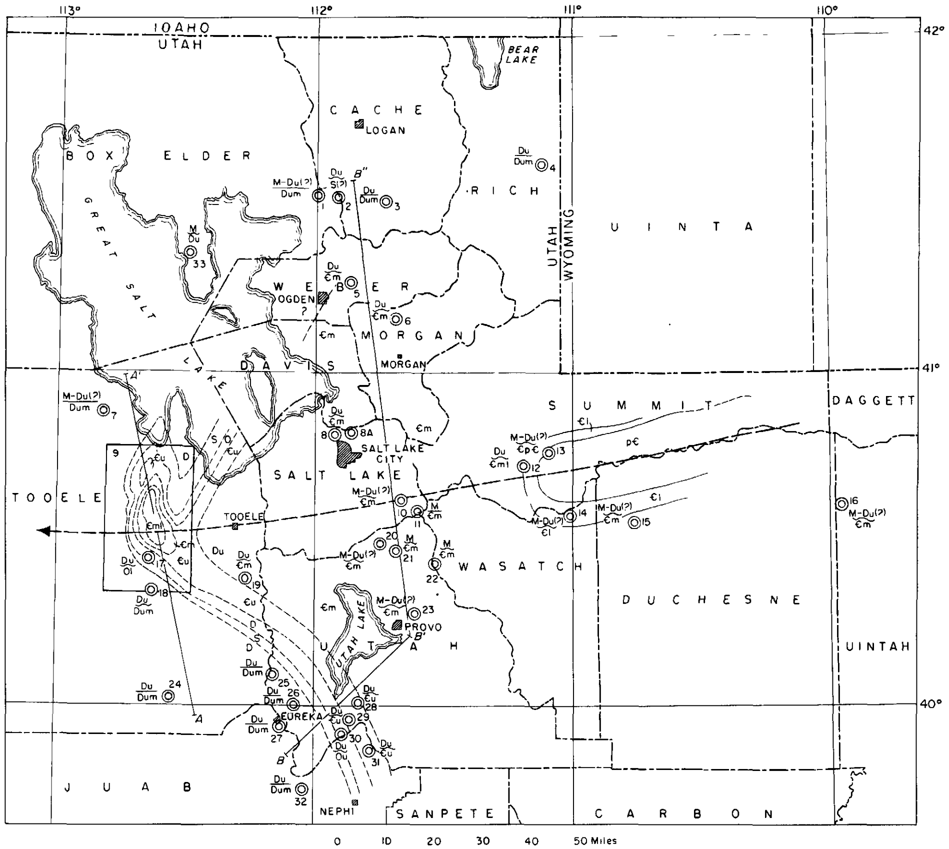
ECONOMIC IMPORTANCE

In the main Tintic district, the Pinyon Peak limestone localizes ore bodies in the Chief No. 1 and Gemini mines, and has produced an unknown but probably important amount of base-metal ore. In the East Tintic and North Tintic districts it is not an ore-producing formation, nor has it been utilized for the production of lime or limestone products.

REGIONAL UNCONFORMITY AT BASE OF PINYON PEAK LIMESTONE

Although no strong unconformity separates the Pinyon Peak limestone and Victoria formation in the East Tintic Mountains, the Pinyon Peak overlies an unconformity of considerable stratigraphic importance throughout a large area, embracing parts of the Wasatch Range and the Stansbury, Oquirrh, and Uinta Mountains, north and northeast of the East Tintic Mountains. The pattern of systemic boundaries on the generalized Late Devonian paleogeologic map (fig. 33) indicates that Cambrian, Ordovician, Silurian, and Devonian strata, with an aggregate thickness of 5,000 to 7,000 feet, were stripped from a complex but dominantly west-trending anticlinal uplift whose axis is nearly coincident with the axis of the present-day Uinta anticline. The total area that was affected by the uplift is not known, but the unconformity extends westward a short distance beyond the Stansbury Mountains, northward to the Willard thrust fault a few miles northeast of Ogden, and southward to a point near Nephi. To the east the uplifted area merges with a broad positive platform that persisted through Devonian time in northeastern Utah, northern Colorado, southern and eastern Wyoming, and parts of South Dakota, Nebraska, and Kansas (Eardley, 1951, pl. 4). The actual position of the northern edge of the main uplifted area beneath the Willard thrust fault is probably located approximately midway between Ogden and Logan, inasmuch as Upper Devonian rocks overlie upper Middle Cambrian rocks at the edge of the thrust sheet a few miles east of Ogden, and Cambrian to Mississippian rocks, in complete section, are present 40 miles east of Logan in the Crawford Mountains, which is the next nearest exposure to the north of the lower plate of the Willard-Bannock thrust fault. The rocks exposed in the upper plate of the Willard thrust fault between Ogden and Logan do not show the erosional effects of the Late Devonian uplift, but they do contain some clastic sediments that were probably derived from the uplifted area.

East of Tooele and Rush Valleys the uplifted zone has the shape of a relatively steep-sided, flat-crested anticlinal nose, which plunges west at a low angle. West of Tooele and Rush Valleys a sharp, north-trending anticline is superposed on the northwest flank of the west-trending fold. This north-trending anticline, which has been described by Rigby (1958, p. 83–88), has about 7,000 feet of structural relief; the limbs dip 11°–12° to the east and west, and the axis plunges 5°–6° to



EXPLANATION

Systemic boundary

Axis of Late Devonian uplifted area.

Overlying rocks – Du – *Unconformity*
Underlying rocks Єm
Locality
Reference number 6

Unconformable stratigraphic relations

Du / Dum 27

Conformable stratigraphic relations

Du
Abbreviations above line

M, *Mississippian rocks equivalent to lower part of Madison limestone or Fitchville formation*
M-Du(?), *Mississippian rocks equivalent to lower part of Madison limestone or Fitchville formation, with probable Upper Devonian rocks at base*
Du, *Mississippian and Upper Devonian rocks equivalent to Three Forks or Pinyon Peak limestone*

Dum
Abbreviations below line

Dum, *Upper and Middle and Devonian rocks equivalent to Jefferson and Victoria formations and Simonson and equivalent dolomites*
S, *Silurian rocks equivalent to Laketown and parts of Bluebell dolomites*
Ou, *Upper Ordovician equivalent to Fish Haven dolomite*
Ol, *Lower Ordovician rocks equivalent to Garden City formation, Pogonip group, and Opohonga limestone*
Єu, *Upper Cambrian rocks equivalent to Ajax, Opex, and Dunderberg formations*
Єm, *Middle Cambrian rocks including Ophir, Maxfield, Lynch, Cole Canyon, and other formations*
Єml, *Middle and Lower Cambrian formations equivalent to Ophir formation and Tintic quartzite*
Єl, *Lower(?) Cambrian Pine Valley quartzite*
ЄpЄ, *Cambrian and Precambrian rocks including Tintic and Pine Valley quartzites and Red Pine shale of Williams (1953)*

Locality References

1. Wellsville Mountain (Williams, 1948, p. 1141)
2. East side of Mantua Valley (Williams, 1948, p. 1138)
3. Southern part of Bear River Range (Williams, 1948, p. 1138-1141, and Holland, 1952, p. 1718-1719)
4. Crawford Mountains (Richardson, 1941, p. 19-20)
5. Ogden Canyon, Wasatch Range (Eardley, 1944, p. 830-831)
6. Durst Mountain (Eardley, 1944, p. 830-831)
7. Lakeside Mountains (Young, 1955, p. 27-28)
8-8a. Becks Spur and City Creek Canyon (Granger, 1953, p. 2)
9. Stansbury Mountains (Rigby, 1958, p 83-88)
10. Montreal Hill, central Wasatch Range (Calkins and Butler, 1943, p. 20-22)
11. Sunset Peak area, central Wasatch Range (Calkins and Butler, 1943, p. 20-22)
12. South Fork basin, western Uinta Mountains (Williams, 1953, p 2740-2741)
13. Smith and Morehouse Creek, western Uinta Mountains (Robert L. Root, oral communication, 1954)
14. Upper Provo River drainage, southwestern Uinta Mountains (Huddle and McCann, 1947, and Baker, Huddle, and Kinney, 1949, p. 1168-1171)
15. Upper Duchesne River drainage, southwestern Uinta Mountains (Huddle and McCann, 1947, and Baker, Huddle, and Kinney, 1949, p. 1168-1171)
16. Whiterocks River area, south-central Uinta Mountains (Kinney and Rominger, 1947, and Baker, Huddle, and Kinney, 1949, p. 1168-1171)
17. Dry Canyon, southwest Stansbury Mountains (original reconnaissance by writers)
18. Rock Springs, southern part of Stansbury Mountains (original reconnaissance by writers)
19. Ophir mining district, central Oquirrh Mountains (Gilluly, 1932, p. 20-22, and supplementary work by the writers)
20. Box Elder Canyon, central Wasatch Range (M. D. Crittenden, Jr., oral communication, 1955)
21. American Fork River area, central Wasatch Range (M. D. Crittenden, Jr., oral communication, 1955)
22. Provo River area near Vivian Park (M. D. Crittenden, Jr., oral communication, 1955)
23. Rock Canyon, central Wasatch Range (Baker, 1947)
24. Area between Lookout Mountain and Lookout Pass, Sheeprock Mountains (original reconnaissance by the writers)
25. North end of Gardison Ridge, East Tintic Mountains (this report)
26. Pinyon Peak, East Tintic Mountains (this report)
27. Fitchville Ridge, East Tintic Mountains (this report)
28. Keigley quarries, southern part of West Mountain (original reconnaissance by writers)
29. Warm Springs Mountain, northern part of Long Ridge (original reconnaissance by writers)
30. Current Creek canyon, Long Ridge (original reconnaissance by writers)
31. North Creek , southern Wasatch Range (original reconnaissance by writers)
32. Southern part of East Tintic Mountains (this report)
33. Promontory Range (Olson, 1956, p. 41-57)

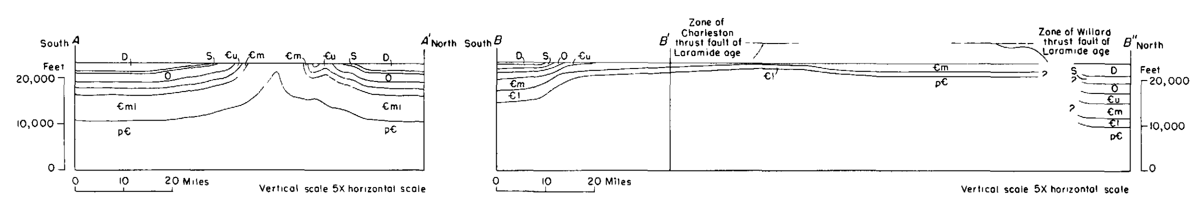


FIGURE 33.—Generalized paleogeologic map and sections of north-central Utah prior to the deposition of the Upper Devonian and Mississippian Pinyon Peak limestone.

the north and south from a point in the north-central part of the Stansbury Mountains. The angular discordance of beds above and below the plane of unconformity in the area of this north-trending fold is readily discernable in many places in the Stansbury Mountains, but such discordance cannot be recognized at the plane of unconformity above the main, west-trending uplifted zone, except locally in the Oquirrh Mountains, and near the Keigley quarry at the southern end of West Mountain 17 miles east of Eureka. In the vicinity of the quarry the Opex formation is reduced in thickness beneath the unconformity from 472 to 220 feet within an interval of 1 mile, and a few degrees of discordance can be observed in some outcrops. The angular discordance is not much greater but somewhat more apparent in the Oquirrh Mountains; at Dry Canyon in the central part of the range a conspicuous white-weathering bed 5 feet thick is cut out beneath the unconformity within a distance of about 150 feet along the strike.

The sedimentary rocks derived from the erosion of the uplifted area range from coarse conglomerates and quartzitic sandstones to interbedded dolomites and calcereous and quartzitic sandstones and sandstone breccias. The coarsest sedimentary rocks derived from the uplifted area are conglomerates exposed near Flux, in the northeastern part of the Stansbury Mountains. These conglomerates have been named the Stansbury formation by Stokes and Arnold (1958, p. 137–148) and are described by them as consisting chiefly of unsorted pebbles, cobbles, and boulders of dolomite enclosed in a dolomite or quartzite matrix. The clasts are subrounded to rounded, and range in size from less than a centimeter to 74 cm in cross section. They are preponderantly dolomite of the same types that characterize the lithologically distinctive Cambrian and Ordovician formations beneath the unconformity. This conglomerate lenses out to the north in the southern part of the Stansbury Mountains and to the north on Stansbury Island, where the Upper Devonian rocks consist almost wholly of white to medium-brown quartzitic sandstone. These sandstones are closely similar to the arenaceous beds of the Victoria formation and Jefferson dolomite and in part are probably continuous with them.

The first beds deposited continuously or nearly continuously across the uplifted area are silty limestones of the Pinyon Peak limestone. The nearly complete absence of conglomerate at the base of the Pinyon Peak, throughout most of the central part of the uplifted area, and the pseudoconformable contacts of the Cambrian rocks with the Pinyon Peak or the Fitchville formation, where the Pinyon Peak limestone has not yet been separated from the Mississippian rocks, indicate that prior to inundation by the sea the crestal area was a nearly featureless plain swept almost clean of clastic debris. Medium to fine wind-frosted grains of sand are, however, thinly scattered through the Pinyon Peak limestone and lower part of the Fitchville formation. These sand grains are not unlike the frosted quartz grains found in the Jefferson and Victoria formations, in the Stansbury formation of Stokes and Arnold (1958, p. 137–148), and in a sandstone at the base of the Pinyon Peak limestone on Beck's Spur north of Salt Lake City, and they may have been derived from the same general source.

The Late Devonian age of the uplift and denudation of the positive area is firmly established by stratigraphic evidence and by fossils. The clastic sediments derived from the uplift are interbedded with fossiliferous carbonate rocks of the Jefferson dolomite of Late Devonian age and with dolomite beds of the equivalent Victoria formation. Several specimens of *Paurorhyncha endlichi* and impressions closely resembling *Cyrtospirifer*, both of Late Devonian age, were collected by Stokes and Arnold (1958, p. 146) from carbonate beds beneath the uppermost quartzite of the Stansbury formation at the type locality. These forms are also found in the Pinyon Peak limestone. In some parts of the uplifted area Mississippian rocks appear to overlie Cambrian beds directly. These areas were probably slightly higher in elevation than the surrounding area and stood as islands until they were eventually inundated by the rising seas.

The Devonian positive area is apparently localized within a tectonically active belt that was the site of both earlier and later crustal warping. It includes most of the area where the thick masses of upper Precambrian quartzites, argillites, and related rocks in the Uinta and Sheeprock Mountains and the central Wasatch Range were downwarped in Precambrian time, and it is superimposed by the broad Uinta anticline of Laramide age, which extends from northwestern Colorado westward to the Wasatch fault. The uplift of both the Devonian positive area and the much younger Uinta anticline may be related to the rise and readjustment of the larger area downwarped in Precambrian time (suggested by M. D. Crittenden, oral communication, 1957); the close correlation of the axes of the Devonian uplifted area and the Uinta anticline strongly suggests that the Uinta folding was a somewhat less extensive refolding of the earlier Devonian anticlinal uplift.

Of possibly more direct structural and economic interest is the apparent alinement along this Devonian structure of intrusive bodies in the Park City, Alta,

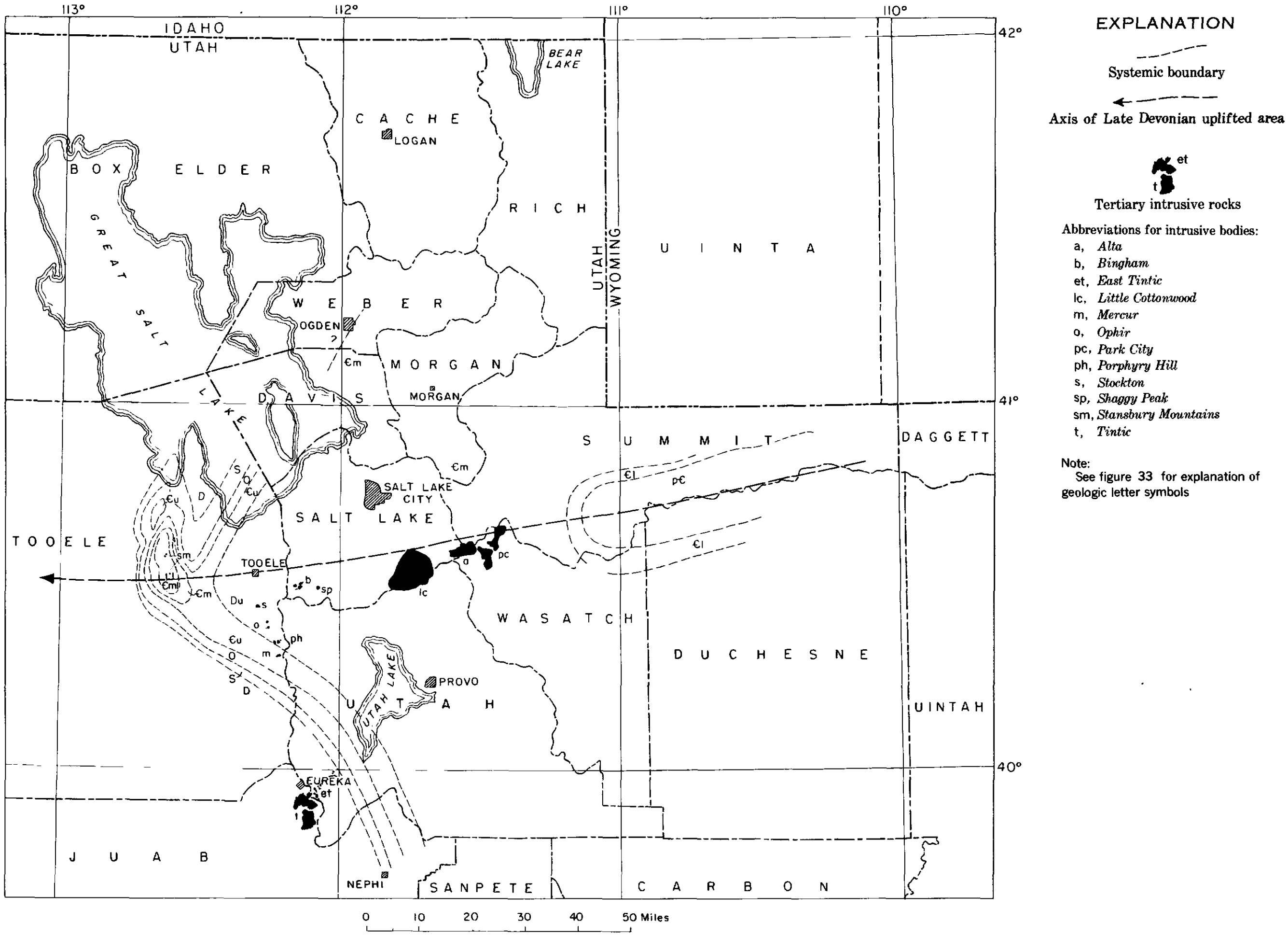


FIGURE 34.—Relation of Tertiary intrusive bodies to axis of Late Devonian uplifted area, north-central Utah.

and Cottonwood areas of the Wasatch Range, the intrusives in the West Mountain (Bingham) mining district, and in the Stansbury Mountains. All these bodies seem to be about on or near the axes of the Devonian uplift and the westward projection of the Uinta anticline (fig. 34). Butler (Butler and others, 1920, p. 100–105) was among the first to point out that the intrusive stocks between Park City and Bingham were alined along a hypothetical extension of the Uinta anticline. This idea was widely accepted and was discussed in considerable detail by Spurr (1923, p. 475–485), Beeson (1927, p. 772–792), and many others. Gilluly (1932, p. 73), however, after his detailed study of the Stockton and Fairfield quadrangles states:

> The supposed extension of the Uinta anticline to the west through Bingham and its superposition upon the folds of northward trend is definitely not a fact, and it remains questionable whether or not the nearly east-west cross axis through Ophir is a reflection of the north-south compression to which the Uinta fold most probably owes its origin.

Gilluly is probably correct in his statement, but unfortunately he did not explain the pronounced alinement of the intrusive masses. Structural localization on such a grand scale as the alinement of intrusive stocks through a distance of approximately 40 miles is admittedly based on tenuous evidence at best, but it is interesting to note that although the Uinta anticline may not extend beyond the Wasatch Range, the axis of the Park City–Bingham intrusive zone is almost coincident with the axis of the Devonian uplift to which the Uinta anticline appears to be related, and we believe that both the folding and the intrusive masses were localized within a tectonic zone that has been intermittently active through a long period of geologic time.

MISSISSIPPIAN SYSTEM

The Mississippian system of the East Tintic Mountains is divided into the Lower Mississippian and Upper Mississippian series. The Lower Mississippian rocks consist of the Fitchville formation and the Gardison limestones, and include all the Lower Mississippian rocks between the Upper Devonian Pinyon Peak limestone and the Upper Mississippian Deseret limestone. The Upper Mississippian rocks include the Deseret, Humbug, and Great Blue formations and part of the Manning Canyon shale.

LOWER MISSISSIPPIAN SERIES

The two formations that constitute the Lower Mississippian series are composed dominantly of marine carbonate rocks, but each is well defined. The Fitchville formation contains both dolomite and limestone and is but sparingly fossiliferous; the Gardison limestone, which overlies it, is principally limestone, much of it cherty, with a few thin beds of carbonaceous shale, and contains abundant fossils.

The contact between the Gardison limestone and the Deseret limestone is conformable and is marked by a bed of phosphatic carbonaceous shale that ranges from 10 to about 150 feet in thickness. This shale is regarded as the basal unit of the Deseret limestone and corresponds to a similar unit in this stratigraphic position throughout central and northern Utah and southeastern Idaho.

The total thickness of the Lower Mississippian rocks ranges from 850 to 1,000 feet.

FITCHVILLE FORMATION

The Mississippian rocks that constituted the greater part of the lower member of the Gardner formation of Loughlin (Lindgren and Loughlin, 1919, p. 39–40) are here treated as a separate formational unit and named the Fitchville formation. This formation, which is about 300 feet thick, is named from excellent exposures on Fitchville Ridge, a short spur that separates Gardner and Eagle Canyons on the north slope of Eureka Ridge. The base of the Fitchville is placed at the bottom of the 8- to 12-inch bed of sandstone, or zone of sandstreaked limestone that is known locally as the sand grain marker bed (see below), and the upper contact is placed at the top of an 18- to 24-inch wavy-laminated limestone bed locally known as the curly limestone.

DISTRIBUTION AND THICKNESS

The Fitchville formation is prominently exposed in the main Tintic district from the Sioux-Ajax fault near Mammoth Peak across the west slopes of Sioux Peak and Godiva Mountain and along Fitchville Ridge to Eureka Gulch. North of Eureka Gulch it is covered by alluvium and Packard quartz latite as far north as Fremont Canyon. In the western part of the North Tintic district it is well exposed in steep beds on the east limb of the North Tintic anticline extending from Fremont Canyon to the Tintic Prince fault, but between that fault and the Gardison Ridge fault it is locally cut out or broken by reverse and normal faults. North of the Gardison Ridge fault, steeply to moderately dipping beds of the Fitchville, trending northwestward, cut diagonally across the north end of Gardison Ridge. The formation is prominently exposed on the west limb of the North Tintic anticline in large areas of gently to moderately dipping beds especially in the upper part of Edwards Canyon, Mill Canyon, and Miners Canyon.

In the eastern part of the North Tintic district, the Fitchville is moderately well exposed east of Greeley Pass and on Wanlass Hill. It also crops out along the west edge of the Selma Hills but is there much disturbed by thrust and normal faults. It is perhaps best exposed and least faulted on Pinyon Peak, of which it forms the upper part.

In the East Tintic district the Fitchville is fully exposed on the south side of Burriston Canyon, near the original Crown Point shaft, and is partly exposed on the lower slopes of Lime Peak (just north of Homansville Canyon), where a quarry has been opened in the sublithographic limestone bed that underlies the curly limestone.

The Fitchville also crops out in the south-central part of the East Tintic Mountains, between the Tintic Chief prospect and County Canyon, and in a second area about a mile or so north of Jericho Pass but it was not studied in detail in these areas.

In its type locality on Fitchville Ridge, it is 280 feet thick. It is probably somewhat thicker on Gardison Ridge, but there the lower part may be repeated along concealed strike faults; it is about 335 feet thick on Greeley Hill, about 6 miles farther east, in the northeastern part of the Allens Ranch quadrangle.

LITHOLOGIC CHARACTER

The Fitchville is composed of eight individually distinctive lithologic units, which are persistent throughout the East Tintic Mountains and thus are useful as horizon markers both at the surface and in mine workings. These units are not established as members in this report, although they are individually named and separately mapped by the mining geologists of the Tintic and East Tintic districts. Beginning at the bottom of the formation these units are: the sand grain marker bed, the blue flaky limestone, the white limestone, the blue shaly limestone, the black cherty dolomite, the sugary limestone, the pink lithographic limestone, and the curly limestone. (G. W. Crane, written communication, 1943).

The sand grain marker bed, also described on page 76, is a persistent bed of sandstone or zone of sand-

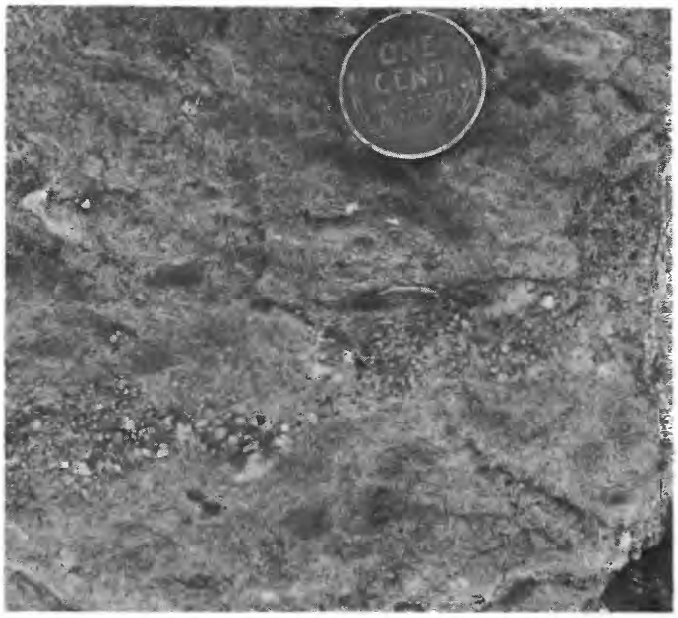


FIGURE 35.—Sandgrain marker bed at base of Fitchville formation. Outcrop near mouth of Broad Canyon, Boulter Peak quadrangle.

FIGURE 36.—Black cherty dolomite in Fitchville formation. Outcrop on Eureka Ridge, Eureka quadrangle.

streaked limestone, commonly less than a foot thick (fig. 35) that is here taken as the base of the formation.

The blue flaky and blue shaly limestones are very similar to each other in appearance and are difficult to distinguish in small exposures if the intervening white limestone is not exposed. The blue flaky unit is somewhat thicker bedded than the blue shaly and has fewer shaly partings between the limestone beds. The blue shaly unit perhaps most nearly resembles the Pinyon Peak limestone, inasmuch as mud cracks, flattened shaly flakes of possible organic origin, and markings that resemble worm trails are characteristic of both.

The white limestone, which lies between the blue flaky and blue shaly units, is a massive, moderately coarse grained, uniform-textured rock of high purity. It is medium to light gray in color at the surface, and grayish- to brownish-white where freshly broken underground.

The black cherty dolomite is one of the most readily distinguished units in the entire stratigraphic sequence. Except locally in the North Tintic district where it is a limestone, it is a dark gray to black, massive-bedded, coarse-grained, dolomite that contains scattered pods of black and brown chert an inch or so thick and several inches long (fig. 36). Quite commonly the chert nodules are completely leached from the enclosing dolomite, leaving cavities that have been partly or wholly filled with coarsely crystalline white dolomite and calcite. These filled cavities form conspicuous "eyes" that are a diagnostic feature of the unit. Syringoporoid coral fossils also occur throughout the unit and aid in its identification.

The sugary limestone is similar to the black cherty dolomite in being coarse grained and sparsely cherty, but it is medium to dark gray in color and well bedded, and includes some layers that appear to consist entirely of fossil fragments. Between 10 and 25 feet below the top of this unit is a widely persistent siliceous zone which in the main Tintic district is characterized by a 12-inch layer of dark gray-green chert (fig. 37). On Pinyon Peak the chert zone is marked by three or more layers of novaculitic quartzite, each a foot to several feet thick, that locally join and enclose pods of

FIGURE 37.—Chert and fine-grained sandstone in sugary limestone unit of Fitchville formation. Outcrop near summit of Pinyon Peak, Eureka quadrangle.

fine-grained arenaceous limestone. In some areas the fine-grained quartzite is dense and chertlike on the weathered surface but it proves to be finely granular on freshly broken fractures. The siliceous zone on Pinyon Peak ranges from 14 to 21 feet in thickness.

The fine-grained pink lithographic limestone is only 6–14 feet thick, but it is persistent throughout the East Tintic Mountains and has also been recognized in the adjacent Stansbury and Oquirrh Mountains and the Wasatch Range. Both the fresh and weathered limestone is exceptionally dense and fine grained and breaks with a conchoidal fracture. This unit has been quarried by the Chief Consolidated Mining Co. as a source of high-purity calcium carbonate used in the production of plaster lime and of metallurgical and chemical $CaCO_3$.

The curly limestone at the top of the formation is a stromatolitic limestone a few inches to approximately 3 feet thick (fig. 38). It has been described in some detail by Proctor and Clark (1956, pp. 313–321). It is characterized by alternating blue-gray and creamy-white laminae about 0.05 to 5 mm thick, averaging about 0.25 mm, that almost everywhere are wavy and in some places are highly contorted. When viewed in cross section the laminae form a regular pattern of domelike or biscuit-shaped structures, 1–10 cm or more high, separated by somewhat flat-bottomed troughs. Some of the laminae can be followed through a distance of 10 feet or more across several of the domes and troughs, but many laminae are cut off against the sides of the steeper, higher domes, and some occur only on the crests of the domes.

Crenulated beds of this type commonly have been attributed to subaqueous slumping shortly following deposition, but the absence of faults, overturned and ruptured minor folds, and breccias seems to rule out this origin. In contrast, the wide persistence, regularity, and uniform small thickness of the curly limestone, and its similarity to modern algal deposits, strongly suggest the activity of sediment-binding algae in shallow warm waters or tidal flats. Proctor and Clark (1956, p. 320) also support this conclusion and describe microscopic branching threads in some of the laminae that were interpreted by J. Harlan Johnson (op. cit., p. 320) as algal threads deposited by an unnamed form in the general family of Spongiostroma. Johnson also points out that the laminae probably represent seasonal deposition.

The following section was measured at the type locality on Fitchville Ridge and is typical of the Fitchville formation throughout the East Tintic Mountains.

Stratigraphic section of Fitchville formation measured on Fitchville Ridge 1,100 feet east-southeast of the Eagle and Bluebell shaft, main Tintic district, in the NE¼NW¼ sec. 19, T. 10 S., R. 2 W. (loc. 14, pl. 3)

[References are to nomenclature of G. W. Crane, written communication, 1943]

	Thickness (feet)	*Distance above base (feet)*
Gardison limestone (lowest bed only):		
Limestone, medium to dark blue-gray, medium- to fine-grained, well-bedded; fossils abundant		280.5
Contact conformable.		
Fitchville formation:		
10. Limestone, alternating light blue-gray and creamy-white laminae, which are locally wavy. Curly limestone of Crane	1.5	279
9. Limestone, light pinkish-gray to dark-gray on both fresh and weathered surfaces, sublithographic, dense, massive; breaks with a conchoidal fracture. Beds 2–3 ft thick. Pink lithographic limestone of Crane	6.8	272.2
8. Limestone, light-blue on fresh surface, pinkish-gray or very light purplish-gray on weathered surface; medium to very fine grained. Entire unit is poorly bedded but has some coarse-grained lenses that appear to be composed wholly of macerated fossils. Upper sugary limestone of Crane	10	262.2
7. Green chert marker bed: Pale bottle-green chert in a single bed about 2 ft thick on Eureka Ridge, but elsewhere this unit is more commonly 3–10 thin bands of white to buff, very fine-grained novaculitic quartzite interbedded with light-blue, very fine grained limestone. Bottle-green chert of Crane	2	260.2
6. Limestone, medium- to light-gray, medium- to fine-grained, locally granular; massive bedded; fossiliferous. Lower half of unit slightly magnesian, and in some areas contains scattered small nodules of light-gray chert. Lower sugary limestone of Crane	46	214.2
5. Dolomite, dusky blue-gray, weathers black, medium- to coarse-grained, massively bedded. Encloses scattered colonies of syringoporoid corals. Many nodular cherts parallel to bedding in central part, but in some areas these cherts are replaced by coarsely crystalline white calcite and dolomite. Black cherty dolomite of Crane	65.0	149.2

	Thickness (feet)	Distance above base (feet)
Fitchville formation—Continued		
4. Limestone, medium- to dark-gray on fresh surface; weathers light gray; fine grained. Beds 2–4 in. thick, separated by shaly limestone partings; fossils scarce to abundant. Base marked by a lenticular bed of fine-grained light-brown calcareous sandstone less than 1 ft. thick, which weathers yellowish gray. Blue shaly limestone of Crane	46. 0	103. 2
3. Limestone, medium- to light-gray; weathers light gray; fine grained, crystalline, massively bedded. Uppermost 6 ft. forms a single smooth-weathering ledge. White limestone of Crane	50. 5	52. 7
2. Limestone, medium- to dark-gray on fresh surface; weathers medium blue-gray, faintly mottled with lighter gray patches; lower half somewhat lighter in color than upper half of unit. Medium- to fine-grained, medium- to well-bedded in layers about 1 ft. thick separated by shaly partings less than 1 in. thick. Contains scattered chert nodules, and abundant fragments of brachiopods, crinoids, and other fossils; organic debris weathers in relief as slightly curved flakes. Upper blue flaky limestone of Crane	52	. 7
1. Quartzite, calcareous, or sand-streaked limestone; medium- to dark-gray; weathers medium to light brownish-gray or rusty-brown. Sand grains, which weather prominently in relief, range from less less than 0.1 mm to several centimeters in diameter. The larger grains are well rounded and all are frosted. Sand grain marker bed of Crane	7	
Total Fitchville formation	280. 5	

Contact conformable.

Pinyon Peak limestone (uppermost beds only):

Limestone, light blue-gray, argillaceous.

As the basal sandstone or sand-streaked bed separates nearly identical limestone units and is commonly concealed by detritus from overlying beds, the base of the Fitchville formation is generally much more difficult to recognize than the top. However, this sand grain marker is known to occur throughout the East Tintic Mountains, and in most areas of its outcrop it usually can be found after diligent search. In areas mantled by soil and talus its position can be determined in a general way either by measuring downward from the black cherty dolomite, which nearly everywhere crops out as a cliffy ledge 30–60 feet high, or by searching for the highly characteristic sand-streaked limestone float, which can be identified by the egg-shaped grains of frosted clear quartz. A search along the strike in these areas usually discloses outcrops of the marker bed, which are readily recognized by the rough-weathering brown crust of sand grains that stands in relief on the surface of the limestone.

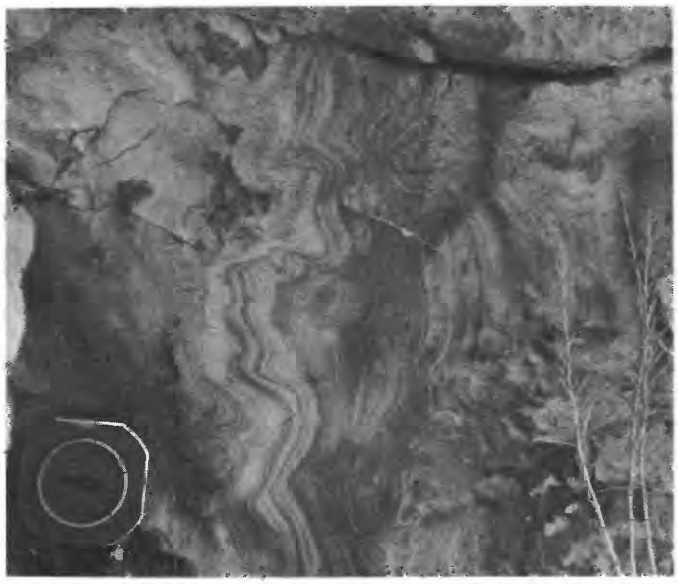


FIGURE 38.—Vertical outcrop of curly limestone marker bed at top of Fitchville formation. Top of bed to right of photograph. Outcrop on Rattlesnake Spur, NE¼ sec. 1, T. 9 S., R. 3 W., Allens Ranch quadrangle.

AGE AND CORRELATION

Fossils collected from nearly every lithologic unit of the Fitchville formation date it as Early Mississippian. Beds containing clisiophyllid corals and Syringoporas of Mississippian aspect also occur a few feet below the basal sand-grain marker of the Fitchville, and grade imperceptibly into beds of Pinyon Peak limestone that contain brachiopods of Late Devonian age.

The corals from the Fitchville, collected in the Allens Ranch quadrangle, were identified by Helen Duncan and the brachiopods by Mackenzie Gordon, Jr. (written communications, July 18, 1951).

Collection No. USGS 12357. W½SE¼ sec. 15, T. 9 S., R. 2 W.

Zaphrentoid? coral fragments
Caninoid? corals
Clisiophyllid corals
Syringopora cf. *S. aculeata* Girty
cf. *S. surcularia* Girty

Collection No. USGS 12358. N½SW¼ sec. 35, T. 8 S., R. 2 W.
- *Dipterophyllum*? sp.
- Caninoid coral fragments
- *Syringothyris*? sp.

Collection No. USGS 12359. S½SE¼ sec. 3, T. 9 S., R. 2 W.
- *Dipterophyllum*? sp.
- *Syringopora* cf. *S. aculeata* Girty
- cf. *S. surcularia* Girty
- *Syringothyris* sp.

Collection No. USGS 12360. S½SE¼ sec. 3, T. 9 S., R. 2 W.
- *Dipterophyllum*? sp.
- *Caninia* sp. indet.
- Clisiophyllid corals, genus indet.
- *Syringopora* cf. *S. surcularia* Girty

Collection No. USGS 12391. Base of blue shaly unit (unit 4 of measured section) of Fitchville formation: E ½ sec. 1, T. 9 S., R. 3 W.
- Caninoid corals
- Clisiophyllid corals
- Crinoid columnals
- *Schuchertella*? sp. indet. (cardinal process only)
- *Avonia*? sp.
- Rhynchonelloid? brachiopod, indet.
- *Spirifer* sp.
- Brachiopods, indet.

Collection No. USGS 12392. Black dolomite and underlying gray dolomite of the blue shaly limestone (units 5 and 4 of measured section) of the Fitchville formation; S ½ SE ¼ sec. 3, T. 9 S., R. 2 W.
- *Dipterophyllum*? sp.
- *Caninia* sp. indet.
- Caninoid coral fragments
- Clisiophyllid coral
- *Syringopora aculeata* Girty
- *surcularia* Girty
- *Spirifer*, 2 spp.
- *Syringothyris* sp.
- Brachiopods, indet.

The following discussion of the Fitchville fauna, its age significance and regional distribution, was written by Helen Duncan (1958).

The fauna of the Fitchville formation consists largely of corals. Brachiopods occur sporadically, but other larger fossil invertebrates have not been found. In general, preservation is exceedingly poor. Specimens ordinarily are crudely silicified, and material exposed on weathered surfaces is corroded. As one might infer from the accompanying lists of fossils, the fauna is not particularly diversified.

Field observations indicate that the corals are essentially in position of growth. Syringoporas in small heads and extensive lenticular masses are a characteristic feature. At localities examined by the writer, the same types of small clisiophyllid and caninoid corals were found in the upper 10–12 feet of the Pinyon Peak and in the basal beds of the Fitchville. Related forms in higher beds attain large size and are conspicuous on bedding surfaces. Owing to the poor quality of preservation, it is not possible to identify accurately the clisiophyllid and caninoid corals; however, several genera seem to be represented, and a number of species probably could be differentiated if better material were available. Clisiophyllids and caninoids of the type that occur in the Fitchville have not been seen in collections from the Gardison, which is distinguished by horn corals characteristic of typical Madison faunas. The common zaphrentoid in the Fitchville is a small subcalceoloid form called *Dipterophyllum*? This coral is readily distinguished from the characteristic Gardison zaphrentoid, *Homalophyllites*, and seems to be a useful guide fossil for the Fitchville in this area. Other types of solitary corals are uncommon in collections so far made from the formation. There are a very few indeterminate amplexoid and zaphrentoid forms. A single specimen of a colonial form that suggests *Cleistopora* has been collected.

Two common Madison species of *Syringopora*, *S. aculeata* Girty and *S. surcularia* Girty are associated with the solitary corals. *Syringopora* with corallites larger than those of typical *S. surcularia* has been found at a few localities; it is regarded as a third species.

Most of the brachiopods were obtained by dissolving pieces of rock in acid. Much of the material is so poorly preserved and fragmentary that it cannot be identified with assurance. *Syringothyris*, which occurs in several collections, is common in Early Mississippian faunas of the West, but the genus ranges back into the Late Devonian. A few collections made after the original study contain brachiopods having more definite Mississippian affinities.

Collections from the Fitchville formation were first studied before the confusion about the stratigraphic sequence and age relationships of the Victoria, Pinyon Peak, and Gardner had been straightened out. The rocks now included in the Fitchville were considered to be either lower Gardner or possibly Pinyon Peak. None of Loughlin's collections from the district came from the unit now called Fitchville, and the original Pinyon Peak collections were apparently meager and not especially diagnostic. During early stages of the present investigation, it was considered possible that some of the beds included in the Fitchville might be of Devonian age.

The Fitchville fauna is not the one ordinarily found in Lower Mississippian strata of the Great Basin and Rocky Mountain regions. Corals are by far the most abundant element, and the solitary forms are quite unlike those commonly found in the earlier Mississippian faunas of this continent.

The principal evidence for a Carboniferous rather than a Devonian assignment was furnished by the clisiophyllid and caninoid corals, which are prevalent in the unit. The Fitchville specimens more closely resemble forms that occur in the Viséan of western Europe and the later Mississippian of North America than they resemble genera characteristic of the earliest Carboniferous faunas. In western Europe, representatives of these coral groups first appear in the Zone d'Etroeungt, generally regarded as a formation of "passage" between the Devonian and Carboniferous. The occurrence of clisiophyllids and caninoids is cited as one of the principal reasons for including this zone in the Carboniferous. Corals of this type are not known in older Devonian rocks, but published records indicate that corals are extremely scarce in the uppermost Devonian (Famennian) all over the world. At a few localities in New Mexico and Colorado, however, corals that belong to that stage occur with the Percha-Ouray brachiopod fauna. This material was studied by the writer and compared with the Fitchville coral assemblage. Insofar as the solitary forms are concerned, the genera that occur in the Percha seem to be significantly different from the groups in the Fitchville.

Subsequent work on the Syringoporas supported a Mississippian assignment. The Fitchville specimens clearly belong to the same species that occur in Lower Mississippian rocks throughout the West. These forms are easily distinguished on external characters from the two species (*S. perelegans* Billings and *S. hisingeri* Billings) Walcott identified in the Devonian of the Eureka district, Nevada. In connection with the studies of the Fitchville fauna, the writer examined all collections from the West in the U. S. Geological Survey stratigraphic series that were reported to contain Devonian *Syringopora*. In the Eureka district and Roberts Mountains, Nevada, the genus seems to be fairly common in Devonian fossil assemblages. Few specimens have been collected from the Middle and lower Upper Devonian of other areas, and both the published records and field observations indicate that *Syringopora* is a rare element in most western Devonian strata. The *perelegans* type of *Syringopora* is the form normally found in Devonian fossil assemblages. The Percha shale has yielded a very few examples of *Syringopora* that seems to be identical with the well known Madison species *S. aculeata* Girty.

The few brachiopods associated with the corals were not of much help for dating the formation, but genera and species diagnostic of Late Devonian faunas are not present in the Fitchville. Such brachiopods as do occur are consonant with an Early Mississippian age.

The finding of the late Late Devonian brachiopod fauna in place beneath the sand-grain marker taken as the base of the Fitchville eliminated previous uncertainties about the position of the Fitchville coral fauna relative to a reliable paleontologic datum.

Detailed search through several sections exposing the beds on both sides of the Pinyon Peak–Fitchville boundary did not reveal that the Late Devonian brachiopod assemblage is associated with corals of Carboniferous aspect comparable to the forms that occur in the Fitchville formation and in the uppermost beds of the Pinyon Peak limestone in the East Tintic Mountains. Although the two faunas are separated by only a few feet, there is certainly no change in lithology that can be interpreted as indicative of a break in deposition or a noticeable modification of sedimentary environment. Nevertheless, the faunal evidence points to the presence of the systemic boundary in the nodular argillaceous limestones that form the upper part of the Pinyon Peak.

Studies of the Fitchville formation in the East Tintic Mountains had an important bearing on reinterpretation of the rocks referred to the Jefferson(?) dolomite in the Ophir district and in the southern Wasatch Mountains. In these areas, a unit composed mainly of dolomite or magnesian limestone occurs between Cambrian limestones and the conspicuously fossiliferous limestones carrying a typical Madison fauna. The tentative assignment of these dolomitic beds to the Jefferson obviously was based on lithology, because the fauna reported from the Ophir district (Gilluly, 1932, p. 21) is definitely not an assemblage characteristic of the Jefferson. Corals, which are commonly the only fossils that can be found in these dolomites, had been generally neglected by paleontologists working on western Paleozoic faunas. Data on the sequence of coral faunas were very incomplete, and little reliance was placed on corals in stratigraphic work. Under the circumstances, it is not surprising that dolomites carrying an unfamiliar fauna were erroneouly interpreted.

Early in the investigation of the fauna from the Fitchville formation of the Tintic district, it was discovered that similar corals had been collected from the Jefferson(?) in American Fork Canyon in the Wasatch Range. This observation lead to reexamination of the material collected in 1926 from the Jefferson(?) of the Stockton-Fairfield quadrangles and reported on by Kirk. It was immediately clear that the Fitchville fauna was the same as the one in the Jefferson(?) in this part of Utah. During August 1951, this dolomite unit was examined at several places in north-central Utah. Additional collections were made from exposures in American Fork and Rock Canyons in the Wasatch Range and from the section at Ophir. A number of sections of the Fitchville in the Allens Ranch and Eureka quadrangles were also examined during visits to the Tintic district in 1951 and 1952. This work demonstrated that an atypical Early Mississippian facies existed in north-central Utah and furnished evidence for the statement quoted by Crittenden, Sharp, and Calkins (1952, p. 9) regarding the age of the rocks formerly called Jefferson(?) dolomite in the Wasatch Range. Berdan's discovery of fossils indicative of the Pinyon Peak fauna in the sandy beds immediately underlying the coral-bearing dolomite in Ophir Canyon provided additional evidence that the rocks in question were in no way related to the Jefferson of the northern Rocky Mountains.

The Early Mississippian dolomite facies apparently has a greater areal distribution than was formerly realized. In the western Uinta Mountains, N. C. Williams (1953, p. 2740–2741) recorded dolomitic beds between a shale carrying a late Late Devonian brachiopod fauna and rocks called Madison limestone. Farther east in the Uintas, along the Duchesne and Whiterocks Rivers, relatively thin dolomitic and sandy units were included in the base of the Madison (Baker, Huddle, and Kinney, 1949, p. 1171). These authors suggested that the beds might be equivalent to the so-called Jefferson(?) of the southern Wasatch Range. In view of the regional situation, it seems reasonable to believe that their interpretation is correct and that the basal beds are a marginal extension of the Early Mississippian dolomite facies.

There is also reason to believe that in central Colorado a good deal of the Dyer dolomite member of the Chaffee formation is of Early Mississippian age. The Chaffee was dated as Devonian on evidence from fossils that occur in the Parting member and in the lower part of the Dyer member at some places. In Glenwood Springs Canyon, the lower 50 to 75 feet of the Dyer is a nodular limestone containing the diagnostic Ouray fauna in great abundance. The overlying dolomite is sparingly fossiliferous; Syringoporas comparable to species that occur in the Lower Mississippian Fitchville were collected, but other types of organisms seem to be very scarce. Relatively few collections have been made from the Dyer in the vicinity of its type area. The supposed Devonian age of the unit as a whole is based on scant and equivocal evidence. The Syringoporas mentioned by Behre (1953, p. 34) as occurring in the member on west Dyer Mountain at Leadville (Collection No. USGS 2430–SD) are comparable to *S. aculeata* and *S. surcularia*. These species are ubiquitous in the Early Mississippian of the West, and no specimen that could be called *S. surcularia* has yet been found in the Upper Devonian of the region. Specimens of *Syringopora* collected at Gilman, Colo., (Collection No. USGS 2428–SD) belong to the same species. Additional field studies of the Dyer member are needed to clarify the position of the Devonian-Mississippian boundary in central Colorado. Evidence available at present suggests that most of the Dyer member is of Early Mississippian age.

The Early Mississippian age of the Fitchville limestone thus appears to be firmly established. Beds similar lithologically and containing identical fossils have been recognized by the writers in the Stansbury and Oquirrh Mountains and the Wasatch Range, but were assigned to the Jefferson(?) dolomite by Gilluly (1932,

p. 20–22), and by Calkins (Calkins and Butler, 1943, p. 20–22). However, geologists working in the central Wasatch Range in 1955 had, by this time, become well aware of the Mississippian age of these rocks (F. C. Calkins, M. D. Crittenden, and A. A. Baker, Jr., oral communications, 1955), and collaborated in the revisions of the stratigraphic section that are presented in this report.

On the basis of its stratigraphic position and the fossils that it contains, the Fitchville formation probably correlates also with the lower part of the Lodgepole limestone of southwestern Montana, with the Leatham formation of Holland (1952), and with the lower part of the Madison limestone of southern Idaho and northern Utah (Holland, 1952, p. 1697–1734).

STRUCTURAL HABIT AND TOPOGRAPHIC EXPRESSION

The Fitchville formation consists mainly of competent limestone and dolomite but includes several shaly and thin-bedded zones that have localized low-angle faults and complex minor folds. The white limestone, sugary limestone, and blue flaky limestone units are comparatively brittle, especially where they have been hydrothermally dolomitized, and are extensively brecciated along faults. The common occurrence of these beds as the host rocks of replacement ore bodies in the Chief No. 1 mine in the Tintic district is no doubt related to their susceptibility to brecciation. In contrast to these competent units, the blue shaly limestone unit in the middle of the Fitchville is commonly dragfolded and internally faulted in almost every area of complex structure, and underground near ore it generally occurs as a jumbled clayey mass displaying little or no bedding.

The lithologic differences between the individual units of the Fitchville are well reflected topographically. The white limestone and black cherty dolomite units weather in relief as large, steplike benches, or, where the formation is steeply inclined, as ridges and knobs separated by small gulches that form along the trace of the adjacent less resistant blue shaly and blue flaky units.

CHEMICAL COMPOSITION

The rocks that constitute the Fitchville include limestone, magnesian limestone, dolomite, and minor sandstone. The chemical composition of composite samples taken from the thicker units is shown in table 14, but some of the samples were undoubtedly taken from outcrops of hydrothermally altered rocks, and probably none of them included the chert nodules that are common in some beds.

TABLE 14.—*Chemical analyses of Fitchville formation*

[Data courtesy Chief Consolidated Mining Co.; samples collected by G. W. Crane]

Unit	Acid insoluble	Fe_2O_3 and Al_2O_3	CaO	MgO	CO_2 [1]	Total
Pink lithographic limestone	3.0	2.1	52.7	0.2	41.6	99.6
Sugary limestone (hydrothermal dolomite)	6.5	.7	31.4	17.5	43.8	99.9
Black cherty dolomite	1.3	1.2	32.4	18.9	46.0	99.8
Blue shaly limestone	2.7	.5	52.8	1.0	42.6	99.6
White limestone	2.0	2.3	53.3	.2	42.1	99.9
Blue flaky limestone	1.0	2.3	52.4	1.3	42.6	99.6

[1] Calculated.

The bulk composition of the pink lithographic limestone quarried for the production of hydrated lime by the Chief Consolidated Mining Co. during the years 1926 and 1927, according to Keiser (1928, p. 298–299), averaged 97.2 percent $CaCO_3$, 0.9 percent $MgCO_3$, 0.5 percent combined Fe_2O_3 and Al_2O_3, and 1.4 percent acid-insoluble. The hydrated product averaged 95.72 percent $Ca(OH)_2$, 1.93 percent $CaCO_3$, and 2.35 percent, in all, of other impurities.

ALTERATION

Near structural channelways utilized by hydrothermal solutions, the sugary limestone and black cherty dolomite marker beds of the Fitchville formation, and the sandstone-free dolomite in the upper 70 to 80 feet of the Victoria formation, are cut by close-spaced veinlets of coarse-grained white and pale-pink dolomite forming patchily striped alteration zones called by the miners zebra rock. The veinlets range from 0.1 inch to more than 1½ inches in width and some are 2 feet or more in length. Many branch and rejoin within a few inches. These veinlets alternate with similar-sized streaks or patches of dark-gray finer grained dolomite that appears to be somewhat less strongly recrystallized. Vugs lined with unit rhombohedrons of dolomite about ¼ inch long and well-terminated quartz crystals ¼–½ inch long are common in the wider veinlets or at the junctions of veinlets.

The localization of the patches of zebra rock chiefly along faults suggests that they are related to the cementation and partial replacement of fault breccias and sheared limestone by hydrothermal dolomite. The hydrothermal solutions apparently moved upward and outward from zones where carbonate minerals were being leached or replaced to cooler zones where redeposition was taking place. That these solutions were hydrothermal is evident chiefly from the extent of the recrystallization and from its three-dimensional pattern, especially in the banded zebra rock, which appears to have developed through the activity of solutions migrating along bedding planes and closely spaced shear fractures.

The zebra rock represents a second or third stage of dolomitization preceding deposition of the ore minerals and because of its close spatial association with ore it is used in conjunction with other evidence as a guide to concealed ore bodies. Not all zebra rock is known to occur in close proximity to ore, but in the Fitchville formation this type of alteration is most common near ore bodies.

Mineralogically the coarse-grained dolomite is nearly identical with the dolomite of the host rock, and much of it may have been formed by recrystallization, combined with the removal of the small amount of bituminous matter that gives the dolomite host rock its dark color. In areas of intense and closely spaced dolomite veining, however, some of the coarser grained dolomite is pale pink or pale brownish gray, suggesting the presence of isomorphous manganese and iron carbonate. Sooty-black manganese oxides and thin crusts of dark-brown hydrous iron oxides, which coat the surfaces of some of the vugs, were evidently derived from the oxidation of the manganian and ferroan dolomite crystals.

The zebra rock from the sugary limestone marker of the Fitchville formation exposed on Fitchville Ridge is virtually indistinguishable in hand specimen from zebra rock in the dolomitized Mississippian Leadville limestone in several of the mining districts of central Colorado (Behre, 1953, p. 36).

ECONOMIC IMPORTANCE

Besides being important as a source of limestone, the Fitchville in the Tintic district is a major host rock for base- and precious-metal replacement ore bodies. The white limestone unit is second only to the combined Fish Haven and Bluebell dolomites as a host for ores in the Chief No. 1 mine, and other units in the Fitchville have also contained much ore in the Plutus (Tetro) and Eagle and Bluebell mines.

GARDISON LIMESTONE

The Gardison limestone is here named from Gardison Ridge, the main central spur of the northern part of the East Tintic Mountains. It consists dominantly of well-bedded, highly fossiliferous limestone, and it is more or less correlative with the stratigraphic units formerly called Madison limestone in the Wasatch Range, Oquirrh Mountains and other ranges in central Utah. The Gardison includes most of the beds assigned to the upper part of the Gardner dolomite by Loughlin (Lindgren and Loughlin, 1919, p. 39–40), but it does not include the "black highly carbonaceous and pyritic shaly limestone," which is here placed at the base of the overlying Deseret limestone. These changes, together with assignment of the remainder of the Gardner to the Victoria, Pinyon Peak, and Fitchville formations, have resulted in abandonment of the name Gardner dolomite. Locally, where Loughlin apparently did not recognize the carbonaceous shale, he unknowingly placed the cherty limestones forming the upper 125 feet or more of the Gardison in the Pine Canyon limestone, which has been abandoned as a stratigraphic unit and replaced by the Deseret limestone in this report (see p. 93–99).

The base of the Gardison is placed at the first limestone or hydrothermal dolomite beds above the curly limestone market of the Fitchville formation, and the top is placed at the bottom of the carbonaceous, phosphatic shales that mark the base of the Deseret limestone.

DISTRIBUTION AND THICKNESS

The Gardison limestone is well exposed in the Tintic district, from the Sioux-Ajax fault just west of Mammoth Peak northward to Eureka Gulch. Near Eureka Gulch excellent outcrops are readily accessible on both sides of Gardner Canyon, but the section is partly repeated along a strike fault that is more or less concealed near the canyon bottom. North of Eureka Gulch, in the North Tintic district, the Gardison is exposed on both flanks of the North Tintic anticline from Fremont and Miners Canyons north to Twelvemile Pass. In this general area it is especially well exposed on Gardison Ridge in the west-central part of the Allens Ranch quadrangle, at the head of Edwards Canyon, and on the ridge between Edwards and Scranton Canyons northeast of the Scranton group of mines.

In the eastern part of the North Tintic district the Gardison crops out on Greeley and Blowhole Hills, and in many exposures in the western half of the Selma Hills, from the Greeley shaft southward to a point a short distance east of the Lehi Tintic mine. The lowermost beds also form the crest of Pinyon Peak and the top of its main southwestward-trending backbone ridge.

In the East Tintic district a nearly complete section of the Gardison crops out in the area immediately north of the Crown Point No. 3 shaft, and the lower part makes up the top of Lime Peak, a short distance north of Homansville Canyon.

The Gardison also crops out along the west edge of the south-central part of the East Tintic Mountains between the Tintic Chief prospect and County Canyon and a mile or less north of Jericho Pass.

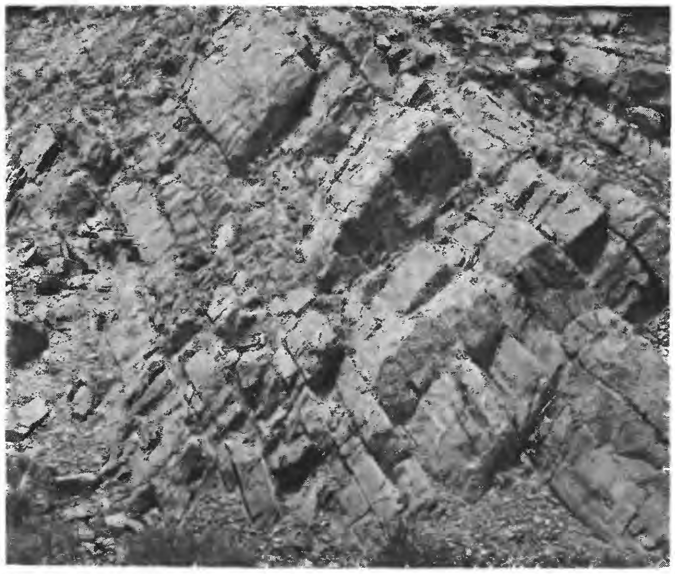


Figure 39.—Prominently bedded lower member of Gardison limestone. Exposure in Chief Consolidated lime quarry in Homansville Canyon, Eureka quadrangle.

The Gardison ranges in thickness from about 450 to 550 feet. On Gardison Ridge, the type locality, it is 495 feet thick, and this thickness is close to the average for the East Tintic Mountains.

LITHOLOGIC CHARACTER

The Gardison limestone is divided into a lower member of well-bedded nearly chert free limestone (fig. 39) and an upper member of more massively bedded cherty limestone (fig. 40). The lower member consists of thin- to medium-bedded dark to medium blue-gray fossiliferous limestone 375 feet thick. It is fine grained within 150–175 feet of the base, but in the upper part it is chiefly coarse grained, locally crossbedded, and clastic. Fossils are moderately abundant, and cross sections of the calcite-replaced shells of Euomphalid gastropods are especially common throughout this member. The upper member is mostly fine grained, but is coarse grained and clastic textured near the base. It is a massive to medium-bedded blue-gray limestone, about 125 feet thick, containing abundant nodules and layers of light-gray brown- and black-weathering chert that locally makes up as much as 30 percent of the rock. The chert lenses are as much as 6 to 10 feet long and average about 3 inches in thickness. Many of the beds are richly fossiliferous, being crowded with crinoid columnals, gastropods, brachiopods, and cup and tubular corals. In many exposures these fossils are partly or wholly silicified and weather in relief (fig. 41).

The following section was measured in the type locality and is typical of the Gardison throughout the East Tintic Mountains.

Stratigraphic section of Gardison limestone measured on Rattlesnake Spur near the north end of Gardison Ridge, North Tintic district, in the NE¼ sec. 1 T. 9 S., R. 3 W. (loc. 15, pl. 3)

	Thickness (feet)	Distance above base (feet)
Deseret limestone:		
Mostly concealed, but surface covered with chips of blue limestone, chert fragments, and chips of orange-weathering phosphatic shale		497. 8
Contact conformable.		
Gardison limestone:		
Upper member:		
9. Limestone, dusky blue-gray, fine-grained; weathers dark blue-gray. Encloses many 1- to 5-in. beds and bands of dark-blue, brown-weathering chert, spaced at intervals of 8–12 in. in massive limestone. Uppermost 5–15 ft of unit is a fine-grained, chert-free, medium to light blue-gray limestone	67	430. 8
8. Limestone, very dark gray, fine-grained; weathers dark blue gray. Upper 10 ft massive; no chert in this unit	30. 5	400. 3
7. Limestone, dusky blue-gray to nearly black, fine-grained; weathers dark blue gray. Abundant 1- to 2-in. beds of brown-weathering blue-gray chert interbedded at intervals of about 1 ft	23. 7	376. 6
Lower member:		
6. Limestone, dark-gray, coarse-grained, crystalline; weathers dark blue gray. No chert present in this unit	18. 8	357. 8
5. Limestone, medium-gray on fresh and weathered surface, coarse-grained; no chert	9. 5	348. 3
4. Limestone, very dark gray, coarse-grained; weathers medium dark gray. Parts of some beds contain a few small chert nodules. Prominently bedded; fossiliferous	132. 7	215. 6
3. Limestone, very dark gray, medium- to coarse-grained, massive; weathers medium gray. A thin (6- to 12-in.) limestone conglomerate marks base	40. 8	174. 8
2. Limestone, nearly black, fine-grained; occurs in well-defined beds 6 in. to about 3 ft. thick; weathers medium blue-gray; ledgy outcrops. A few scattered chert nodules are present locally; fossils replaced by calcite and silica abundant; silicified fossils weather in relief	149. 4	25. 4
1. Limestone, very dark gray, fine-grained; weathers medium to light blue gray. Highly fossiliferous; locally silicified fossils weather in relief. A few scattered small nodules of chert in some beds	25. 4	
Total Gardison limestone	497. 8	
Contact conformable.		
Fitchville formation (uppermost bed only):		
Limestone laminated medium- and light-gray; curly limestone marker.		

FIGURE 40.—Cherty limestone in upper part of Gardison limestone. Outcrop of nearly vertical beds, top to right of photograph. Exposure on Rattlesnake Spur, Allens Ranch quadrangle, NE¼ sec. 1, T. 9 S., R. 3 W.

The upper 100–150 feet of the Gardison limestone is a massive, cliff-forming unit that is readily identified by the abundant thin layers of chert of the upper member. The topmost 15–30 feet of beds that directly underlie the phosphatic and carbonaceous shale unit of the Deseret limestone are chert free, however, and somewhat lighter colored than the average limestone of the Gardison.

FIGURE 41.—Silicified horn corals and other fossils in Gardison limestone. Outcrop near Twelvemile Pass, Boulder Peak quadrangle.

AGE AND CORRELATION

The Gardison limestone is the lowest limestone in the section that contains large numbers of well-preserved fossils, a feature that helps identify the formation in small outcrops. Most of the fossils that are typical of the Gardison are included in the following collections:

Collection No. USGS 10409. Locality 150 yards west-southwest of Crown Point No. 3 shaft, SW¼SE¼ sec. 20, T. 10 S., R. 2 W. Fossils collected from a bed 175 feet above top of Fitchville formation. Corals identified by Helen Duncan; brachiopods and gastropods identified by J. Steele Williams (May 5, 1949).

- *Vesiculophyllum*? sp.
- *Cystelasma* sp.
- *Zaphrentites*? sp.
- *Homalophyllites* sp.
- Syringoporoid coral fragments
- *Spirifer centronatus* Winchell
- *Cleiothyridina* cf. *C. hirsuta* (Hall)
- *Punctospirifer solidirostris* (White)
- *Dielasma*? sp.
- Other brachiopod fragments
- Euomphalid gastropod fragments

Fossils in other typical collections from the Gardison were identified by Helen Duncan and Mackenzie Gordon, Jr. (written communications, July 18, 1951).

Collection No. USGS 12363. Lower member of Gardison limestone, NW¼ sec. 22, T. 9 S., R. 2 W.

- *Homalophyllites* sp. indet.
- *Zaphrentites* sp., possibly fragments of *Zaphrentites excavatus* (Girty)
- *Vesiculophyllum*? sp. (fragment)
- Auloporoid coral fragments
- Strophomenid brachiopod indet.
- *Chonetes loganensis* Hall and Whitfield
- *Productus* sp.
- *Punctospirifer* aff, *P. solidirostris* (White)
- *Straparollus* sp.
- *S.* sp. indet. (young)
- *Loxonema*? sp. indet.
- Gastropods indet.
- Ostracode, gen. and species indet. (smooth form)

Collection No. USGS 12365. Lower member of Gardison limestone, NW¼ sec. 26, T. 8 S., R. 2 W.

- Zaphrentoid coral
- Auloporoid coral fragment
- *Michelinia* sp. indet.
- *Chonetes loganensis* Hall and Whitfield
- *Straparollus* sp.

Collection No. USGS 12373. Lower member of Gardison limestone, E½ sec. 22, T. 9 S., R. 2 W.

- *Homalophyllites* sp. A
- Auloporoid coral fragment
- *Schuchertella* sp.
- *Chonetes loganensis* Hall and Whitfield
- *Productus* sp. indet.
- *Pustula* sp.

Punctospirifer aff. *P. solidirostris* (White)
Spirifer centronatus Winchell?
Composita? sp. indet.
Aviculopecten? sp. indet.
Straparollus sp.
Proetus cf. *P. loganensis* Hall and Whitfield

Collection No. USGS 12375. Lower member of Gardison limestone W½ sec. 10, T. 9 S., R. 2 W.
Schuchertella? sp.
Chonetes sp. indet. (a fragment)
Productus sp. indet.
Camarotoechia? 2 spp.
Punctospirifer aff. *P. solidorostris* (White)
Composita claytoni Hall and Whitfield
Brachiopod indet.
Straparollus (*Euomphalus*) *utahensis* Hall and Whitfield

Collection No. USGS 12388. Lower member of Gardison limestone approximately 275 feet above base, W½ sec. 10, T. 9 S., R. 3 W.
Cystelasma sp.
Homalophyllites sp. A
Auloporoid coral
Fenestella sp. indet.
Schuchertella? n. sp. (*Streptorhynchus inflatus* of Hall and Whitfield, 1877, not of White and Whitfield, 1862)
Schuchertella sp.
Chonetes loganensis Hall
Productus aff. *P. sedaliensis* Weller
Spirifer centronatus Winchell?
Spirifer sp.
Composita? sp.
Euomphalus ophirensia Hall and Whitfield
Straparolus sp.
Nautiloid indet.

Collection No. USGS 12389. Lower member of Gardison limestone 100 feet above base, E½ sec. 1, T. 9 S., R. 3 W.
Homalophyllites sp. A
Vesiculophyllum sp.
Cystelasma sp.
Aulopora sp.
Spirifer centronatus Winchell
Spirifer sp. A
Composita claytoni Hall and Whitfield

Collection No. USGS 12374. Upper member of Gardison limestone N½ sec. 15, T. 9 S., R. 2 W.
Lithostrotionella sp.

Collection No. USGS 12379. Upper member of Gardison limestone, sec. 12, T. 9 S., R. 3 W.
Zaphrentites? sp.
Cystelasma sp.
Rotiphyllum? sp.
Cyathaxonia sp.
Vesiculophyllum sp.
Syringopora cf. *S. surcularia* Girty
Pustula sp.
Spirifer sp.
Martinia? rostrata Girty

Collection No. USGS 12386. Upper member of Gardison limestone, N½ sec. 23, T. 9 S., R. 2 W.
Syringopora cf. *S. surcularia* Girty

Concerning the corals in these collections, Helen Duncan stated (July 18, 1951):

> The general aspect of the Gardison coral fauna is quite different from that of the Fitchville. Colonies of *Syringopora* seem to be rare or absent, but fragments of syringoporoid or auloporoid corals occur in almost every lot. *Vesiculophyllum*—a characteristic Early Mississippian genus—is more common in the Gardison than the collections listed here indicate. The most widely distributed horn coral is a small species of *Homalophyllites* that is probably undescribed. This genus is ubiquitous in the Lower Mississippian formations of the West and seems to be one of the best guides to rocks of Madison age that we have in the coral faunas. Some of the collections contain fragments of other zaphrentoids, but the material in general is too meager for identification. Two specimens in USGS 12363 are identified as *Zaphrentites;* these possibly are fragments of the common Madison species Girty originally described as *Menophyllum excavatum.* Girty identified this species in some collections from the so-called Madison of the Stockton-Fairfield area.

Concerning other elements in the fauna, Gordon stated in part (July 18, 1951):

> All of these collections are typical of the so-called Madison in the Stockton and Fairfield quadrangles. Particularly characteristic are the straparollid gastropods, which are very abundant in some beds.

The Gardison limestone is strictly equivalent to the unit called Madison limestone in the Stockton and Fairfield quadrangles (Gilluly, 1932, p. 22–25), where it is 462 feet thick. It is also generally equivalent to the Madison limestone in the Cottonwood–American Fork area (Calkins and Butler, 1943, p. 23–24, and Crittenden, Sharp, and Calkins, 1951, p. 9) and in the Provo area (Baker, 1947), but, according to Helen Duncan (written communication, Apr. 28, 1958), beds of Lower Mississippian age, which may be equivalent to beds in the upper member of the Gardison limestone in the East Tintic Mountains, are probably included in the lower part of the Deseret limestone in these two areas. The Gardison limestone is also correlated with the Joana limestone of eastern Nevada (Spencer, 1917, p. 24–26; and Nolan, Merriam, and Williams, 1956, p. 54–56) and with the part of the Madison limestone that is exposed in the Gold Hill quadrangle (Nolan, 1935, p. 24–27).

TOPOGRAPHIC AND STRUCTURAL CHARACTERISTICS

The conspicuously bedded units of the lower part of the Gardison limestone characteristically weather in ledgy, steplike outcrops partly buried by blocky talus. In contrast, the more massive uppermost beds are most commonly exposed as a rounded bluff or cliff 100 feet or more high, ribboned and corrugated by thin layers of chert that project from the surface. In areas of deep weathering, silicified horn corals and brachiopods, and chert nodules that have weathered free from the limestone matrix, are common in the soil and surface debris over the outcrop.

Although the more massive units and thick beds are structurally competent, they are only moderately brecciated adjacent to crosscutting faults, and the breccias developed in the well-bedded units do not generally extend far from the walls of the faults. Where both the bedded and massive limestones are hydrothermal dolomite, however, breccia zones are prominently developed.

CHEMICAL COMPOSITION

Analyses of the Gardison limestone show a noteworthy percentage of insoluble material, which is probably represented by dispersed chert, by sand grains in the rock, and by silicified fossils. As noted above, some beds contain as much as 30 percent of chert; obviously these units are not included in the analyses presented in table 15.

TABLE 15.—*Chemical analyses of Gardison limestone*

Data courtesy Chief Consolidated Mining Co.; samples collected by G. W. Crane. Lower member equivalent to blue fossiliferous limestone of Crane and upper member equivalent to gray fossiliferous limestone of Crane]

Unit	Acid insoluble	Al_2O_3 and Fe_2O_3	CaO	MgO	CO_2 [1]	Total
Lower member, Gardison limestone remote from ore	5.0	.8	49.6	2.1	41.2	98.7
Upper member, Gardison limestone hydrothermally dolomitized, close to ore	6.0	.8	27.6	20.7	44.3	99.4

[1] Calculated.

ECONOMIC IMPORTANCE

The Gardison limestone is a host rock for replacement ore bodies in the Chief No. 1, Plutus (Tetro), Iron Blossom No. 3, and other mines in the main Tintic district, and for small bodies of iron and manganese ore in the East Tintic district. In the North Tintic district the zinc and lead ore bodies of the Scranton group of mines are largely in the upper beds of the Gardison, below a bedding-plane fault zone that has been localized in the basal phosphatic shale member of the Deseret limestone.

UPPER MISSISSIPPIAN SERIES

The Upper Mississippian rocks in the East Tintic Mountains are from 4,000 to 5,000 feet thick, and are subdivided chiefly into 3 formations: the Deseret limestone, about 1,000 feet thick; the Humbug formation, 675 feet thick; and the Great Blue formation, about 2,500 feet thick. The Manning Canyon shale is in part Upper Mississippian and in part Lower Pennsylvanian, but the actual thickness of the beds of Late Mississippian age in this formation is not accurately known. All of these formations are individually distinctive and can be further subdivided into members that commonly are separately mapped to aid in showing complexities of geologic structure.

The base of the Upper Mississippian series is placed at the lower contact of the lowest member of the Deseret limestone. This unit is a carbonaceous, phosphatic, shaly limestone that contains a sparse fauna of Meramec age (Mackenzie Gordon, oral communication, Aug. 12, 1954). The top of Upper Mississippian series is not accurately known, but is arbitrarily placed near the base of the middle limestone of the Manning Canyon shale.

The considerable thickness of the Great Blue formation in the East Tintic, Oquirrh, and adjacent mountains suggests that it was the first unit deposited in the downwarping basin that later received the tremendously thick sediments which constitute the Oquirrh formation of Pennsylvanian and Permian age. In the north-central Wasatch Range and in the Uinta Mountains, where the rocks equivalent to the Oquirrh formation are relatively thin, the Great Blue formation is also thin or missing. The development of this basin across the area that was uplifted prior to the deposition of the Pinyon Peak limestone and Fitchville formation is additional evidence of crustal instability of the zone of the westward prolongation of the present Uinta-Cottonwood arch.

DESERET LIMESTONE

The Deseret limestone was named by Gilluly (1932, p. 25) from the Deseret mine in the Ophir district, 30 miles north-northwest of Eureka, Utah. The name has been adopted for more or less equivalent beds in the central Wasatch Range (Calkins and Butler, 1943, p. 24–26; and Baker, 1947) and is here used for the limestone unit originally named the Pine Canyon limestone by Loughlin (Lindgren and Loughlin, 1919, p. 40–41). The Deseret also includes the carbonaceous and phosphatic shale horizon placed in the top of the Gardner dolomite by the mining geologists of the Tintic district (Crane, written communication, 1943). As defined by Loughlin the Pine Canyon limestone extended from the base of the lowest cherty bed above the "black dense carbonaceous shaly limestone" (or phosphatic shale), here placed at the base of the Deseret limestone, to the base of the lowest sandy or shaly bed in the Humbug formation. Thus, with the exception of the phosphatic shale beds, the Pine Canyon included all the beds that are here included in the Deseret limestone. However, owing to the generally poor outcrop of the phosphatic shale, Loughlin in mapping the Tintic mining district apparently failed to recognize the base of the Pine Canyon as he defined it, and in many places included within its boundaries the phosphatic beds and the cherty upper member of the Gardison limestone. Because of the discrepancies between the Pine Canyon limestone as it was defined and as it was mapped, this formation name is abandoned, and is here replaced by the Deseret limestone, which has found a wider acceptance as a stratigraphic unit in central and northeastern Utah.

DISTRIBUTION

In the main Tintic district, the steeply dipping Deseret limestone on the west limb of the Tintic syncline underlies the greater part of Godiva Mountain between the Sioux-Ajax and Centennial faults. In this area the lower limestone beds immediately above the basal phosphatic shale form the crests of Mammoth, Sioux, and Godiva Peaks. The less steeply dipping beds on the east limb of the syncline crop out in the western part of the East Tintic district from near the Yankee shaft south to the edge of the lava cover a short distance east of the Iron Blossom No. 3 shaft. In Spy and Pine Canyons in the easternmost part of the main Tintic district, where erosion has stripped away the overlying Humbug formation, the Deseret limestone is continuously exposed across the axis of the Tintic syncline.

In the North Tintic district, the Deseret is well exposed in many areas on Boulter and Gardison Ridges, on Topliff Hill, and in and near the Selma Hills. On Boulter Ridge it is extensively exposed between Miners Canyon and Twelvemile Pass on the west-dipping limb of the North Tintic anticline. Exposures of the Deseret near the crest and on the east limb of the anticline, which form part of the south slopes of Topliff Hill, are readily accessible and especially suitable for a detailed study of the formation.

On Gardison Ridge the Deseret crops out in nearly vertical beds from a point about a mile north of Holdaway Canyon south to the edge of the lava in Fremont Canyon north of Packard Peak. In this area the formation is considerably faulted, but it may be studied to advantage in several of the fault blocks. Southeast of Gardison Ridge, the Deseret is widely exposed on the lower western and southern slopes of Bismark Peak. Between Davis Canyon and the Homansville Pass road the formation forms the core of a north-trending anticline, and it is similarly exposed in the faulted extension of the same anticline in sec. 20, T. 9 S., R. 2 W. Parts of the Deseret also crop out in the vicinity of the Paymaster No. 2 shaft, in the W½ sec. 21, T. 9 S., R. 2 W.

In the Selma Hills the Deseret is exposed in the lower plate of the Allens Ranch thrust fault in the E½ sec. 15, the E½E½ sec. 22, the SW¼ sec. 14, and the W½ sec. 23, all in T. 9 S., R. 2 W. North of these exposures it is also exposed in the NW¼ and the W½NE¼ sec. 10, also in T. 9 S., R. 2 W. A steeply overturned section of Deseret and some of the lowermost beds of the Humbug formation form the lower eastern slopes of Wanlass Hill; it also makes up the greater part of the hill northwest of Rattlesnake Pass near the center of sec. 34, T. 8 S., R. 2 W. On Blowhole Hill and Long Point Hill the lower part of the Deseret is preserved in the troughs of two parallel north-northwesterly trending synclines, and in the folded hanging wall of a north-northwesterly fault on the hill whose crest is about a mile east-southeast of the crest of Blowhole Hill. It is also widely exposed in the eastern part of Greeley Hill and the small areas of exposed bedrock that surround it.

In the south-central part of the East Tintic Mountains, the Deseret is exposed near the west edge of the range a short distance south of County Canyon, and in a separate area half a mile north of Jericho Pass but it was studied only in reconnaissance fashion in this part of the range.

THICKNESS

Near Sioux Peak on Godiva Mountain the Deseret is 1,110 feet thick. P. D. Proctor (written communication, 1952) reports a thickness of 900 feet on Gardison Ridge and a thickness of 718 feet in the Selma Hills in the lower plate of the Allens Ranch thrust fault. In the type locality near the Deseret mine in the Oquirrh Mountains, Gilluly (1932, p. 25–26) describes 650 feet of Deseret limestone between the Madison limestone and the Humbug formation on the north side of Ophir Canyon. In the Cottonwood–American Fork area in the central Wasatch Range, Calkins (Calkins and Butler, 1943, pl. 5) assigns 900 feet of cherty limestone, magnesian limestone, and dolomite to the Deseret on the basis of its resemblance to the Deseret limestone of the Ophir district and its stratigraphic position. In the south-central Wasatch Range, east of Provo, Utah, Baker (1947) reports the Deseret to be 621 feet thick. In this area, as well as in the Cottonwood–American Fork area, however, the lower part of the Deseret is reported by Crittenden, Sharp, and Calkins (1952, p. 10) to contain beds of Lower Mississippian age that may be equivalent to strata in the upper member of the Gardison limestone in the East Tintic Mountains.

LITHOLOGIC CHARACTER

The base of the Deseret limestone is marked in the Tintic district and in most other exposures in central and northern Utah by a black carbonaceous shale or shaly limestone that locally contains one or more layers of pelletal phosphorite. This unit, which is here named the phosphatic shale member, is rarely well exposed at the surface but is well known in underground workings of the Grand Central, Chief No. 1, Yankee, and Crown

Point No. 3 mines, and in diamond-drill holes in the main Tintic district. At the surface it is almost invariably concealed by soil and an accumulation of thin chips of gray and tan-weathering silty dolomite, angular and blocky fragments of coal-black chert an inch or less in diameter, and platy fragments of phosphatic shale which weather lavender gray to dull orange red but which are sooty black on the freshly broken surface. One of its best exposures is on the south side of Blowhole Hill in the northeastern part of the Allens Ranch quadrangle. On Topliff Hill, where the phosphatic shale member is less than 10 feet thick, its position is marked by a bright orange-red soil. Throughout the central part of the main Tintic district the phosphatic shale member is as much as 150 feet thick, but there it contains a large amount of interbedded silty limestone and dolomite and bedded black chert. The basal 16 feet or more of the member exposed in the Chief No. 1 and No. 2 mines is a pelletal, vanadiferous phosphorite with such a high percentage of sooty hydrocarbons that it readily smudges the fingers.

The limestones above the phosphatic shale member in the Tintic mining district are divided into two members, here named the Tetro member and the Uncle Joe member. Beyond the limits of the mining district proper, however, the lithologic characteristics of the Deseret change so markedly that these members are not easily distinguished.

The Tetro member, which overlies the phosphatic shale member, was named by Crane (written communication, 1943) from the Tetro mine at the north end of Godiva Mountain; it is approximately 475 feet thick. It is a uniform sequence of massive-bedded, medium to light blue-gray cherty limestones, which contain a high percentage of silt and fine sand grains that accumulate on the weathered surface of the rock (fig. 42). The chert, which may make up as much as 30 percent of the bulk composition of the Tetro member, is chiefly nodular, but some of it occurs in bedded masses 2–4 inches thick and several tens of feet long. The nodular cherts are generally lenticular, 1 or more inches thick and 3–5 inches long. Most of the nodular and bedded chert is dark-gray to black in color, but some of it is white. In contrast to the overlying Uncle Joe member, the Tetro is only sparsely fossiliferous, and most of the corals and bryozoa it contains are so poorly preserved that they cannot be identified with certainty. The Tetro closely resembles the cherty upper member of the Gardison, but may be distinguished from it by the paucity of well-preserved fossils and the appearance of a diverse bryozoan fauna in the Tetro.

FIGURE 42.—Thin-bedded cherty limestone in Tetro member of Deseret limestone. Outcrop in southern part of Topliff Hill, Boulter Peak quadrangle.

The Uncle Joe member, named from the Uncle Joe claim on the crest of Godiva Mountain, includes the so-called "Humbug" limestones of the mining geologists of the Tintic district; the name "Humbug" when used in this sense refers to the limestones that enclose the ore bodies of the Humbug mine and are not the limestone beds of the Humbug formation. The Uncle Joe is less uniform lithologically than the Tetro member, but is principally composed of coarse-grained, massive coquinoid[6] limestone containing much nodular chert. Where it was measured on the east slope of Sioux Peak it is 544 feet thick. The coquinoid limestone units are from 20 feet to more than 165 feet thick and are composed of fragmented brachiopod shells and crinoid plates and columnals arranged in crude laminae and cross beds (fig. 43).

The color of these beds is light pinkish gray to very pale grayish orange, and thin chips of the rock are surprisingly translucent. The chert nodules in the coquinoid beds are commonly large and smoothly ellipsoidal; some from the upper part of the Deseret on the northeast slope of Godiva Mountain near the Yankee mine are almost spherical and about 6 inches in diameter. Individual nodules 6–18 inches thick and from 1 to 4 feet long are not uncommon. Few if any of the chert nodules in the Uncle Joe member are banded as are many of the chert pods of the Tetro member (fig. 44). Interlayered with the coquinoid limestones are fine- to medium-grained medium to dark blue-gray limestones and dolomite units that contain abundant chert; these beds are locally streaked with medium- and coarse-grained brown-weathering sand. Within 100–150 feet of the top, the Uncle Joe member contains a thick unit of thin-

[6] Composed almost entirely of fossiled broken shells, crinoid columnals, and corals.

bedded, platy weathering dolomite or limestone that is a useful marker in locating the upper boundary of the formation.

The following section is believed to be typical for the area of the Tintic and East Tintic districts but is similar only in its general features to the Deseret in the northern part of the East Tintic Mountains.

Stratigraphic section of Deseret limestone measured across Sioux Peak, main Tintic district, in the SE¼SE¼ sec. 19 and SW¼SW¼ sec. 20, T. 10 S., R. 2 W. (loc. 16, pl. 3)

	Thickness (feet)	*Distance above base (feet)*
Humbug formation:		
Alternating limestone and quartzitic sandstone in units 2–12 ft. thick. Lower contact placed at base of lowest sandstone or orthoquartzite		1,110
Contact conformable.		
Deseret limestone:		
Uncle Joe member:		
11. Limestone, coquinoid, medium light-gray, coarse grained, sparsely cherty	35	1,075
10. Limestone, dark blue-gray, weathers medium blue gray; medium grained; moderately well bedded. Contains abundant nodules of black chert, which weather gray or brown, and rosettes of milky white quartz crystals 1 in. in diameter	82	993
9. Dolomite, medium- to dark-gray, fine grained, massive bedded with closely spaced parting planes. Weathers brownish or purplish gray with a surface accumulation of fine sand and silt particles, and in subdued outcrops with surface covered by large thin chips. Platy gray marker of local usage	38	955
8. Limestone, medium- to dark-blue on fresh-broken surface, weathers medium blue gray; medium grained; massive. Topmost 3–5 ft. contain large smooth-surfaced nodules of black chert 3–8 in. thick and 24–36 in. long which weather brown and black. Contains scattered well-preserved cup corals	15	940
7. Limestone, coquinoid, medium- to light-gray on weathered surface, translucent yellow-pinkish- or orange-gray on fresh fracture; coarse to medium grained; massive to medium bedded, some layers faintly cross-bedded. A few beds contain scattered 3- to 4-in. by 24- to 48-in. pods of black chert. Fossils abundant and well preserved. Forms prominent outcrop	165	775
6. Dolomite, dark-gray on fresh fracture, weathers tan and brown with silty and sandy surface; prominently sand streaked in upper half. Does not contain chert but contains what appear to be geodes, 1–2 in. in diameter, filled with milky-white quartz	33	742
Deseret limestone—Continued		
Uncle Joe member—Continued		
5. Limestone, coquinoid, light-gray, speckled with medium-gray fossil fragments; coarse grained, highly fossiliferous. Contains no chert	22	720
4. Limestone, light blue-gray, streaked and mottled with light-gray to white silty limestone; medium grained. Contains nodules of black- and brown-weathering chert that make up about 20 percent of the bulk composition of the rock; chert nodules 1–3 in. thick and 6–24 in. long. Where this unit has been converted to hydrothermal dolomite it is medium to light gray and the cherts are partly replaced by calcite	92	628
3. Limestone, coquinoid, gray on fresh surface, weathers tan to brown with an accumulation of sand and silt on surface; coarse grained; massive. Contains much brown-weathering gray and black chert. Fossils abundant. Forms saddle east of crest of Sioux Peak	62	566
Tetro member:		
2. Cherty limestone medium to light blue-gray streaked and mottled with light-gray; medium grained; weathered surface shows an accumulation of fine sand grains and silt. Cherts nodular and bedded 1–3 in. thick and a few inches to several feet long; amount of chert varies considerably along strike. Chert mostly black or dark gray but weathers brown. Entire unit massively bedded but upon weathering breaks up into platy chips ¼–½ in. thick and a few inches across. Topmost beds form crest of Sioux Peak	475	91
Phosphatic shale member:		
1. Mostly covered at surface; mantle rock is an accumulation of thin chips of gray- and tan-weathering silty dolomite, black chert, and vanadiferous phosphatic shale that weathers lavender gray to dull orange red. Forms west slope of Mammoth and Sioux Peaks	91	0
Total Deseret limestone	1,110	
Contact conformable.		
Gardison limestone (uppermost beds only):		
Limestone, chert-free, blue-gray, well-bedded; about 15 ft. thick; overlies massive blue-gray fossiliferous limestone that contains abundant bedded chert.		

In the Allens Ranch and Boulter Peak quadrangles, which include the greater part of the North Tintic mining district, the Deseret is less cherty and considerably more sandy than it is in the main Tintic district. In these areas also the phosphatic shale member is seldom

FIGURE 43.—Cliff formed by ledge of coquinoid limestone in Uncle Joe member of Deseret limestone. Outcrop in southern part of Topliff Hill, Boulter Peak quadrangle. Upper light-weathering cliffs are limestone beds in Humbug formation.

FIGURE 44.—Banded chert pod in Tetro member of Deseret limestone. Outcrop in southern part of Topliff Hill, Boulter Peak quadrangle.

more than 25 feet thick and locally is missing or entirely concealed by surface debris. On Gardison Ridge the phosphatic shale zone is about 20 feet thick and forms the basal beds of a unit of thin-bedded gray cherty dolomite and limestone about 125 feet thick. There the Tetro member comprises a series of medium- to dark-brown crossbedded calcareous sandstones and dusty blue-gray sand-streaked limestones containing scattered chert nodules. The Uncle Joe member is not sharply separated from the Tetro member on Gardison Ridge, but it contains much less sandstone and many more nodular and bedded cherts. However, the crossbedded sandy coquinoid limestones characteristic of the Uncle Joe member are prominently developed in the Bismark Peak area, as are the platy weathering dolomites and limestones near the top of the formation.

In the northwestern part of the range, specifically in the area between Scranton Canyon and Twelvemile Pass and on Topliff Hill, the middle part of the Deseret is characterized by sandstreaked limestone beds 5–25 feet thick interlayered with many limy sandstone beds 2–15 feet thick, and in these areas it might be confused with the Humbug formation. The coquinoid limestones and the platy weathering dolomite beds with rosettes of white quartz are present, however, throughout the East Tintic Mountains, and are useful in identifying and marking the top of the formation.

AGE AND CORRELATION

Several collections of fossils were made from the Deseret limestone in the Eureka and Allens Ranch quadrangles; the forms were identified chiefly by Helen Duncan and Mackenzie Gordon, Jr. The following statements by Duncan and Gordon concern the collections made from the Deseret limestone exposed in the Allens Ranch quadrangle:

Collection No. USGS 16651. Phosphatic shale member of Deseret limestone, Blowhole Hill, SW¼NE¼ sec. 26, T. 8 S., R. 2 W.

[Collected by P. D. Proctor, identified by Mackenzie Gordon, Jr. (Feb. 25, 1953)]

Keeled crinoid columnals
Leiorhynchus carboniferum polypleurum Girty

The stemlike bodies were shown to Edwin Kirk, who positively identified them as crinoid stems and said he had never before seen any with keeled columnals. The *Leiorhynchus* is one that ranges through a considerable section of Caney-like shale of Meramec and Chester age in Arkansas and Oklahoma. I have found the same species associated with "*Productus*" *hirsutiformis* Walcott in a collection (USGS loc. 12461) I made in the Allens Ranch quadrangle in the SE¼ sec. 22, T. 9S., R. 2 W., about 5 miles due south of Blowhole Hill, in platy shales 85–90 feet above the top of the upper cherty limestone member of the Gardison limestone. This is probably the same general lithologic unit from which the Blowhole Hill collection was taken.

Apparently the shaly beds that mark the lower part of the Deseret limestone in the Ophir district in the Oquirrh Mountains introduce a sparse Moorefield type of fauna. So far, this fauna has not been recognized in beds of Osage age or earlier in the midcontinent, and the overlying limestones in the Allens Ranch quadrangle carry a fauna that appears to have Meramec, rather than Chester, affinities.

Collection No. USGS 12366. Deseret limestone, W½ sec. 23, T. 9 S., R. 2 W.

Fenestella sp.

Collection No. USGS 12376. Deseret limestone, E½ sec. 10, T. 9 S., R. 3 W.

- Auloporoid coral
- *Michelinia* sp.
- Crinoid columnals
- Fistuliporoid bryozoan, incrusting type
- *Fenestella* sp.
- *Polypora* sp.
- *Penniretepora* sp.
- *Cystodictya* sp.
- Rhomboporoid bryozoans
- *Spirifer* sp. (group of *S. bifurcatus* Hall and *S. washingtonensis* Weller)

Collection No. USGS 12382. Upper part of Deseret limestone, SE¼ sec. 29, T. 9 S., R. 3 W

- Zaphrentoid corals, indet. (2 immature specimens)
- Crinoid columnals
- Stenoporoid bryozoans, ramose forms
- Fenestellid bryozoan fragments
- *Cystodictya* sp. fragment
- *Rhipidomella* aff. *R. dubia* (Hall)
- Spiriferoid brachiopod, indet.

Concerning the bryozoan and coral fauna in the above collections, Duncan writes (July 18, 1951):

Most of the collections from the Deseret limestone contain a fair representation of bryozoa. This group seems to be absent or extremely scarce in most collections from the Gardison, probably because of the clastic nature of the limestones. The Deseret bryozoans are fragmentary and not particularly adequate for study, but the genera recognized are common Mississippian forms. *Fenestella* and *Cystodictya* are the most abundant types. These genera have long ranges in the Paleozoic. Inasmuch as the species cannot be identified, the Deseret bryozoans are not of much value for establishing the precise age of the formation or its parts . . . We generally find that bryozoans are more abundant in the Upper Mississippian in the West, though this observation cannot be taken as a rule-of-thumb for distinguishing Lower from Upper Mississippian. The occurrence of bryozoans is controlled in part by ecological conditions. They are ordinarily found in brachiopod–horn coral–crinoid facies and are usually rare or at least less abundant in rocks formed in a sedimentary environment suitable for the clisiophyllid–caninoid–compound coral association, such as seems to be represented in the Fitchville.

Except in a few collections, corals are scarce or absent in the collections made from the Deseret limestone in this area. The tabulate corals in USGS 12376 are not particularly diagnostic. Comparable specimens occur in the Gardison and Madison but are not restricted to these and correlative formations.

The fossils collected in the Eureka quadrangle were taken from exposures of the Deseret limestone that crop out of Godiva Mountain. They were identified by Helen Duncan who reports as follows (Jan. 25, 1953):

Collection No. USGS 15925, Eureka quadrangle, Utah. Godiva Mountain, just south of the Tetro shaft, SW¼SE¼ sec. 18, T. 10 S., R. 2 W. Tetro member of Deseret limestone, 100–475 ft above base

Two lithologic types are represented—chert and limy sandstone.

Two specimens of the coral *Cyathaxonia* and a fragment of an indeterminate "zaphrentoid" were found in the chert, which also shows indications of Bryozoa. Most of the bryozoan material in the chert is in such small pieces and is so altered that it cannot be identified as to genus. There are a good many fragments derived from fenestrate zoaria, but the only genera I am able to recognize are *Fenestella* and *Cystodictya*.

Bryozoan fragments are abundant in the sandy phases. The zoarial forms are mainly fenestrate and pinnate, so that in spite of poor preservation, the following genera could be identified:

- Stenoporoid bryozoan, genus indet.
- *Fenestella*, several species
- *Polypora* sp.
- *Ichthyorachis* sp.
- *Penniretepora* sp.
- *Cystodictya* sp.

Neither the corals nor the bryozoa belong to genera that have narrowly restricted ranges, but the assemblage would not occur in pre-Carboniferous rocks. The small horn corals look like forms that ordinarily occur in the Lower Mississippian, but *Cyathaxonia* ranges from Mississippian to Permian and is fairly common throughout the Mississippian in the West. Other collections from the East Tintic Mountains indicate that bryozoans are very inconspicuous or absent in the Fitchville and Gardison but abundant in parts of the Deseret. This is to be expected because, ordinarily, fenestrate and pinnate zoaria are best developed in thin-bedded shales, siltstones, and limestones. When these forms occur in bioclastic limestones, the zoaria are commonly so broken up that the presence of bryozoan material can be demonstrated only in thin sections. The bryozoan facies seems to be well developed in the Deseret of this area and should be useful in distinguishing the formation from the Lower Mississippian Fitchville and Gardison formations.

Collection No. USGS 15924, Eureka quadrangle, Utah. Near Yankee mine. Uncle Joe member of the Deseret limestone. Collected from a zone within 100 feet of the Humbug contact.

The slabs contain a great many corals most of which appear to belong to the taxon I have been calling *Timania?* About 50 specimens were sectioned only to find the preservation of internal structures exceptionally poor. Fortunately the coral *Timania?* has some distinctive characters that permit its recognition even though specimens are poorly preserved and fragmentary, and we know that it is one of the most characteristic fossils in the Deseret and lower part of the Humbug in this area. I am fairly sure that some other genera of horn corals are present but am unable to identify them from the material in hand.

The collection contains also indications of two species of *Fenestella*, another crudely silicified bryozoan that I think is probably *Cystodictya* and a fragment of *Spirifer* sp. indet. (examined by Mackenzie Gordon).

So far, we have no evidence that the coral *Timania?* occurs in the Madison and its equivalents. *Timania* (*sensu stricto*) is supposedly restricted to the Upper Carboniferous (C_3) and Permian in Russia, and I have not seen any record of it in the Lower Carboniferous elsewhere. Several years ago, I studied some of our western specimens in detail, and it seemed to me that they had all the characteristics attributed to the genotype. Since then the Russian workers have erected the genus *Pseudotimania* for the "*Timanias*" that occur in their Middle Carboniferous. I have not restudied our material with reference to possible reassignment. Whatever the Mississippian form is, however, it is widely distributed in our Upper Missis-

sippian. In addition to its occurrence in the Deseret and Humbug of the Ophir and Tintic districts in Utah, I have identified it in collections from the "Brazer" of Idaho, the Upper Mississippian of the Osgood Mountains in Nevada, and the Alapah limestone of the Lisburne group in northern Alaska.

The majority of the fossils collected from the limestone units of the Deseret in the East Tintic Mountains are not sufficiently restricted in stratigraphic occurrence to date specifically the enclosing rocks other than as Early or Late Mississippian or both. However, the faunas of the basal phosphatic shale appear to be no older than early Meramec and therefore seem to restrict the Deseret to the Late Mississippian. Stratigraphically the Deseret of the East Tintic Mountains is directly equivalent to the Deseret limestone of the Oquirrh Mountains, which was considered by Girty (quoted by Gilluly, 1932, p. 26) to be equivalent to part of the Brazer limestone of northeastern Utah and therefore of Late Mississippian age. The Deseret also is equivalent to part of the Brazer limestone (Mansfield, 1927, p. 63–71) as that formation is commonly recognized in northeastern Utah and adjoining areas, to most of the Deseret limestone of the Cottonwood–American Fork and Provo areas in the central Wasatch Range (Calkins and Butler, 1943, p. 24–26; Baker, 1947), and to at least part of the Woodman limestone of the Gold Hill quadrangle (Nolan, 1935, p. 27–29).

CHEMICAL AND PHYSICAL CHARACTER

The limestones of the Deseret range in composition from nearly pure calcite to beds that are largely silica in the form of chert and sand. Analyses of the limestone strata of the Deseret are presented in the following table.

TABLE 16.—*Chemical analyses of Deseret limestone*

Rock units	Acid insoluble	Fe_2O_3 and Al_2O_3	CaO	MgO	CO_2 [1]	Total
Composite sample, limestone beds of the Uncle Joe member [2]	16.9	0.6	42.0	3.7	36.9	100.1
Composite sample, limestone beds of the Tetro member [2]	31.5	2.5	35.9	.8	29.0	99.7
Coarse-grained (coquinoid) bed [3] of the Uncle Joe member	.57	(Fe_2O_3) .9	55.22	.41	43.84	100.94

[1] Calculated.
[2] Data courtesy Chief Consolidated Mining Co. Samples collected by G. W. Crane.
[3] Analysis from Tower and Smith, 1899, p. 625.

The composite samples probably do not contain any megascopic chert, but the high value for "acid insoluble" indicates that sand, microscopic blebs of chert, or some other form of silica is present. Dolomite, especially the hydrothermal variety, is more common in the Deseret of the ore-producing centers of the Tintic and East Tintic district than the above analyses suggest.

The chemical composition of parts of the basal phosphatic shale member is presented and discussed below.

Physically, the limestone beds are comparatively brittle and brecciate readily where they are adjacent to large faults. The shaly beds at the base of the formation, on the other hand, are highly incompetent, and where they are well exposed underground they are commonly crumpled and faulted, and show structures that indicate mass flowage. The shaly phosphorite zone near the Crown Point No. 3 mine localizes a low-angle fault zone that appears to cut out part of the Tetro member.

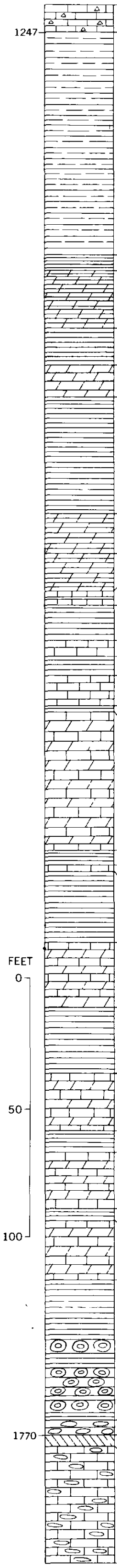
ECONOMIC IMPORTANCE

The Uncle Joe member of the Deseret limestone is the principal host rock of the replacement ore bodies of the Godiva and Iron Blossom ore zones in the eastern half of the main Tintic district. A large part of the ore produced in the Iron Blossom No. 3, Northern Spy, and Godiva mines, and all, or nearly all, of the ore produced from the Sioux Consolidated, Colorado, Beck Tunnel, Yankee, Humbug, Mountain View, May Day, Salvador, Utah, and Little Spy mines, came from deposits in the coarse-grained coquinoid limestones of this member. A much smaller amount of ore was also produced from the cherty Tetro member in the Iron Blossom No. 3, and in the Tetro and Godiva mines. Cook (1957, p. 65) has estimated the gross value of ore produced from the Deseret limestone in the Tintic district at $46,500,000.

The phosphatic shale member includes near the base one or more beds of vanadiferous phosphorite that may have economic importance. The composition of the phosphorite varies considerably along the strike, but near Eureka the grade of the lower part approaches that of certain beds in the Phosphoria formation of Idaho and Montana that are used as a raw material source of elemental phosphorus. The phosphatic shale member is cut by underground workings of the Chief No. 1, Chief No. 2, Victoria, and Grand Central, and possibly other mines, and appears to warrant detailed sampling and further study.

PHOSPHATIC SHALES: PETROGRAPHY, COMPOSITION, AND ORIGIN

The phosphatic shales and phosphorites of the phosphatic shale member of the base of the Deseret limestone in the Tintic mining district approach, in composition and thickness, some phosphorites utilized commercially in the thermal-reduction method of producing elemental phosphorus (Waggaman and Bell, 1950, and Dengler, 1957), and may represent a potential minable source of phosphate compounds, vanadium, uranium and other elements (fig. 45). The individual beds of



Rock type	Computed thickness (feet)	eU	U	V_2O_5	P_2O_5	Loss on ignition	Acid insoluble
		Chemical analysis (percent)					
Limestone, gray, and black chert	± 5						
Shale, gray and black	43 0						
Shale, black	3 0	0 001	0 001	0 45	3 00	8 67	81 09
Shale, dolomitic, gray	11 0						
Shale, black	2 5	000	001	21	80	8 57	82 85
	2 5	001	001	18	58	19 16	61 52
	1 5	001	001	13	85	11 81	79 03
Dolomite, gray	6 1						
Shale, black	11 5						
	3 5	000	001	17	1 65	5 29	86 80
	3 5	001	001	20	1 95	9 31	83 24
	3 5	000	001	18	1 45	9 09	85.00
Shale, dolomitic, gray and black	4 1	001	001	14	1 01	19 51	54 39
	3 5	001	001	12	85	15 62	61 59
Shale dolomitic, gray	7 4						
Limestone, gray, and black shale	2 6	002	001	23	1 65	19 62	49 83
	1 6	003	001	54	5 90	12 38	60 91
Shale, black	1 4	001	001	33	4 55	9 51	64 22
	3 1	001	001	40	3 85	10 21	71 60
	2 1	004	001	41	5 60	14 15	66.82
Shaly limestone	3 0						
Shale, black	3 5	003	001	40	4 90	10 96	69 88
Limestone, gray	5 7						
Shale, black	1 0	002	001	31	3 90	11 89	20 60
Limestone and dolomite, gray	26 4						
Shale, black	2 6	004	003	19	10 10	19 95	36 63
Limestone	1 3						
Shale, black	5 1	002	002	23	10 70	10 57	53 96
	5 8	004	003	47	8 10	13 07	54 33
	2 6	005	002	57	6 45	19 06	52 63
Limestone and dolomite, gray	12 6						
Shale, black	3 5	003	003	40	9 80	18 48	49 20
	3 5	002	002	15	1 05	10 04	77 61
	5 5	001	001	17	1 84	25 38	36 07
Limestone and dolomite, gray	11 0						
Shale, black	4 0	003	002	17	6 50	25 04	31 70
Limestone and dolomite, gray	11 2						
Shale, black	2 4	.002	002	40	3 70	14 22	60 58
Limestone and dolomite, gray	11 7						
Shale black, graphitic, and pelletal phosphorite	1 3	002	002	36	1 70	26 61	36 86
	2 3	003	003	1 02	•6 30	17 30	52 09
	2 1	005	003	1 22	5 20	20 14	52 72
	4 7	002	003	51	7 35	18.71	42 63
	6 4	006	005	27	15 25	13 65	36 84
	6 4	006	004	37	15 25	12 17	39 34
	3 9	005	005	14	23 62	9 68	15 75
Shale siliceous, black	2 6	006	006	36	65	2 98	90 81
Jasperoid	2 0						
Limestone, silicified gray	20 0						

Figure 45.—Columnar section of phosphatic shale member of Deseret limestone showing percentage of V_2O_5, P_2O_5, loss on ignition, and acid-insoluble fraction. Part of log of E. J. Longyear diamond-drill hole 1A, sec. 7, T. 10 S., R. 2 W., Eureka quadrangle, after D. C. Duncan, 1953.

phosphatic shale and pelletal phosphorite range in thickness from a few inches to about 30 feet; they are interlayered with beds of dark-gray to black silty limestone and dolomite, which enclose nodules and thin lenses of coal-black chert. As stated on page 95, the maximum thickness of the phosphatic shale member near Eureka is 150 feet, but it thins northward to about 10 feet on Topliff Hill, in a distance of about 11 miles. Only slightly more than one-half of the basal member near Eureka consists of phosphatic shale, and of greatest potential economic importance is a zone from 3 feet to about 16 feet thick at the base that contains 15–25 percent P_2O_5.

These basal beds are fine- to medium-grained dark-brown to shiny black pelletal phosphorite, but they grade upward into fine-grained sooty-black laminated shale. Specimens of the laminated shale examined in thin sections were found to consist of angular grains of detrital quartz 10–50 microns (approximately 0.0005–0.002 inch) in diameter, embedded in a nearly opaque carbonaceous, phosphatic, and calcitic matrix. Calcite grains of the same generation as the detrital quartz are sparsely distributed throughout most of the rock, and ramifying calcite veinlets which crosscut all earlier structures are common.

In contrast, the phosphorite, when examined under the microscope, was found to consist of densely crowded pellets in a matrix of phosphate, calcite, and carbonaceous material. These pellets are so exceptionally opaque in thin section, owing to finely dispersed carbonaceous material, that it was not possible to identify the mineral species. However, X-ray studies showed the material to be carbonate-apatite (Altschuler, Cisney, and Barlow, 1953), similar in its X-ray pattern to the carbonate-fluorapatite of the Phosphoria and Brazer formations. (T. M. Cheney, oral communication, 1957.) The individual pellets in the phosphorite are rarely more than 1 mm (about 0.04 inch) in diameter, and many are moderately distorted or broken. All are sooty black, but some in the thinnest parts of the rock slice are slightly translucent. Most of them have a faint, but distinct, finely radiating structure, with prominent closely spaced concentric bands at the periphery. Near the edges of some pellets, small arcuate cracks are filled with fine-grained carbonaceous and phosphatic material or with calcite; but many pellets are unbroken. The nuclei of most of them are large relative to their total diameter and appear to consist of amorphous apatite intermixed with carbonaceous matter which is entirely devoid of organic structure. Some of the pellets appear to have built up around particles of quartz and, more rarely, fragments of fossils. The interstices between the pellets are chiefly filled with imperfectly spherulitic calcite, in elongate crystals that radiate from carbonaceous particles. Other carbonaceous material is interspersed with the spherules, and minute flakes of mica are also present.

The sooty blackness of hand specimens and the extreme opacity of thin sections of the laminated shales and pelletal phosphorites indicate that the carbon content of the phosphatic shale member is very high. This was pointed out by J. M. Schopf, of the coal geology laboratory of the U.S. Geological Survey, in a communication to D. C. Duncan in 1952 and was later confirmed by chemical analyses. The samples that were analyzed were collected from a section of the lower part of the Deseret limestone exposed on the 1,600-foot level of the Chief No. 1 mine in the Tintic district, and they represented the blackest, most definitely pelletal beds—aggregating about 17 feet in thickness—in a section 40 feet thick. The total carbon content ranges from 5.7 percent to 13.3 percent and averages 8.28 percent. Of this the carbon in carbonate minerals ranges from less than 0.1 percent to 2.7 percent, averaging 0.95 percent, and the organic carbon (determined by difference) ranges from 6.7 to 13.3 percent, averaging 7.33 percent. Schopf suggested that the carbon may correspond in rank to anthracite and in part may be graphitic, especially that which is near the surface of the pellets and between them. However, the high loss on ignition (fig. 45) and the low carbonate-mineral content of the rock suggest that only a small percentage of the carbonaceous material is actually graphite.

In areas where the phosphatic shale member has been deformed, as at the crests of minor drag folds, minor structures have developed in the pelletal beds that indicate failure of the rock by mass flowage. As seen in thin sections, some of which were examined by Schopf (written communication to D. C. Duncan, 1952) and others of which were studied by the writers, this rock is composed of small pillow-shaped structures that are cemented together. The internal structures of these distorted pellets are little disturbed, but their outer parts are considerably altered. The pillow-shaped structures are extremely opaque, but in the thinnest part of the thin sections they show finely divided carbonaceous material dispersed in a grayish transparent matrix that does not appear to be crystalline even under high magnification, although the high P_2O_5 content of the rock suggests that it is phosphatic in composition. The interstitial material between the distorted pellets consists of exceptionally fine grained debris, evidently derived from the original carbonaceous fragments. In some of the thin sections examined this microbreccia was thoroughly silicified and calcitized, evidently after the shale was deformed.

ANALYSES

Chemical and spectrographic analyses of selected samples of diamond-drill core from a hole that apparently cut a complete but somewhat faulted and drag-folded section of the phosphatic shale member of the Deseret limestone are presented in figure 45 and table 17. These tabulations were prepared from analyses made of material collected and prepared by D. C. Duncan, who has described these rocks in another report (Duncan, 1953, p. 61–66). The partial chemical analyses show all the laminated and pelletal beds to be phosphatic but to range widely in P_2O_5, V_2O_5, and minor-element content. The pelletal beds within a few feet of the base contain the largest concentrations of P_2O_5 and higher than average amounts of uranium, but the laminated shale that closely overlies the pelletal zone contains the greatest concentrations of V_2O_5. The spectrographic analyses summarized in table 18 show that both the pelletal phosphorite and laminated shale contain appreciable amounts of chromium, zinc, nickel, lanthanum, yttrium, and other elements; however, these analyses are semiquantitative and show only the general composition of the rock and the relative amount of the trace concentrations of the rarer elements.

The concentrations of uranium, strontium, and rare earths in general vary directly with the concentration of P_2O_5, but the highest concentration of vanadium occurs in a sample with only 5.20 percent P_2O_5, and it seems probable that the accumulation of vanadium and some of the heavy metals (table 17) was somewhat independent of the factors that caused the calcium phosphate to precipitate. McKelvey and his coworkers (oral communication, 1957) has found that vanadium, silver, chromium, nickel, molybdenum and other heavy metals are concentrated in some of the phosphorite beds of the Phosphoria formation, but that the highest concentrations of these elements are in highly carbonaceous shales of low phosphate content.

ORIGIN

The phosphatic shale member appears to have originated through an alternating deposition of calcareous sediments that became limestones and dolomites, and carbonaceous phosphatic muds that became pelletal phosphorites, or laminated phosphatic shale where they were mixed with quartz silt and with clay minerals. The phosphatic sediments at the base of Brazer lime-

TABLE 17.—*Spectrographic analyses of drill-core samples of the phosphatic shale member of the Deseret limestone, Tintic mining district, Juab County, Utah; hole 1A of E. J. Longyear Drilling Company, SE¼SW¼ sec. 7, T. 10 S., R. 2 W.*

[Analyst, R. G. Havens, U.S. Geological Survey. Looked for but not found at spectroscopic limits shown in parentheses: As (0.1), Au (0.002), Bi (0.001), Ce (0.02), Ge (0.001), Hf (0.01), In (0.001), Li (0.02), Nb (0.001), Pd (0.0003), Pt (0.003), Re (0.005), Rh (0.005), Sb (0.01), Sn (0.001), Ta (0.02), Th (0.02), Tl (0.05), and W (0.01). Beds intersected by drill hole dip 65°–75°, are locally faulted, and deformed by flowage at the crests and troughs of drag folds. True thickness of basal phosphatic shale member is about 150 feet]

Sample Nos.	Depth intercept (field No.)	Computed thickness (feet)	Si	Al	Fe	Ti	Mn	P	Ca	Mg	Na	Ag	B	Ba	Be
52501	1333–1339	3.0	xx.	0.x	0.x	0.0x	0.00x	x.	x.	0.0x	0.00x	0.00x	0.00x	0.00x	0.000x
52502	1365–1370	2.5	xx.	.x	.x	.0x	.00x	.x	x.	.x	.00x	.00x	.00x	.00x	.000x
52503	1370–1375	2.5	xx.	.x	.x	.0x	.0x	.x	x.	x.	.00x	.00x	.00x	.00x	.000x
52504	1375–1378	1.5	xx.	.x	.x	.0x	.00x	.x	x.	.x	.00x	.00x	.00x	.00x	.00x
52505	1395–1400	3.5	xx.	.x	.x	.0x	.00x	.x	x.	.0x	.00x	.000x	.00x	.0x	--------
52506	1400–1405	3.5	xx.	.x	.x	.0x	.00x	.x	x.	.0x	.00x	.00x	.00x	.00x	--------
52507	1405–1410	3.5	xx.	x.	.x	.0x	.00x	.x	x.	.0x	.00x	.00x	.00x	.00x	--------
52508	1410–1415	4.1	xx.	.x	.x	.0x	.0x	.x	.x	x.	.00x	.000x	.000x	.0x	--------
52509	1415–1420	3.5	xx.	x.	.x	.0x	.0x	.x	x.	x.	.00x	.00x	.000x	.0x	--------
52510	1433–1437	2.6	xx.	.x	.x	.0x	.0x	.x	x.	.x	.00x	.000x	.000x	.00x	--------
52511	1437–1443	1.6	xx.	x.	.x	.0x	.0x	x.	x.˙	.x	.0x	.00x	.00x	.0x	--------
52512	1443–1447	1.4	xx.	x.	x.	.0x	.0x	x.	x.	.x	.00x	.00x	.00x	.0x	--------
52513	1447–1454	3.1	xx.	x.	x.	.0x	.0x	x.	x.	.x	.00x	.00x	.00x	.00x	--------
52514	1454–1459	2.1	xx.	x.	x.	.0x	.00x	x.	x.	.x	.0x	.00x	.00x	.0x	--------
52515	1465–1472	3.5	xx.	x.	x.	.0x	.00x	x.	x.	.x	.0x	.00x	.00x	.0x	--------
52516	1483–1485	1.0	x.	.x	.x	.0x	.0x	x.	xx.	x.	.0x	.00x	.000x	.00x	--------
52517	1526–1530	2.6	xx.	x.	.x	.0x	.0z	x.	xx.	.x	.0x	.00x	.00x	.00x	Tr
52518	1532–1540	5.1	xx.	.x	.x	.0x	.0x	x.	xx.	.x	.000x	.00x	.000x	.00x	--------
52519	1540–1549	5.8	xx.	.x	.x	.0x	.00x	x.	x.	.x	.0x	.00x	.00x	.00x	--------
52520	1549–1553	2.6	xx.	x.	.x	.0x	.00x	x.	x.	.x	.0x	.00x	.00x	.0x	Tr
52521	1575–1582	3.5	xx.	x.	.x	.0x	.00x	x.	x.	.x	.0x	.00x	.00x	.00x	Tr
52522	1582–1589	3.5	xx.	x.	.x	.0x	.0x	.x	x.	.x	.00x	.00x	.00x	.00x	--------
52523	1589–1600	5.5	xx.	.x	.x	.0x	.0x	.x	xx.	x.	.00x	.000x	.000x	.00x	--------
52524	1622–1630	4.0	xx.	x.	.x	.0x	.0x	x.	xx.	x.	.00x	.00x	.00x	.00x	--------
52525	1660–1669	2.4	xx.	x.	.x	.0x	.0x	x.	x.	.x	.00x	.00x	.00x	.00x	--------
52526	1708–1713	1.3	x.	.x	.x	.0x	.0x	.x	.x	x.	.0x	.00x	.00x	.00x	--------
52527	1713–1722	2.3	xx.	x.	.x	.0x	.00x	x.	x.	.x	.0x	.00x	.00x	.00x	Tr
52528	1722–1730	2.1	xx.	x.	.x	.0x	.00x	x.	x.	.x	.0x	.00x	.00x	.0x	Tr
52529	1730–1740	4.7	xx.	x.	.x	.0x	.0x	x.	x.	.x	.0x	.00x	.00x	.00x	Tr
52530	1740–1750	6.4	xx.	x.	.x	.0x	.0x	x.	x.	.x	.0x	.00x	.00x	.0x	Tr
52531	1750–1760	6.4	xx.	x.	.x	.0x	.00x	x.	x.	.x	.0x	.00x	.00x	.00x	Tr
52532	1760–1766	3.9	x.	.x	.x	.0x	.00x	x.	xx.	.x	.x	.000x	.000x	.00x	--------
52533	1766–1770	2.6	xx.	.x	.x	.0x	.0x	.x	.x	.0x	.000x	.000x	.00x	.0x	Tr

Sample Nos.	Cd	Co	Cr	Cu	Ga	La	Mo	Ni	Pb	Sc	Sr	V	Y	Zn	Zr
52501	--------	--------	0.0x	0.00x	--------	0.00x	--------	0.00x	--------	0.000x	0.00x	0.0x	0.0x	0.0x	0.00x
52502	--------	--------	.00x	.00x	--------	--------	--------	.00x	--------	.000x	.000x	.0x	.00x	.0x	.00x
52503	--------	--------	.00x	.00x	--------	--------	--------	.00x	--------	.000x	.00x	.0x	.00x	.0x	.00x
52504	--------	--------	.00x	.00x	--------	--------	--------	.00x	--------	.000x	.000x	.0x	.00x	.0x	.00x
52505	--------	--------	.00x	.00x	--------	.00x	0.000x	.00x	--------	.000x	.00x	.00x	.00x	.0x	.00x
52506	--------	--------	.0x	.00x	--------	.00x	.000x	.00x	--------	.000x	.00x	.0x	.00x	.0x	.00x
52507	--------	--------	.00x	.00x	--------	.00x	.000x	.00x	0.00x	.000x	.00x	.0x	.00x	.0x	.00x
52508	--------	--------	.00x	.00x	--------	--------	.000x	.00x	.000x	.000x	.00x	.0x	.00x	.0x	.0x
52509	--------	--------	.00x	.00x	--------	--------	--------	.00x	--------	.000x	.00x	.0x	.00x	.0x	.0x
52510	--------	--------	.00x	.00x	--------	--------	--------	.00x	--------	--------	.00x	.0x	.00x	.0x	.00x
52511	--------	0.000x	.0x	.00x	0.000x	.00x	.00x	.0x	.000x	.000x	.0x	.0x	.0x	.0x	.00x
52512	--------	.000x	.0x	.00x	.000x	.00x	.00x	.0x	--------	.000x	.0x	.0x	.0x	.0x	.00x
52513	0.00x	.000x	.0x	.00x	.000x	.00x	.00x	.0x	--------	.000x	.0x	.0x	.0x	.0x	.00x
52514	.00x	.000x	.0x	.00x	.000x	.0x	.00x	.0x	--------	.000x	.0x	.0x	.0x	.x	.00x
52515	.00x	.000x	.0x	.00x	.000x	.00x	.00x	.00x	--------	.000x	.0x	.0x	.0x	.x	.0x
52516	--------	--------	.0x	.00x	.000x	.00x	.000x	.00x	--------	.000x	.0x	.0x	.00x	.0x	.00x
52517	.00x	--------	.0x	.00x	.000x	.0x	.00x	.0x	--------	.000x	.0x	.x	.0x	.0x	.00x
52518	.00x	--------	.0x	.00x	.000x	.0x	.00x	.0x	--------	.000x	.0x	.0x	.0x	.x	.00x
52519	.00x	.000x	.0x	.00x	.000x	.0x	.00x	.0x	--------	.000x	.0x	.0x	.0x	.x	.00x
52520	.00x	.000x	.0x	.00x	.000x	.00x	.00x	.0x	--------	.000x	.0x	.x	.0x	.0x	.00x
52521	.00x	.000x	.0x	.00x	.000x	.0x	.00x	.0x	--------	.000x	.0x	.x	.0x	.0x	.00x
52522	--------	.000x	.00x	.00x	.000x	--------	.000x	.00x	--------	.000x	.00x	.00x	.00x	.0x	.00x
52523	--------	.000x	.00x	.00x	--------	--------	.00x	.00x	--------	.000x	.00x	.00x	.00x	.0x	.00x
52524	--------	--------	.0x	.00x	.000x	.0x	.00x	.0x	--------	.000x	.0x	.0x	.0x	.0x	.00x
52525	--------	--------	.0x	.00x	.000x	.00x	.00x	.00x	--------	.000x	.00x	.0x	.0x	.0x	.00x
52526	.00x	.000x	.00x	.00x	.000x	--------	.00x	.00x	--------	--------	.00x	.0x	.00x	.0x	.00x
52527	.00x	.000x	.0x	.00x	.000x	.00x	.00x	.00x	--------	.000x	.0x	.x	.0x	.0x	.00x
52528	.00x	.000x	.0x	.00x	.000x	.00x	.00x	.0x	--------	.000x	.0x	.x	.0x	.0x	.00x
52529	.00x	.000x	.0x	.00x	.000x	.00x	.00x	.0x	--------	.000x	.0x	.x	.0x	.x	.00x
52530	.00x	.000x	.0x	.00x	.000x	.0x	.000x	.0x	--------	.000x	.0x	.x	.0x	.x	.00x
52531	.00x	.000x	.0x	.00x	.000x	.0x	.00x	.0x	--------	.000x	.0x	.0x	.0x	.0x	.00x
52532	--------	--------	.00x	.00x	--------	.0x	.00x	.0x	--------	.000x	.0x	.0x	.0x	.x	.00x
52533	--------	.000x	.00x	.00x	--------	--------	.000x	.00x	--------	.000x	.00x	.0x	.00x	.0x	.00x

TABLE 18.—*Mean (in percent) of spectrographic analyses of the 35 drill-core samples shown in table 17 for the phosphatic shale member of the Deseret limestone*

[All samples are from Longyear No. 1A drill hole in Chief Consolidated mine, sec. 7, T. 10 S., R. 2 W., Tintic district, Utah. Looked for but not found at the spectroscopic limits shown in parentheses: As (0.1), Au (0.002), Bi (0.001), Ce (0.02), Ge (0.001), Hf (0.01), In (0.001), Li (0.02), Nb (0.001), Pd (0.000s), Pt (0.003), Re (0.005), Rh (0.005), Sb (0.01), Sn (0.001), Ta (0.02), Th (0.02), Tl (0.05), and W (0.01). The concentrations of the elements as determined by semiquantitative spectrographic analyses are bracketed into groups each of approximately one-third of an order of magnitude, X+ indicating the higher portion (10–5 percent); X, the middle portion (5–2 percent); and X−, the lower portion (2–1 percent). Comparisons of this type of semiquantitative methods, either chemical or spectrographic, show that the assigned group includes the quantitative value in about 60 percent of the analyses]

Element	Mean	Element	Mean	Element	Mean
Na	0.0X+	Ti	0.0X	Ag	0.00X−
K	----------	Zr	.00X+	Zn	.0X+
Be	Tr.	V	.0X+	Cd	.00X−
Mg	.X	Cr	.0X−	B	.00X−
Ca	.X+	Mo	.00X−	Al	X. −
Sr	.0X−	Mn	.0X−	Ga	.000X−
Ba	.00X+	Fe	.X	Si	XX.
Sc	.000X	Co	.000X−	Pb	.000X−
Y	.0X−	Ni	.00X+	P	. X.
La	.00X	Cu	.00X		

stone (Cheney, 1957, p. 11–13) are widespread and probably accumulated on a shelving platform or in an embayment of rather large size. The absence of coarse detrital sediments in the phosphatic shale member of the Deseret indicates that the bordering land masses were relatively low and contributed only small amounts of fine-grained quartz and clay. The increase of clastic sediments in the Deseret limestone northwest of the Tintic district, however, points to a land mass of at least small size in this direction. The abundance and preservation of carbonaceous material suggests a profusion of marine plants and animals, and an oxygen-deficient depositional environment. The stratigraphic and paleontologic relations indicate further that no exceptionally long period of time is represented by the phosphatic shale member.

Many theories have been proposed concerning the origin of stratified marine phosphorites, but most of them seem to be inadequate to account for all the chemical and geological characteristics of the deposits. Kazakov (1937), however, has presented a theory that answers most of the objections made to other theories. His paper has been discussed by McKelvey, Swanson, and Sheldon (1953, p. 54–62) as it applies to the origin of the Phosphoria formation and their conclusions are reviewed here. According to their modification of Kazakov's hypothesis:

> The Phosphoria formation accumulated in a large shelving embayment bordered by lands of low relief that contributed little detritus to the sea. Cold, phosphate-rich waters upwelled into this basin from the ocean reservoir to the south or southwest.[7] Phosphorite was deposited from these ascending waters, probably in depths of 1,000 to 2,000 meters, as their pH increased along with increase in temperature and decrease in partial pressure of CO_2. Carbonates were precipitated from these waters when they reached more shallow depths, at a somewhat higher pH. The phosphate-rich waters nurtured a luxuriant growth of phytoplankton, as well as higher forms of plant and animal life, some remains of which were concentrated with fine-grained materials in deeper waters away from shore. Part of the phosphate and probably some of the fine-grained silica in the formation were concentrated by these organisms. Finally, these conditions persisted over much of the Permian time.

[7] More recent work indicates that the ocean reservoir was west of the principal areas of phosphate deposition (T. M. Cheney, oral communication, May 27, 1958.)

The many similarities in the lithologic character and composition of the phosphatic shale member of the Deseret limestone and the Meade Peak phosphatic shale member of the Phosphoria formation suggests that the above hypothesis of origin conceivably may be applied as well to the basal Deseret. The principal differences in the thickness and average P_2O_5 content of the phosphatic beds of the two units are probably attributable to differences in the time interval of accumulation, composition of the sea water, dilution by clastic sediments, and other geologic factors. Of these the time interval of accumulation is probably of major importance. As stated above, McKelvey, Swanson, and Sheldon (1953, p. 56–57, 62) believe that the Phosphoria formation accumulated through much of Permian time, whereas the basal member of the Deseret limestone was deposited during only part of the Meramec time interval of the Mississippian period. The high P_2O_5 content of many of the Phosphatic beds of the Phosphoria and related deposits is also related to the absence of large amounts of clastic material, which contrasts with the relative abundance of fine-grained detrital quartz and other acid-insoluble material in many of the phosphorite and phosphatic shale beds in the basal Deseret.

The rarer elements that are characteristic of the carbonaceous shales and pelletal phosphorite beds are present in tremendous concentrations as compared with concentrations of the same elements in present-day sea water and ordinary marine shales, but are quite comparable to those in other carbonaceous shaly phosphorites. This abnormal concentration probably reflects a combination of some of the following processes: (a) biologic activity, (b) adsorption, (c) ion exchange, and (d) reaction and precipitation. It may be significant that many of the metallic elements concentrated in this carbonaceous deposit are those that are utilized biologically by certain marine organisms (Rankama and Sahama, 1950, p. 319–366), and it seems entirely probable that large amounts were initially concentrated within the tissues and hard parts of living organisms. Concerning this, Krauskopf (1956, p. 31) states.

> It is worth emphasizing that four of the rare metals most characteristic of black shales and asphalts (V, Ni, Co, Mo) belong to the group which, according to the experiments, cannot possibly be controlled in sea water by precipitation of sulfides. The first three are also in the group for which adsorption is an

inadequate explanation, and are among the metals known to be greatly concentrated in some marine organisms. Such a combination of facts is difficult to explain without assuming that biologic processes play an important role in the enrichment of these metals in sedimentary rocks.

However, McKelvey (oral communication 1957) believes that much if not most of the heavy metals may have been adsorbed directly from sea water by organic matter and other compounds, and may thus be fixed in the sediments as metallic-organic compounds, although some may be fixed in the lattice of clay minerals. The relatively high concentrations of uranium and rare earths in the phosphorite beds may similarly reflect the chemical adsorption of these elements by apatite and colloidal phosphate. Moore (1954, p. 652–658) has demonstrated that phosphate rock is an effective adsorbant of uranium under laboratory conditions, as are peat, lignite, coal, and other hydrocarbons.

The lack of preservation of recognizable organic structures in even the most highly carbonaceous rock may be the result of complete maceration of the organisms, together with the decaying action of saprophytic, anerobic bacteria, which eventually converted most of the organic material into a structureless sapropelic gel intermixed with precipitated carbonate-fluorapatite, detrital quartz and other products of normal sedimentary deposition.

In summary it may be stated that the carbonate-fluorapatite was probably precipitated directly from sea water, and that vanadium nickel, cobalt, molybdenum, silver, and other heavy metals were concentrated chiefly by living organisms, although some of these elements may have been adsorbed directly from sea water on decaying organic matter and other compounds. Some of the uranium, strontium, and rare earths may also have been concentrated by living organisms, but the most significant amounts were probably adsorbed on colloidal carbonate-fluorapatite, which was eventually converted to pelletal phosphorite.

HUMBUG FORMATION

DISTRIBUTION

The Humbug formation crops out extensively in the northern and south-central parts of the East Tintic Mountains, but it has been stripped by erosion from most of the north-central part of the range, except for two small erosion remnants of the lower part of the formation that are preserved in the trough of the Tintic syncline. One of these remnants forms the country rock near the adits of the Humbug tunnels from which the formation was named by Tower and Smith (1899, p. 625–626).

In the western part of the North Tintic district complete stratigraphic sections of the Humbug are well exposed in a faulted band of outcrops that crosses Topliff Hill they can best be studied in secs. 9, 15, 22, and 23, T. 8 S., R. 3 W. Excellent exposures also are found near the west margin of the East Tintic Mountains between Bell and Miners Canyons, but the rocks are even more faulted in this area than on Topliff Hill.

In the eastern part of the North Tintic district incomplete sections of the Humbug extend south along the east edge of Gardison Ridge from a point nearly due west of Allens Ranch to Herrington Basin (north of Packard Peak). Between Bismark Peak and the Homansville Pass road several partial and complete sections of the Humbug are exposed on the limbs of the minor folds in the axis of the Tintic syncline. The best of these are on the flanks of the anticline in sec. 20, T. 9 S., R. 2 W. Erosional remnants of the Humbug also crop out in a north-trending synclinal trough in the E½E½ sec. 22, and the E½E½ sec. 15, T. 9 S., R. 2 W.; along the east side of Wanlass Hill northward from Greeley Pass to a point in sec. 24, T. 8 S., R. 2 W.; in the extreme northeast corner of the Allens Ranch quadrangle; and on the 5,006-foot hill in sec. 14, T. 8 S., R. 2 W.

Along the western edge of the south-central part of the range the Humbug is prominently exposed a short distance north of County Canyon and also a short distance north of Jericho Pass. In these areas it has much the same character as in the northern East Tintic Mountains.

LITHOLOGIC CHARACTER

The Humbug formation consists of a series of alternating quartzitic sandstones and sandstreaked and pure limestones, with minor dolomite beds and a few thin layers of shale.

The abundant sandstone beds distinguish it from the dominantly limy Deseret and Great Blue formations, between which it lies. The lower contact is placed at the base of the lowest prominent sandstone or quartzite bed of the zone of abundant quartzite in the Upper Mississippian section; similarly the upper contact is placed at the top of the uppermost prominent quartzite or sandstone bed. All the sandstone or quartzite beds are lenticular, and the lowest sandstone bed of a given section may be tens of feet stratigraphically lower or higher than the lowest sandstone in another section a few hundred feet along the strike. The thickness of the formation consequently varies from place to place, and the individual sandstone lenses cannot be used as horizon markers except locally.

The sandstone or quartzite beds, which make up about one-half of the total thickness of the Humbug formation and which are most closely spaced in the lower third of it, are most commonly between 8 inches and 15 feet thick, but some attain a thickness of 30–50 feet or more (fig. 46). Their weathered surfaces range in

FIGURE 46.—Crossbedded clastic limestone in Humbug formation. Dark bed near center of photograph is quartzitic sandstone; lighter beds are sand-streaked limestone. Outcrop on Topliff Hill, Boulter Peak quadrangle.

FIGURE 47.—Light-gray-weathering limestone marker beds in upper part of Humbug formation. Outcrop on Topliff Hill, Boulter Peak quadrangle.

color from dusky red to light brown, but are most commonly dark reddish brown. The color of the freshly broken rock is pale gray green to light brown, and scattered throughout the rock are many dark-brown specks, presumably an iron-bearing carbonate that upon weathering contributes the characteristic brown colors to the quartzites. The quartz grains are moderately well rounded and well sorted and are chiefly cemented by calcite with some silica, but other carbonates constitute the bonding agent in a few beds. Many of the sandstone layers are prominently crossbedded and some are ripple marked.

The lower limetone beds are similar in many respects to those in the Deseret limestone, and, unlike the intercalated sandstones and quartzites, they are commonly fossiliferous. The limestones near the base are medium blue gray and medium grained; some are coarse grained, crinoidal, and relatively pure, but many are streaked with sand and weather buff to rusty brown. Some of the blue-gray limestones contain nodules of black and brown chert and are similar to the cherty beds of the Deseret.

A persistent zone of white-weathering very fine grained limestone beds a short distance below the middle of the Humbug is a fairly reliable marker zone throughout the East Tintic Mountains (fig. 47). The limestones above the white beds closely resemble the limestone beds of the Great Blue formation, being medium blue gray to dark blue, fine grained, and well bedded. Some of these beds are also cherty and sand streaked, and most of them contain well-preserved brachiopods and cup corals. In general, the contacts of the limestone and quartzite beds throughout the formation are abrupt, but a few are gradational through a thickness of several inches.

Shale beds make up somewhat less than 5 percent of the Humbug and are almost everywhere concealed at the outcrop by talus and soil. The shales in the upper part of the formation are dark blue to black, fine grained and fissile; but the shales in the lower part are light brown and distinctly sandy, and intergrade with sandstone or sandy dolomite along the strike.

Dolomite is far less common in the Humbug than limestone, but it is fairly abundant in the lower half of the formation. Nearly everywhere in the East Tintic Mountains the lowermost carbonate beds of the Humbug consist of platy-weathering medium-grained gray dolomite that weathers tan to yellowish gray. Rosettes of milky-white quartz, similar to those in the upper part of the Deseret limestone, are abundant in these beds. A persistent bed of yellowish-gray massive dolomite in the upper part of the formation is a useful marker bed through a considerable area in the northern part of the East Tintic Mountains, as it is commonly less than 50 feet below the Great Blue formation.

THICKNESS

Because the sandstone beds that are taken as the lower and upper contacts of the Humbug are lenticular, precisely measured sections within a short distance of each other are not of equal thickness. However, the average thickness of the Humbug throughout the East Tintic Mountains approximates the 645 feet reported by Gilluly (1932, p. 28) in the Oquirrh

Mountains. On Topliff Hill, in sec. 15, T. 8 S., R. 3 W., the Humbug is about 50 feet thinner than this (597 feet), but on the prominent hill near the mouth of Chiulos Canyon, in sec. 20, T. 9 S., R. 2 W., about 9 miles southeast of Topliff Hill, it is 652 feet thick. Only the lower 250 feet of the formation is present in the area of the Humbug tunnels in the Tintic district (Lindgren and Loughlin, 1919, p. 41–42).

The following detailed section, measured near the crest of Topliff Hill, is typical of the Humbug throughout most of the East Tintic Mountains, but it contains more quartzite, especially in the upper part of the formation, than is common southward and eastward from this locality.

Stratigraphic section of Humbug formation measured on Topliff Hill, North Tintic district, in the S½ sec. 15, T. 8 S., R. 3 W. (loc. 17, pl. 3).

	Thickness (feet)	Distance above base (feet)
Great Blue formation:		
Topliff limestone member (lower beds only):		
Limestone, light blue-gray, medium- to fine-grained, well-bedded; locally sand streaked		597
Contact conformable.		
Humbug formation:		
35. Quartzite, pale-green, medium-grained; weathers brown	5	592
34. Limestone, medium blue-gray, fine-grained; blocky fracture	13	579
33. Quartzite, sandy; weathers brown	2.5	576.5
32. Dolomite, yellowish-gray, medium-grained	25	551.5
31. Limestone, sandy, medium-gray, coarse-grained, coquinoid	2.5	549
30. Quartzite, brown-weathering, crossbedded	27	522
29. Limestone, medium-gray, sand-streaked	3.5	518.5
28. Sandstone, tan-weathering	5	513.5
27. Limestone, medium-gray, sand-streaked	6	507.5
26. Sandstone, tan-weathering, limy	12	495.5
25. Limestone, light-gray, coarse-grained, coquinoid; lower 6 in. streaked with sand	13	482.5
24. Sandstone; weathers brown	12	470.5
23. Limestone, medium-gray, medium-grained	5	465.5
22. Sandstone, quartzitic, weathers brown	33	432.5
21. Limestone, light gray, fine-grained to sublithographic; contains scattered 1- to 2-in. pods of white dolomite	12	420.5
20. Quartzite and sandstone, brown weathering, medium-grained, limy	51	369.5
19. Limestone, medium- to light-gray, fine-grained	27	342.5
18. Quartzite, sandy, medium-grained; weathers brown; includes several beds of light-gray, fine-grained limestone	78	264.5
17. Limestone, white to light-gray, very fine grained; without sand or chert. This is a useful marker bed	28	236.5
16. Quartzite, brown-weathering	7	229.5
15. Limestone, light-gray, medium-grained, sand-streaked	8	221.5
14. Sandstone, quartzitic; weathers brown	4	217.5
Humbug formation—Continued		
13. Limestone, medium- to light-gray, medium-grained, sand-streaked	3.5	214
12. Sandstone, quartzitic, pale gray-green, brown-weathering, crossbedded; includes a few beds of tan-weathering dolomite	71	143
11. Limestone, dolomitic, light-gray, medium-grained, sand-streaked	4	139
10. Limestone, medium-gray, sand-streaked; 2-ft zone of coquinoid limestone at top	13	126
9. Sandstone, brown-weathering; includes a few thin bands of sandy limestone	9	117
8. Limestone, dolomitic, light-gray, medium-grained; contains scattered rosettes of milky-white quartz crystals	8	109
7. Limestone, light-gray, coarse-grained, sand-streaked, coquinoid	11	98
6. Dolomite, tan-weathering, medium-grained; includes several 1- and 2-ft beds of brown quartzite	29	69
5. Quartzite, medium- to fine-grained; weathers brown; includes several thin beds of tan-weathering dolomite	23	46
4. Dolomite, light-gray, medium-grained; lower and upper 5–6 ft of unit contain large nodules of brown chert	22	24
3. Quartzite, weathers brown; includes several thin beds of tan-weathering dolomite	18	6
2. Dolomite, medium-grained, sand-streaked, sparsely cherty; weathers tan to yellowish gray; contains scattered rosettes of milky-white quartz	4	2
1. Quartzite, pale gray-green, medium- to fine-grained, crossbedded; weathers brown	2	
Total Humbug formation	597	
Contact conformable.		
Deseret limestone (uppermost bed only):		
Dolomite, gray, tan-weathering, medium-grained; streaked with fine sand; contains many ½- to 2-in. rosettes of white quartz; breaks into platy chips and fragments at outcrop.		

Many of the arenaceous beds in the above section and elsewhere resemble quartzite on weathered surfaces, but a freshly broken surface will effervesce slightly to moderately upon the application of cold dilute hydrochloric acid. This suggests that the siliceous matrix on the surface of such quartzite beds may be a "case-hardening" effect caused by weathering; however, some of the quartzite beds contain little carbonate, even in their unweathered parts.

AGE AND CORRELATION

No paleontologic collections were made from the Humbug formation in the East Tintic Mountains during the present study, but as it lies between limestone units that have yielded well-preserved fossils of Late

Mississippian age, it must also be Late Mississippian. According to G. H. Girty (quoted *in* Gilluly, 1932, p. 28, and *in* Calkins and Butler, 1943, p. 27–28), fossils collected from the Humbug formation both in the Oquirrh Mountains and the central Wasatch Range find their closest affinities with the earlier faunas of the Brazer limestone as used by Girty.

The Humbug also occurs in the south-central Wasatch Range (Baker, 1947); to the west it is correlated with part of the Chainman shale of the Eureka area, Nevada (Nolan, Merriam, and Williams, 1956, p. 59–60) and with part of the Woodman formation and perhaps the lowermost part of the Ochre Mountain limestone of the Gold Hill mining district (Nolan, 1935, p. 29–31).

TOPOGRAPHIC EXPRESSION

Most exposures of the Humbug formation can be identified from a considerable distance by the long talus slopes of brown blocky quartzite fragments that tend to collect in the small hillside gulches. These talus slopes locally conceal the limestone beds of the formation, thus giving the casual observer the erroneous impression that the bulk of the formation is quartzite or sandstone.

The alternating beds of quartzite and limestone characteristically weather in steplike outcrops, and where flat lying they develop a ledge-and-slope topography.

ECONOMIC IMPORTANCE

No ore has been found in the Humbug formation in the East Tintic Mountains, and its rocks do not appear to be suitable for the production of nonmetallic commodities.

GREAT BLUE FORMATION

The Great Blue formation is here divided into four members, which are, in ascending order, the Topliff limestone member, the Paymaster member, the Chiulos member, and the Poker Knoll limestone member. The Topliff limestone member is named from the now-abandoned Topliff quarries near Topliff Hill, where it was formerly quarried by the American Smelting and Refining Co. and the United States Smelting and Refining Co. for metallurgical limestone. The Paymaster member is named from Paymaster Hill, in sec. 20, T. 9 S., R. 2 W. The Chiulos member, which includes shales and several thick beds of quartzite and limestone, is named from Chiulos Canyon, where a complete section of it is exposed. The Poker Knoll limestone member is named from Poker Knoll, near the west entrance of Tenmile Pass in the south-central part of the Fivemile Pass quadrangle (7½-minute series).

DISTRIBUTION

Within the limits of the East Tintic Mountains a complete, unfaulted section of the full thickness of the Great Blue formation occurs only on the northeast slopes of Topliff Hill and adjoining knolls, in secs. 3, 4, 9, and 10, T. 8 S., R. 3 W.; parts of this section, however, are concealed by colluvium. The Topliff limestone member is moderately well exposed in this locality, but is perhaps best exposed on the north side of Edwards Canyon in the S½SE¼ sec. 31, T. 8 S., R. 3 W., and the N½NE¼ sec. 6, T. 9 S., R. 3 W., and on both limbs of the Paymaster anticline in sec. 20, T. 9 S., R. 2 W. Partial sections of the Topliff member are also exposed on the lower easterly slopes of Bismark Peak south of the mouth of Holdaway Canyon in the NE¼ sec. 24, T. 9 S., R. 3 W., and the S½ sec. 19, T. 9 S., R. 2 W.; along the east edge of Gardison Ridge in the E½NE¼ sec. 12, T. 9 S., R. 3 W.; north of Herrington Basin in the north-central part of sec. 31, T. 9 S., R. 2 W., and at the crest of the small hill 650 feet west of the Homansville Pass road, which is cut by the line separating secs. 32 and 33, T. 9 S., R. 2 W.

The Paymaster member is very similar to the Topliff member in the distribution of its exposures. It is perhaps best exposed on the northeast flank of Topliff Hill in the NW¼ sec. 14, T. 8 S., R. 3 W.; on the west limb of the Paymaster anticline in the NW¼ sec. 20, T. 9 S., R. 2 W.; and along the west edge of the East Tintic Mountains between Edwards and Bell Canyons in the E½ sec. 31, T. 8 S., R. 3 W.

The shales of the Chiulos member are readily eroded and are not well exposed except in a very few localities. The member as a whole is perhaps best seen south and east of Chiulos Canyon, in the SE¼ sec. 30 and the NE¼ sec. 31, T. 9 S., R. 2 W. On the northeast slopes of Topliff Hill in sec. 14, T. 8 S., R. 3 W. the Chiulos member is somewhat disturbed by faulting and is partly covered with colluvium, but the outcrops in this area give a general impression of its character. Incomplete sections of the Chiulos member crop out north and south of Holdaway Canyon, chiefly in secs. 18 and 19, T. 9 S., R. 2 W., along the axis of a syncline in the W½ sec. 20, T. 9 S., R. 2 W., and in a number of localities along the west edge of the East Tintic Mountains north and south of Edwards Canyon.

The Poker Knoll limestone member is nowhere fully exposed in the East Tintic Mountains, but almost all of it crops out, or is concealed only by a thin cover of colluvium, on Poker Knoll and adjoining hills north of Topliff Hill in the S½ sec. 33, T. 7 S., R. 3 W., and in the NE¼ sec. 4 and the W½ sec. 3, T. 8. S., R. 3 W. Its lower part also crops out in the axial area of the Tintic syncline where it is exposed near the Tintic Davis shaft in the SW¼ sec. 29, SE¼ sec. 30, NE¼ sec. 31, and the NW¼ sec. 32, all of T. 9 S., R. 2 W.

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The Topliff limestone, Paymaster, and Chiulos members, and perhaps the lowermost part of the Poker Knoll limestone member crop out on the north side of County Canyon in the south-central part of the range, but none of these exposures except those of the Chiulos member were studied in detail during the present survey.

THICKNESS

The aggregate thickness of the four members of the Great Blue, each measured where it is best exposed, is about 2,500 feet. The apparent thickness of the Topliff member near the mouth of Edwards Canyon is 462 feet, but on Paymaster Hill it is only about 300 feet thick. As indicated above under the discussion of the Humbug formation, however, this wide difference in thickness over a distance of only 8 miles may be due to the appearance in the Paymaster Hill area of additional lenses of quartzite above the one selected as the top of the Humbug formation in the Edwards Canyon area.

The Paymaster member is somewhat thicker than the Topliff, being 623 feet thick near the mouth of Edwards Canyon. On Paymaster Hill it may be much thinner but is not sufficiently well exposed to be measured accurately.

The Chiulos member is relatively uniform in thickness throughout the northern part of the East Tintic Mountains. It is 899 feet thick in the vicinity of Chiulos Canyon and 850 feet thick on the southwest side of Tenmile Pass. No other exposures in the range are suitable for measuring the unit.

The only reasonably complete section of the Poker Hill limestone member is on the southeast side of Tenmile Pass. Although the top of the unit is not well exposed there, at least 600 feet and possibly as much as 700 feet of limestone is present between the Chiulos member and the Manning Canyon shale. Southeast of Chiulos Canyon, in the trough of the Davis syncline, the top has been eroded and less than 200 feet of the member remains.

LITHOLOGIC CHARACTER

TOPLIFF LIMESTONE MEMBER

The Topliff member is entirely limestone in well-defined beds from 6 or 8 inches to 6 feet or more in thickness. The base is not well defined but is placed at the top of the uppermost quartzite bed assigned to the Humbug formation. This quartzite bed is selected as the highest in a section where quartzite is common, but the lower part of the Topliff contains a few scattered thin lenses of Humbug-like quartzite. The limestones of the Topliff are of two types: The predominant one is fine grained and medium bedded, and weathers blue gray; the other is medium grained, medium gray, and more massive. The finer grained variety locally carries nodules of black and brown chert, but in general chert is not common in the Topliff. Fossils are abundant in some beds and in some places they are silicified. The top of this member is placed at the base of the brown-weathering dolomitic sandstone and red-weathering silty limestone or dolomite beds that mark the base of the Paymaster member.

The following measured section is typical of the Topliff limestone member throughout most of the East Tintic Mountains, but is somewhat thicker than the exposures east of Gardison Ridge.

Type stratigraphic section of Topliff limestone member of the Great Blue formation measured on the north side of Edwards Canyon, North Tintic district, on the S½SE¼ sec. 31, T. 8 S., R. 3 W., and the N½NE¼ sec. 6, T. 9 S., R. 3 W. (loc. 18a, pl. 3)

	Thickness (feet)	Distance above base (feet)
Paymaster member:		
Basal unit of olive-green shale with thin lenses of quartzite is overlain by interlayered gray shaly limestone and reddish-tan weathering dolomite; mostly covered		462
Contact conformable.		
Topliff limestone member:		
10. Limestone, dark blue-gray, weathers light blue-gray; fine-grained, in distinct beds 6 in.–3 ft thick	42	420
9. Limestone, similar to unit above but with nodules and thin bands of brown-weathering black chert	30	390
8. Limestone, dark-gray, weathering light blue-gray; fine-grained; well bedded in units 6 in.–2 ft thick	82	308
7. Limestone, nearly black, weathering dark-gray; medium-grained; occurs in distinct beds 1–3 ft thick. Silicified horn corals and brachiopods abundant	92	216
6. Limestone, argillaceous; weathering light-gray	2	214
5. Limestone, medium- to fine-grained, in alternating beds that weather medium- to light-gray and dark-gray	80	134
4. Dolomite, medium-grained; weathers tan with an accumulation of silt on surface. Layer of siltstone 2 ft thick at base	14	120
3. Limestone, dark-gray, weathering light-gray; fine-grained; well-bedded	19	101
2. Sandstone, pale olive-green; weathers brown; fine-grained	1	100
1. Limestone, dark-gray, weathering light blue-gray; fine-grained to very fine grained; contains a few scattered lenses of brown-weathering quartzite 4–6 in. thick	100	
Total Topliff limestone member	462	
Contact conformable.		
Humbug formation (uppermost bed only):		
Quartzite, olive-green on fresh fractures but reddish-brown; 5–35 ft thick.		

When viewed from a distance, the Topliff limestone member is characterized by ledgy outcrops of clean well-bedded blue limestones. It differs from the Humbug formation in its relative lack of quartzite, and from the Paymaster member in its lack of shale, quartzite, and cherty silty limestones.

PAYMASTER MEMBER

The Paymaster member is largely limestone, but it contains abundant interbedded brown-weathering olive-green shales and quartzites. The base is placed at the base of the first shale or quartzite above the thick section of well-bedded limestones of the Topliff. The top is put at the base of the massive unit of brownish- or gray-green-weathering black shale that forms the lowest part of the Chiulos member. Some of the limestones of the Paymaster member closely resemble those of the Topliff member, but most of them are streaked with tan- and brick-red-weathering silt and clay. Nodules, pods, and thin layers of chert are common; these range in color on weathered surfaces from black to brown, pink, and brick red. Some of the carbonate beds do not react with cold dilute hydrochloric acid and appear to be syngenetic dolomite. The shale beds interlayered with the limestones range in thickness from 6 inches to 5 feet or more. At the outcrop they are mostly olive green, tan, or greenish brown, but on fresh fractures they are black to dark green. The quartzite beds almost invariably overlie or underlie shale beds and only rarely occur between beds of limestone. They resemble the quartzite beds of the Chiulos member.

The following detailed section of the Paymaster member is a continuation of the measured section of the Topliff limestone member presented above and like it is somewhat thicker than the equivalent beds at the head of Cedar Valley. It also contains less shale and quartzite than the equivalent beds in the Tenmile Pass area.

Type stratigraphic section of Paymaster member of the Great Blue formation measured on the north side of Edwards Canyon, North Tintic district, in the N½NE¼ sec. 6, T. 9 S., R. 3 W. (loc. 18b, pl. 3)

	Thickness (feet)	Distance above base (feet)
Chiulos member:		
Basal unit is extremely thin-bedded, gray-green-weathering black shale; mostly covered		623
Contact conformable.		
Paymaster member:		
19. Limestone, gray, medium-grained; weathers tan, with accomulations of fine sand on surface	10	613
18. Covered zone; surface debris suggests interlayered thin-bedded argillaceous limestone and shale	75	538
17. Limestone, medium-gray, medium-grained; weathers tan to gray with mottles and seams of tan to brown silt and clay; beds 1 in.–2 ft thick	67	471
16. Limestone, medium-gray, medium-grained; scattered nodules of brown chert in middle	48	423
15. Limestone, medium blue-gray, fine-grained; in distinct beds 6 in.–2 ft thick. Closely resembles limestones of Topliff member	68	355
14. Limestone, fine- to medium-grained, medium-gray; contains many nodules of brown chert about 2 in. thick by 1 ft long	26	329
13. Limestone, fine-grained, medium blue-gray, well-bedded	22	307
12. Limestone, coarse-grained, coquinoid and oolitic, medium- to light-gray; beds 2 ft thick	10	297
11. Limestone, fine- to medium-grained, medium- to light-gray; streaked with brown-weathering silt and clay, in beds 2–3 ft thick. Large pods of brown chert abundant	39	258
10. Interlayered tan dolomitic limestone, olive-green shale, and brown-weathering quartzite	6	252
9. Limestone argillaceous, fine-grained, gray	6	246
8. Quartzite, fine-grained, pale olive-green, weathers brown. Platy brown shale at base and top	11	235
7. Limestone; dolomitic, silty; and limy dolomite, medium-grained, tan	40	195
6. Limestone, fine-grained, medium blue-gray; brown-weathering black cherts abundant at base but decrease in amount upward	102	93
5. Limestone, fine-grained, light-gray, well-bedded in layers 6 in.–3 ft thick; brown-weathering black chert abundant	17	76
4. Limestone, silty, fine-grained, medium-gray, tan-weathering	16	60
3. Quartzite, fine- to medium-grained, crudely banded, olive-green, brown, tan, and pink. Shaly- and platy-weathering at top and base	16	44
2. Covered zone; probably shaly quartzite	18	26
1. Shale, olive-green; includes thin lenses of quartzite, overlain by interlayered gray shaly limestone and reddish-tan-weathering dolomite; mostly covered	26	
Total thickness Paymaster member	623	
Contact conformable.		
Topliff limestone member (uppermost bed only):		
Limestone, fine-grained, blue-gray; well bedded, in layers 6 in.–3 ft thick.		

The differential weathering of the shale and limestone beds cause the outcrop of the Paymaster member to present a ribbed or corrugated surface. The shale beds are commonly concealed by soil and talus, but a careful search usually discloses fragments of shale, especially in ant mounds. The quartzite beds crop out prominently; the thicker lenses may locally be confused with the quartzites of the Chiulos member or the Humbug formation but are readily distinguished by their common association with shale and thin bedded limestone.

CHIULOS MEMBER

The Chiulos member is a distinctive, thick, and well-defined unit that may ultimately be considered worthy of formation rank. Its contact with the Paymaster is sharp and easily traced throughout the East Tintic Mountains. The lower half of the member is principally black shale that weathers gray green to greenish brown at the outcrop. Thin beds of medium-grained brown-weathering crossbedded quartzite occur locally in the middle and upper parts of the shale, and sporadic lenses of medium-grained blue-gray-weathering limestone in the lower part (fig. 48). Most of the shale is extremely fissile and breaks into paper-thin chips, but some beds are dense and more closely resemble fine siltstones.

The upper half of the Chiulos member is dominantly quartzite, but it also contains a large proportion of shale and rare lenses of argillaceous, sand-streaked limestone. The quartzite layers are massive and range from a few feet to as much as 350 feet in thickness. Most of them are fine to medium grained and conspicuously crossbedded, and most weather in bold outcrops. The color of the freshly broken rock is pale olive green, but brown, tan, and white rocks are not uncommon. The weathered surface of the quartzite is nearly everywhere coated with accumulations of iron oxide and ranges in color from greenish brown to dark reddish brown or purple. Most of the quartzite beds and some of the shale layers are cut by veinlets of milky-white quartz; these are so widespread as to be useful in identifying the member.

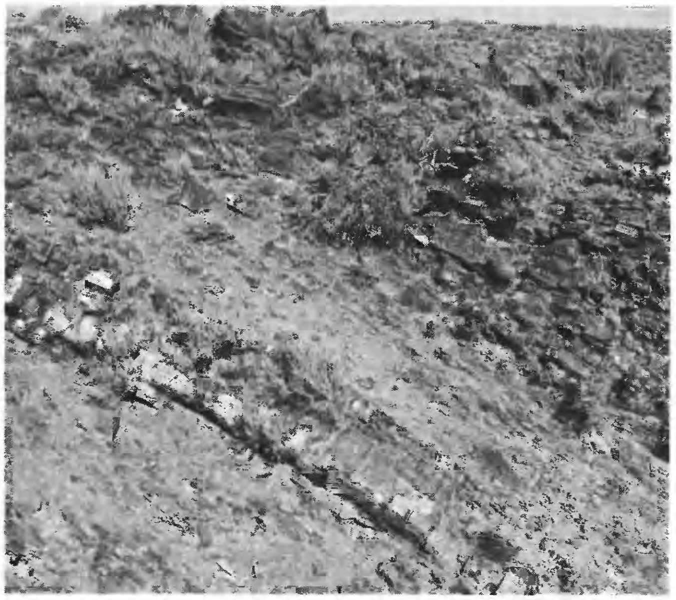

FIGURE 48.—Interbedded quartzite and shale in Chiulos member, Great Blue formation. Outcrop in northeastern part of Topliff Hill, Fivemile Pass quadrangle.

The following section of the Chiulos member at the type locality in Chiulos Canyon near the head of Cedar Valley contains somewhat less shale in the upper part than the equivalent section on the southwest side of Tenmile Pass, but it is representative of the Chiulos member throughout the East Tintic Mountains. Detailed studies indicate that the quartzite units are actually lenses within the shale, most of them showing a wide range in thickness within short distance along the strike.

Type stratigraphic section of Chiulos member of Great Blue formation measured on the west limb of the syncline southeast of Chiulos Canyon, near the Tintic Davis shaft, North Tintic district, in the S½SE¼ sec. 30 and the N½NE¼ sec. 31, T. 9 S., R. 2 W. (loc. 18c, pl. 3)

	Thickness (feet)	*Distance above base (feet)*
Poker Knoll limestone member:		
Limestone largely silty; gray to black, weathering blue-gray; fine- to medium-grained, cherty, platy		899
Contact conformable.		
Chiulos member:		
13. Quartzite, gray-green, fine-grained; weathers red brown	3	896
12. Covered zone, probably a platy-weathering shaly quartzite	19	877
11. Quartzite, brownish-gray, fine-grained; crossbedded; 1-in. shale partings separate beds 1 ft thick	16	861
10. Covered zone; surface material chiefly shale and quartzite	59	802
9. Quartzite, fine- to medium-grained, massive; color of fresh rock ranges from gray green to tan, pink, and white; weathered surface streaked with brown and red-purple bands; some layers crossbedded. One or two beds of black shale in lower part	330	472
8. Shale, greenish-black, fissile; weathers greenish brown. Contains scattered lenses of brown-weathering quartzite from a few inches to 2 ft thick	140	332
7. Shale, black, extremely fissile	53	279
6. Shale, micaceous greenish-brown; weathers tan	73	206
5. Shale, black on fresh fracture, dark-brown on weathered surface	50	156
4. Shale, dense, silty; weathers into brown platy fragments	39	117

	Thickness (feet)	Distance above base (feet)
Chiulos member—Continued		
3. Limestone, agrillaceous, medium-grained; weathers purplish gray	19	98
2. Covered zone; probably black shale	27	71
1. Shale, greenish-black on unweathered surface; weathers tan to brown. Interlayered with 2- to 4-in. beds of fine-grained quartizite and 9- to 12-in. beds of brown siltstone	71	
Total Chiulos member	899	
Contact conformable.		
Paymaster member (uppermost bed only):		
Limestone medium-grained gray, containing interlayed purple and brown shales.		

The shales of the Chiulos erode easily and commonly underlie strike valleys or form colluvium-floored depressions or reentrants into the mountain range. In contrast, the quartzite units are resistant to erosion and characteristically stand out in knobs and ridges. These bold-weathering brown and purple quartzite masses are useful in identifying the Great Blue formation.

POKER KNOLL LIMESTONE MEMBER

The Poker Knoll limestone member is the least well exposed of the four members of the Great Blue formation, owing in large part to its position between two thick units composed chiefly of shale that commonly are deeply eroded and covered with surface debris. However, the outcrops at the type locality on Poker Knoll and other hills near Tenmile Pass and in the trough of the Tintic syncline near the Tintic Davis shaft represent the greater part of the member; they include the lower contact and are closely similar to exposures of equivalent beds in the southern part of the Oquirrh Mountains. The lower contact of the Poker Knoll is abrupt and well defined, but isolated exposures indicate that the contact of the Poker Knoll and the Manning Canyon shale is transitional through a thickness of about 20 feet; the contact is arbitrarily placed where shales become dominant. The limestones that make up virtually all of the Poker Knoll are medium to fine grained and thin bedded, weathering into platy chips (fig. 49). They are dark gray to tan and weather light blue with a purplish cast. The platy chips are almost invariably coated on weathered surfaces with clay or light-brown silt. Much brown-weathering black chert is interlayered with the limestones in beds 1–12 inches thick, and also forms elongated nodules. In cross section the chert layers show prominent diffusion bands that appear to be primary features. The tendency of the chert to break up on weathering into small rectangular blocks and the prominent diffusion rings are useful identifying features of the member.

The weathered surfaces of some of the limestone beds react very slowly with cold dilute hydrochloric acid, suggesting that the beds are dolomitic; but freshly broken surfaces react more vigorously, so it is probable that the clay and silt which accumulates on the weathered surfaces prevents rapid attack of calcite by the acid.

Clay shales at a horizon near the middle of the Poker Knoll member are exposed in the clay pits and mines north of State Route 73 in the southernmost foothills of the Oquirrh Mountains. Scattered thin beds of black and brown shale are found locally in the Poker Knoll member but are not prominantly exposed in the East Tintic Mountains.

Owing to the uniform character of the rock and to the absence of complete well-exposed sections of the Poker Knoll limestone member, no detailed stratigraphic sections were measured. The Poker Knoll was mapped in considerable detail, however, in the Tenmile Pass area, (Disbrow, 1957) and its total thickness was established as not less than 600 feet but probably not more than 700 feet.

AGE AND CORRELATION

The Great Blue formation was first described by Spurr (1895, p. 374–376), and later redescribed by Gilluly (1932, p. 29–31, 32), from exposures in the Mercur and Dry Canyon areas of the Oquirrh Mountains, 25 miles north-northwest of the Tintic district.

FIGURE 49.—Thin-bedded argillaceous limestone in Poker Knoll limestone member, Great Blue formation. Outcrop in northeastern part of Topliff Hill, Fivemile Pass quadrangle.

North and south of Mercur Canyon and north of Dry Canyon this formation conformably overlies the Humbug formation and is conformably overlain by the Manning Canyon shale. Extensive collections of fossils were made from the Great Blue in these areas by Girty, Gilluly, Edwin Kirk, and their associates. Girty, according to Gilluly (1932, p. 30–31), reported that all these collections were of Late Mississippian age and similar to collections from lower and middle parts of the Brazer formation (as used by Girty) of northern Utah and southern Idaho.

Because the Late Mississippian age of the Great Blue formation had been so firmly established by this work in the Oquirrh Mountains a few miles to the north, relatively few collections of fossils were made from the formation in the East Tintic Mountains. These collections were relatively small and not especially representative of the Great Blue and, therefore, are not presented here.

The Great Blue formation appears to correlate with the greater part of the Ochre Mountain limestone of the Deep Creek Mountains (Nolan, 1935, p. 29–31). Like the Great Blue formation, the Ochre Mountain limestone includes a shale unit, the Herat shale member, composed of black shale with thin lenses of sandstone.

In the Cottonwood area of the central Wasatch Range, Calkins and Butler (1943, p. 27) assigned 300–400 feet of dark-gray to black fine-grained somewhat cherty limestone, with a layer of black shale and limestone near or somewhat above the middle, to the top of the Humbug. These beds overlie the interbedded limestones, sandstones and minor shale beds that are typical of the lower part of the Humbug in the central Wasatch area and characteristic of the Humbug in the Oquirrh and East Tintic Mountains, and thus may correspond to part of the Great Blue formation. As the result of more recent field work, Crittenden, Sharp, and Calkins (1952, p. 10–11) have revised this part of the stratigraphic column, placing the black shale zone and the overlying 200 feet of thin-bedded limestone in a unit designated by the field term Doughnut formation. This formation has yielded Late Mississippian fossils to within a few feet of the top and therefore may be equivalent to part of the Great Blue formation. The Humbug formation as redefined by Crittenden, Sharp, and Calkins (1952, p. 10) still includes 200–275 feet of blue limestone at the top that is probably equivalent to Topliff and possibly the Paymaster members of the Great Blue.

In the Wasatch Range east of Provo, approximately 30 miles south of the Cottonwood area, and across the Charleston thrust fault, Baker (1947) found the Great Blue formation to be about 2,800 feet thick, but he did not subdivide it into members.

The Long Trail shale and Chiulos members of the Great Blue formation do not appear to be equivalent. Gilluly (1932, p. 29) described the Long Trail shale member as being 85 feet or less in thickness; in the Ophir area it is underlain by 500 feet of limestone and overlain by 2,600 feet of limestone. The Chiulos member, on the other hand, is 800–1,000 feet thick, is underlain by 1,000–1,100 feet of limestone and shale, and is overlain by 600–800 feet of argillaceous and cherty limestone. Both are largely composed of carbonaceous shale, but the Chiulos contains a substantial amount of quartzite and thick beds of limestone. As mapped south of Mercur by Gilluly (1932, pl. 12), the Long Trail crops out on Eagle Hill and extends southward along the east side of Sunshine Canyon to a point less than a mile south of the old townsite of Sunshine, where it turns southwestward and within a short distance is cut off by a fault. Reconnaissance of the area southeast of these outcrops, in stratigraphically higher beds, disclosed a zone of dark shale and quartzite in the upper part of the Great Blue at about the horizon of the shale and quartzite of the Chiulos member. These beds are believed to pinch out northward, and in the Ophir and Dry Canyon areas are represented only by thin and relatively unimportant shales and quartzites in the upper part of the Great Blue. In the East Tintic Mountains, therefore, the Long Trail is probably represented by one or more of the black shale beds found in the lower part of the Paymaster member.

The Chiulos member apparently continues to increase in thickness southward and westward and may be as much as 2,000 feet thick on the West Tintic and Sheeprock Mountains, 15–20 miles west of Eureka.

ECONOMIC IMPORTANCE

Although the Great Blue formation is an important host rock for ore bodies in the southern part of the Oquirrh Mountains, no deposits of base- or precious-metal ore have been found in it in the East Tintic Mountains. However, it is an excellent source of clay shale and contains large available reserves of limestone. In past years the Topliff limestone member was extensively quarried in the Fivemile Pass quadrangle (Disbrow, 1957) for metallurgical limestone, which was used by the smelter industry of the Salt Lake Valley. The quarries were abandoned when other sources of calcium carbonate became available closer to the point of use. Large reserves of limestone are still available, however, at the quarry sites, and also at the outcrops of the Topliff member near the head of Cedar Valley and in the area of Bell and Edwards Canyons on the west side of the East Tintic Mountains.

The clay shales of the Poker Knoll limestone member, about 300 feet below the top of the Great Blue formation, are mined underground and in open pits at Fivemile Pass for the production of brick clays (Disbrow, 1957). The most desirable clay is in a single bed, about 25 feet thick, between two thick units of limestone which apparently stand well in underground openings. The shale ranges in color from tan or brown near the surface to sooty black in the deepest mine workings; where it is unweathered much of it contains disseminated pyrite. Near the surface it is stained with limonite and jarosite, and some layers are crowded with pseudomorphs of limonite after cubic pyrite crystals. The commercial finished-clay product is said to be a yellow-firing common brick that commands higher than average prices (Chester P. Cahoon, oral communication to Disbrow, 1955).

MISSISSIPPIAN AND PENNSYLVANIAN SYSTEMS

MANNING CANYON SHALE

The Manning Canyon shale, which was named by Gilluly (1932, p. 31) from Manning Canyon in the Oquirrh Mountains, underlies both Fivemile Pass and Tenmile Pass, at the northern and southern boundaries of the Thorpe Hills in the northernmost part of the East Tintic Mountains. In both these areas, the formation is largely concealed by valley fill or lacustrine deposits but crops out in scattered exposures, which can be identified and studied, for the most part in some detail. In the south-central part of the East Tintic Mountains, the Manning Canyon formation seems to be entirely cut out by the County Canyon fault, which brings the Chiulos member of the Great Blue formation against the lower part of the Oquirrh formation, and by the fault that is inferred to lie a short distance north of Jericho Pass.

DISTRIBUTION

The upper half of the Manning Canyon shale, including its contact with the Oquirrh formation, is well exposed on the south side of Fivemile Pass in secs. 10 and 11 of T. 7 S., R. 3 W., and also at the southeastern end of the Thorpe Hills, in the N½ sec. 14, T. 8 S., R. 3 W. The lowest beds in the Manning Canyon shale are exposed in the Fivemile Pass area at the Kenner prospect, near the common corner of secs. 2, 3, 10, and 11 and T. 7 S., R. 3 W. The whole formation is well known, however, from excellent exposures in the Oquirrh and Lake Mountains and the Wasatch Range.

THICKNESS

The thickness of the Manning Canyon shale, as determined in the course of detailed mapping in the Fivemile Pass and Tenmile Pass areas, is approximately 1,050 feet. This is fairly close to the 1,140 feet which Gilluly (1932, p. 32) believed to be the most reliable measure of its thickness in the Oquirrh Mountains. A. E. Disbrow (oral communication, 1955) found it to be 1,060 feet thick in the Lake Mountains 24 miles north-northeast of Eureka, and A. A. Baker (1947) reports a thickness of 1,645 feet on the divide between Rock Canyon and Pole Canyon in the Wasatch Range east of Provo, Utah.

LITHOLOGIC CHARACTER

The Manning Canyon shale consists chiefly of black to dark-brown shale interbedded with abundant limestone and medium- to coarse-grained, partly conglomeratic, quartzite or sandstone. Both the lower and upper contacts are gradational, which may account for moderate differences in measures of its thickness. A limestone, 30–80 feet thick, approximately in the middle of the formation, generally makes it possible to divide the Manning Canyon into three parts—an upper shale, a middle limestone, and a lower shale. The limestone member, which is also recognized in the Oquirrh and Lake Mountains and the Wasatch Range, is medium bedded to massive, fine grained, and medium blue gray, and crops out prominently in most areas of its exposure. It contains few if any fossils. The shale unit below the limestone consists mainly of fissile brown-weathering black shale, which contains abundant well-preserved brachiopods and other fossils. The upper part of it is only partly exposed in the East Tintic Mountains, but, as in the Oquirrh and Lake Mountains, it contains several beds of conglomeratic quartzite composed of moderately well rounded fragments of quartzite, limestone, and shale. The fragments, which are well sorted, range in size from large sand grains to pebbles approximately 1 inch in diameter, and all lie in a matrix of medium-grained quartzite (fig. 50).

The lower part of the lower shale unit is entirely concealed, but exposures in the Oquirrh Mountains show it to consist principally of carbonaceous shale that weathers tawny brown. It contains several beds of fine-grained limestone, some of which weather lavender-pink and should be locally useful as horizon markers.

Above the middle limestone, the Manning Canyon consists chiefly of shale but has a few interbedded layers of dark-gray to black fine-grained limestone, and several lenses of quartzite 1–5 feet thick. The shale units are extremely thin bedded and weather to paper-thin brown chips mixed with soil and fragments of limestone and quartzite. The shale and limestone beds intergrade through a zone of limy shale and argillaceous limestone a few inches to several feet thick. The thin limestones within 50 feet above the base of

FIGURE 50.—Conglomerate in Manning Canyon shale. Specimen collected in Lake Mountains, 25 miles northeast of the East Tintic Mountains.

the upper unit are petroliferous; they are greenish black on the fresh surface but weather rusty brown and, where they are tilted, they crop out in low parallel ridges. The quartzite beds of the upper member are chiefly found at the top of the formation, where they are interbedded with black shale and with limestones like those of the Oquirrh formation. They are medium to fine grained and thin to medium bedded; most of them are olive green to brown on the freshly broken surface but weather dark red brown. The contact of the Oquirrh and Manning Canyon formations is placed at the top of the uppermost quartzite bed, and as the lower 750 feet of the Oquirrh is limestone that is virtually free from quartzite, it makes an excellent boundary marker.

In limited exposures the Manning Canyon shale may be confused with the Chiulos member of the Great Blue formation. However, the Manning Canyon can usually be distinguished by the larger amount of interbedded limestone it contains, and by the presence of conglomerates and conglomeratic quartzites, which are readily distinguished from the fine- to medium-grained quartzites in the Chiulos.

AGE AND CORRELATION

The age of the Manning Canyon shale was determined to be Late Mississippian and Pennsylvanian by Girty, from five collections of fossils made by Girty, Gilluly, and New in the Oquirrh Mountains (Gilluly, 1932, p. 32–34). Although the Manning Canyon is also abundantly fossiliferous in the East Tintic Mountains, it did not seem necessary to make additional collections of fossils to confirm this age designation, inasmuch as the unit is nearly identical in the two ranges. The actual position of the boundary between the Upper Mississippian and Lower Pennsylvanian is not accurately known; it is arbitrarily placed near the base of the middle limestone member on plates 4 and 5. In the Oquirrh Mountains (Gilluly, 1932, p. 32–34), Mississippian fossils occur 78 feet below the base of the middle limestone member (Gilluly's unit No. 3), and Pennsylvanian fossils occur about 325 feet above the top of the same unit. Collections were not made from the intervening rocks, which were searched but found to be virtually unfossiliferous.

The Manning Canyon is also recognized in the Wasatch Range (Baker, 1947), in the Deep Creek Mountains, and in other intervening areas in west-central Utah where Mississippian and Pennsylvanian rocks are exposed. The fossils reported from the Manning Canyon of the Deep Creek Mountains (Nolan, 1935, p. 31–33) were regarded by Girty as Pennsylvanian or suggestive of Pennsylvanian age. However, it is not indicated that any collections were made from the lower part of the formation.

ECONOMIC IMPORTANCE

The shale beds of the lower part of the Manning Canyon shale are quarried for brick clays in the Lake Mountains but have not been utilized in the East Tintic Mountains. No ore bodies are known to occur in the Manning Canyon shale.

PENNSYLVANIAN AND PERMIAN SYSTEMS

OQUIRRH FORMATION

The Oquirrh formation is composed largely of limestone and dolomite in the East Tintic Mountains, but in the middle portion it contains many of the beds and lenses of brown-weathering quartzitic sandstone that characterize it in the Oquirrh Mountains and the Wasatch Range. Fossils are abundant in the limestone beds, but the formation as a whole is identified chiefly by its stratigraphic relations and tremendous thickness. Large intervals of the Oquirrh display remarkably uniform lithologic character, but many widespread and readily identified marker beds can be recognized and are very useful in mapping structural details within the formation.

DISTRIBUTION AND THICKNESS

The Oquirrh is prominently exposed in several widely separated areas near the northern and southern extremities of the range. The northern exposures make up the greater part of the Thorpe Hills and include the lower 4,000 feet of the formation (fig. 51).

FIGURE 51.—Outcrop of Oquirrh formation at southern terminus of Thorpe Hills, Fivemile Pass quadrangle. Top of prominent cliff at right center of photograph marks upper boundary of basal limestone member.

The principal exposure in the East Tintic Mountains lies at their southern end, west of Furner Valley. It begins on the south side of County Canyon and extends southward about 3¾ miles to the north side of Sandstone Gulch. The beds here are nearly vertical and a great thickness of the Oquirrh is exposed, including its contact with the overlying Permian Diamond Creek(?) sandstone. The lower part of the formation in this area is in fault contact with the Chiulos member of the Great Blue formation, and the upper middle part of the formation is broken by at least one strike fault of unknown displacement. Study of the outcrop pattern of the formation on aerial photographs, and a reconnaissance measurement in the field, led the writers to estimate the total thickness of beds exposed to be about 12,400 feet. The fault at the base cuts out 600–800 feet or more of the lower part of the formation. The displacement along a strike fault recognized in the middle of this exposure of the formation was not definitely determined, but from the evidence at hand the stratigraphic displacement along it is believed to be no greater than that along similar northeast-trending faults in the East Tintic Mountains, whose displacements, with but two exceptions, are less than 4,000 feet. Because of the lack of time required for a detailed study, it was impossible to determine whether beds were repeated or cut out along the fault.

A complete unfaulted section of the Oquirrh formation exposed in Provo Canyon in the Wasatch Range, about 40 miles northeast of the East Tintic Mountains, is reported to be 26,000 feet thick (Baker, 1947). Gilluly (1932, p. 34–38) describes 16,000 to 18,000 feet of beds at the type locality in the Oquirrh Mountains, but the top is eroded. An unfaulted exposure of the full thickness of the formation is not known to crop out within a reasonable distance south and west of the East Tintic Mountains, and the thickness of beds exposed between County Canyon and Sandstone Gulch must therefore be considered as only a rough approximation of the true thickness of the Oquirrh in this area.

LITHOLOGIC CHARACTER

The Oquirrh formation of the East Tintic Mountains may be divided broadly into three units: a basal unit about 1,550 feet thick, composed chiefly of limestone; a middle unit about 6,700 feet thick, which consists of alternating beds of limestone and sandstone with some siltstone and shale; and an upper unit about 5,000 feet thick, which consists dominantly of limestone and dolomite but which contains some prominent sandstone beds. The dolomite, which chiefly makes up the upper half or more of the upper unit, is not recognized in other exposures of the Oquirrh formation and is believed to be of hydrothermal origin.

The basal limestone unit is fully exposed in the Thorpe Hills. It is equivalent to the basal limestone member of the Oquirrh in the Wasatch Range east of Provo, described by Baker (1947) as being 1,245 feet thick, and to a similar unit in the Oquirrh Mountains, described by Gilluly (1932, p. 34). In the Thorpe Hills it is composed of two types of limestone, one of which is thin to medium bedded, fine grained, and argillaceous, and the other medium to massive bedded, coarse grained, and locally coquinoid. Fossils are rare in the fine-grained limestone but abundant in the coarse-grained variety and are commonly silicified. In the Thorpe Hills, two beds of medium-grained crossbedded quartzitic sandstone 3–5 feet thick divide the lower limestone unit into nearly equal parts. These quartzite beds weather tan to light brown and are separated by a bed of white coquinoid limestone about 20 feet thick. The cherty limestones above them (fig. 52) crop out in thick ledges. The cherts form nodules that are black to dark brown; some are as much as 1 foot long but most of them are 6–8 inches long and 2–3 inches thick. Some thin quartzite beds are interlayered with the limestones near the top of the basal unit, but they are of minor importance compared with the abundant quartzite in the overlying middle unit.

The base of the Oquirrh in the Thorpe Hills is placed at the top of the uppermost persistent shale or quartzite bed of the Manning Canyon. In general this contact is reasonably well defined, since quartzite and shale beds are sparse in the lowermost Oquirrh but are characteristic of the upper part of the Manning Canyon. The top of the basal limestone unit is marked by a bold ledge of limestone 30–35 feet thick that crops out prominently in the Thorpe Hills, below a ledge-and-slope surface marking the middle unit.

In the southern part of the East Tintic Mountains the 730 feet or so of the lower limestone unit of the

FIGURE 52.—Quartzite-chert pods in crossbedded sandy limestone and limy sandstone, middle of basal limestone unit of Oquirrh formation. Outcrop in west-central part of Thorpe Hills, Fivemile Pass quadrangle.

Oquirrh formation that crops out on the south of the County Canyon fault, consists chiefly of medium- to dark-gray, medium- to fine-grained, medium-bedded limestone. Many beds contain scattered nodules and thin stringers of black and brown chert and silicified fossils that project in relief on the weathered surfaces. Other layers that are strongly crossbedded consist almost wholly of fragments of corals, brachiopods, and other fossils. The basal limestone member becomes progressively more sandy upward, and the top is placed at the base of a bed of medium-grained sandstone, about 65 feet thick that weathers light brown. In gross composition, the part of the lower limestone member occurring south of the County Canyon fault is 90–95 percent limestone and 5–10 percent sandstone.

The middle unit of the Oquirrh is typically an alternating sequence of quartzitic sandstone and argillaceous and arenaceous limestone, but in places it includes thin and thick layers of siltstone, shale, and dolomite, and massive beds of sand-free medium to light blue-gray coquinoid limestone. The average thickness of the individual beds is about 10 feet, but both the limestone and sandstone beds range from 2 to 100 feet or more in thickness. The arenaceous limestones, which make up about 45 percent or more of the middle unit and are the predominant rock in the lower one-third of the middle unit, are thin to medium bedded and medium grained, and weather brownish gray with coatings of sand and silt on the surface. The coquinoid limestones, which are greatly subordinate to the arenaceous limestones, contain silicified brachiopods, bryozoans, and corals. Fusilinids, which are common in the limestone beds of the Oquirrh formation of the Wasatch Range, are not especially abundant in the equivalent but much thicker and more extensive limestones of the East Tintic Mountains. However, the coral *Chaetetes* was found in abundance by A. E. Disbrow (1956 written communication), in a single medium- to light-gray-weathering limestone bed, 3–8 feet thick, which crops out in the east-central part of the Thorpe Hills, about 2,300 feet above the base of the Oquirrh. A similar bed, which occurs in the central Wasatch Range about 3,550 feet above the base of the Oquirrh, is reported by Baker (1947) to be a useful horizon marker over a considerable area. In the southernmost part of the East Tintic Mountains, a short distance south of Jericho Pass, *Chaetetes* was also collected; but, owing to faulting and limited exposures, the precise stratigraphic distance above the base of the Oquirrh of this horizon of fossils is not known.

The quartzitic sandstone beds of the middle unit of the Oquirrh closely resemble those of the Humbug formation. They are mostly fine grained, but some are medium grained; they are gray to light brown on fresh fractures, and medium to dark brown or reddish brown on weathered surfaces. Many of them are crossbedded and show other evidence of shallow-water origin, but almost none show ripple marks, mud cracks, or raindrop impressions. Although they resemble true quartzites on the weathered surface, they are chiefly cemented by calcite, for they react vigorously with cold dilute hydrochloric acid on freshly broken surfaces.

Siltstone and shale that weather maroon and olive brown make up somewhat less than 5 percent of the middle unit, but locally they appear to be much more abundant. The thickest siltstone and shale beds do not exceed 25 feet and average 10 feet or less. Many shale beds, 1 foot thick or less, undoubtedly occur throughout the middle unit, but most of them are concealed at the outcrop. In general, the siltstones and shales are fissile and somewhat limy. The carbonate beds associated with the siltstones and shales are mostly fine- to medium-grained dolomites that contain a large amount of admixed silt and clay, and weather tan or brown.

In its exposures north of Sandstone Gulch, the upper unit of the Oquirrh formation is 85–90 percent carbonate rock, which is dominantly hydrothermal dolomite in the upper 2,800–2,900 feet. This dolomite, which does not occur in the Oquirrh formation in the Oquirrh Mountains and Wasatch Range and in the section exposed north of Dog Valley Pass on Long Ridge only 9–10 miles to the east, is similar to other hydrothermal dolomites in the East Tintic Mountains. It is medium gray to brownish gray, medium grained and prominently bedded. Many beds contain much brown, black, and gray chert in stringers and nodules from less than an inch to several feet long. Most of the dolomite is streaked with sand and is fossiliferous, but the fossils are poorly preserved. The limestone beds in the lower part of the upper unit are light, medium, and dark blue gray; they are medium grained and contain many well-preserved fossils. The weathered surfaces of some of the limestone beds are encrusted with silt and sand grains, which occur in large enough amounts in a few of the beds to make them limy sandstones. These beds grade into true sandstones that are brownish to greenish gray on fresh fractures and weather light yellowish brown to dark reddish brown. Most of the sandstone beds are very fine grained, but some are medium grained and others approach siltstone in grain size. Unlike many of the arenaceous beds in the middle unit, they are not commonly quartzitic. The base of the upper unit is somewhat indefinite but is placed where the abundant sandstone beds of the middle member cease to be common and limestone becomes predominant. The top of the unit is placed at the base of the basal sandstone conglomerate of the overlying Permian Diamond Creek(?) sandstone. The uppermost 100 feet or so of beds of the Oquirrh formation on the north side of Sandstone Gulch are stained with iron oxide and appear to have been deeply weathered before the deposition of the Diamond Creek(?) sandstone.

AGE AND CORRELATION

Baker (1947) has made many collections of fusulinids from the Oquirrh formation in the Wasatch Range. These have been determined by L. G. Henbest as ranging in age from early Middle Pennsylvanian to early Permian (Atoka through Des Moines, Missouri, Virgil and Wolfcamp), with forms of Wolfcamp age distributed through the upper 8,000 feet of the formation as exposed south of the central part of Provo Canyon. The collections reported by Gilluly (1932, p. 36–37), which were taken from the lower and middle parts of the incomplete section exposed in the Oquirrh Mountains, are all of Middle Pennsylvanian age (Atoka and Des Moines).

Only one collection of fossils was made from the Oquirrh formation in the parts of the East Tintic Mountains that were mapped during the present survey. This collection came from the middle sandy unit a short distance stratigraphically above the lower limestone unit. Corals and bryozoans were identified by Helen Duncan, brachiopods by Mackenzie Gordon, Jr.

Collection No. USGS 12390. From low hill 1,000 feet south of Tenmile Hill in the SW¼ sec. 19, T. 8 S., R. 2 W., Allens Ranch quadrangle.

Caninia sp. indet.
Auloporoid coral aff. *Pseudoromingeria* sp. indet.
Cheilotrypa? sp.
Leioclema? sp.
Stenoporoid bryozoan fragments
Rhomboporoid bryozoans
Linoproductus prattenianus (Norwood and Pratten)
Spirifer opimus Hall
Phricodothyris perplexa (McChesney)

Concerning the corals and bryozoa Duncan writes in part:

> . . . the few corals are Carboniferous types; by themselves neither *Caninia* nor the auloporoid have any special stratigraphic significance. The bryozoa, particularly the rhomboporoid types, are known to be especially abundant in rocks of Pennsylvanian age in the west . . . . the other bryozoans are not particularly diagnostic.

Concerning the brachiopods Gordon writes:

> The brachiopods represent a fauna that Girty called Pottsville, which was found in the lower part of the Oquirrh formation in the Oquirrh Range. It can also occur in the Manning Canyon shale, but the lithologic character almost certainly restricts the material that was submitted to the Oquirrh.

Rocks of Pennsylvania age are well known in areas surrounding north-central Utah; probably all of them are partial equivalents of the lower or Pennsylvanian part of the Oquirrh formation. The Morgan and Weber formations (Baker, Huddle, and Kinney, 1949, p. 1179–1183) appear to be facies equivalents of part of the lower part of the Oquirrh formation but are separated from it by a thrust fault of large displacement (Baker, 1947). The Morgan formation, which underlies the Weber, consists chiefly of limestone and may be directly equivalent to the lower limestone unit of the Oquirrh. Farther north, in northeastern Utah and southeastern Idaho, the Pennsylvanian and Permian(?) Wells formation, as described by Richardson (1941, p. 24–25) and Mansfield (1927, p. 71–73), consists of interbedded sandstone, quartzite, and limestone 2,400 feet thick and may be a facies equivalent of the Oquirrh.

ECONOMIC IMPORTANCE

No ores or nonmetallic mineral products have been produced from the Oquirrh in the East Tintic Mountains.

DISCONFORMITY AT THE TOP OF THE OQUIRRH FORMATION

The iron-stained vuggy dolomite at the top of the Oquirrh formation exposed on the north side of Sandstone Gulch preserves a faint conglomeratic texture, and appears to have been a deeply weathered zone that was thoroughly recrystallized by late hydrothermal solutions. This zone is overlain by the Diamond Creek(?) sandstone, but in the southern Wasatch

Range east of Provo, the Oquirrh and Diamond Creek formations are separated by the Kirkman limestone, which is 1,600 feet thick at its type locality in Kirkman Hollow (Baker, 1947). The Kirkman is described by Baker and Williams (1940, p. 625–627) as being a gray to black, fetid limestone, in part finely laminated, that commonly is a recemented breccia of small angular fragments of the laminated limestone. The basal unit at many localities is a breccia of angular fragments of quartzite in a sandy calcareous matrix. Baker and Williams (1940, p. 626) further describe the Kirkman as having been deposited upon a surface of considerable relief, since the thickness of the formation decreases to only 75 feet in the vicinity of Spanish Fork, 10 miles from Kirkman Hollow, and the unit is absent in some areas nearby.

No beds closely resembling the Kirkman limestone have been recognized above the Oquirrh formation in the East Tintic Mountains, and it is believed that this area was uplifted and partly eroded before the Diamond Creek(?) sandstone was deposited. The time interval represented in this period of erosion is presumably short, since rocks of Permian age both underlie and overlie the disconformity.

PERMIAN SYSTEM

DIAMOND CREEK(?) SANDSTONE

The Diamond Creek(?) sandstone of the East Tintic Mountains crops out only in the southern part of the range. It is a thick sequence of buff and yellowish-gray, fine- to medium-grained crossbedded sandstone, which is provisionally correlated with the Diamond Creek sandstone of the Wasatch Range (Baker, 1947) and the Coconino sandstone of the San Rafael Swell in southeast-central Utah (Gilluly, 1929, p. 80–81, and Baker, 1946, p. 48–50).

The Diamond Creek(?) is exposed in Sandstone Gulch and on the opposite side of the mountain along the southwest side of Furner Valley, but is partly concealed by talus of the Fernow quartzlatite, which unconformably covers the sedimentary rocks in this area. Sandstone Gulch is almost wholly carved from the near vertical outcrop of the soft sandstone, which is bounded stratigraphically by much more resistant formations composed principally of dolomite.

The thickness of the beds assigned to the Diamond Creek(?) sandstone in the East Tintic Mountains is 685 feet. Muessig (1951 [8], p. 190) measured 355 feet of white to pinkish, medium- to coarse-grained, massive calcareous sandstone at Dog Valley Pass on Long Ridge, about 11 miles east of the Sandstone Gulch exposures, and assigned it to the Diamond Creek sandstone. Baker, Huddle, and Kinney (1949, p. 1188) report the formation to be from 835 to 1,000 feet thick between Hobble Creek and Spanish Fork in the south-central Wasatch Range, near the type locality. In this area it is gray or buff to red, fine to coarse grained, and crossbedded; the sandstone is largely calcareous and friable, but locally it is cemented by silica and is quartzitic.

[8] See footnote p. 16.

LITHOLOGIC CHARACTER

The lower 200 feet of the Diamond Creek(?) sandstone of the East Tintic Mountains consists of interbedded medium blue-gray limestone, gray dolomite, and red to purplish-red, partly conglomeratic mudstone or fine-grained sandstone, in units 3–50 feet thick. The basal contact is sharp and is marked by a conglomerate composed of angular dolomite fragments in a mudstone matrix. Unlike the buff- or yellow-weathering sandstone of the middle and upper parts of the formation, the lower sandstones are prevailingly orange red to purplish red. Many of them are conglomeratic, and some are streaked and zoned by layers of mudstone or very fine sandstone. The dolomites are gray, medium grained, dense, and apparently devoid of fossils. They were probably formed by hydrothermal dolomitization of dense grayish-white to pink partly crystalline limestones, only one or two beds of which have escaped alteration in this area.

The main mass of the Diamond Creek(?) formation consists of massive friable sandstone that is strongly crossbedded (fig. 53). The crossbedding, which is a dominant feature of the rock, is chiefly of the tangential type, although the deposit appears to have accumulated originally as windblown sand. The sand

FIGURE 53.—Yellow-weathering, crossbedded, friable sandstone in upper part of Diamond Creek(?) sandstone. Outcrop in Sandstone Gulch, southwestern part of East Tintic Mountains.

grains are frosted subangular to subrounded fragments of quartz, with few if any accessory minerals. The cementing agent is soft calcite stained faintly red and yellow by iron oxides. In the upper 100 feet of the formation, quartz is the bonding agent of some beds that should properly be termed quartzite. At the top of the Diamond Creek (?) the quartzite beds are interlayered with thick and thin beds of banded white chert and cherty gray dolomite. The upper contact is placed at the top of the uppermost buff-colored sandstone or quartzite bed of considerable thickness.

The following section, measured in Sandstone Gulch, is believed to be typical of the formation in the East Tintic Mountains.

Stratigraphic section of Diamond Creek (?) sandstone measured in Sandstone Gulch, in the southern East Tintic Mountains, southern part of T. 13 S., R. 2 W. (loc. 19, pl. 3)

	Thickness (feet)	*Distance above base (feet)*
Park City and Phosphoria formations:		
Basal beds are medium-grained gray hydrothermal dolomite, interlayered with beds of buff sandstone and white chert 6 in.–4 ft thick. Base taken at top of uppermost thick sandstone		685
Contact conformable.		
Diamond Creek (?) sandstone:		
14. Sandstone, calcareous; dominantly pale yellow or buff with brick-red zones near base, fine to medium grained, friable and crossbedded throughout; some beds of edgewise conglomerate at base; toward top the sandstone is locally cemented with silica and resembles quartzite; makes poor outcrop	470	215
13. Dolomite (hydrothermal?), gray, fine- to medium-grained, well-bedded	19	196
12. Sandstone, brick-red, fine-grained	21	175
11. Dolomite (hydrothermal?), gray, medium-grained, friable	4	171
10. Sandstone, brick-red, fine-graned, friable	14	157
9. Dolomite and partly dolomitized limestone, light brownish-gray, medium-grained; in beds 4–12 in. thick; laminated and sand streaked	5	152
8. Sandstone, white to pink, fine-grained; weak calcareous cement	23	129
7. Limestone, pink, translucent, dense; in part visibly crystalline	3	126
6. Sandstone, pale purplish-red, fine-grained, soft; calcareous cement	7	119
5. Limestone, sandy, gray to pinkish-gray, dense, crystalline	4	115
4. Sandstone, variegated, white, pink, and purplish-red, fine-grained, friable; calcareous cement	28	87
3. Dolomite (hydrothermal), light-gray, medium- to fine-grained; streaked and colored by intermixed pink to red mudstone	30	57

	Thickness (feet)	*Distance above base (feet)*
Diamond Creek (?) sandstone—Continued		
2. Sandstone, brick-red to purplish-red, fine-grained, conglomeratic; interbedded with purplish-red mudstone	50	7
1. Dolomite breccia, cemented with red mudstone and fine-grained sandstone. Angular fragments average 1 in. in length	7	
Total Diamond Creek (?) sandstone	685	
Unconformity.		
Oquirrh formation:		
Uppermost 10–125 ft recrystallized dolomite, which apparently was weathered and iron stained before the deposition of the overlying standstone.		

AGE AND CORRELATION

No fossils were found in the Diamond Creek (?) sandstone in the East Tintic Mountains, but because of its characteristic lithology and its relations to the Oquirrh and Park City formations it is provisionally correlated with the type Diamond Creek sandstone of Permian age, in the Wasatch Range. The Permian age of the Diamond Creek in the Wasatch Range is well established by its position above the Permian Kirkman limestone and immediately below the Park City limestone, which contains abundant well-preserved fossils of Permian age.

On the basis of its stratigraphic position, Baker (1947) provisionally correlates the Diamond Creek with the lithologically similar Coconino sandstone of the San Rafael Swell, which is also 685 feet thick.

ECONOMIC IMPORTANCE

No ore bodies occur in the Diamond Creek (?) sandstone, and no part of it is utilized for the production of nonmetallic mineral commodities.

PARK CITY AND PHOSPHORIA FORMATIONS

Conformably overlying the Diamond Creek (?) sandstone is an incomplete sequence of hydrothermally altered beds, consisting of two units of cherty dolomite separated by a unit which is composed largely of thin-bedded siliceous and phosphatic mudstone, but which also contains several beds of cherty argillaceous dolomite and one or more beds of friable brown-weathering sandstone. No diagnostic fossils were collected from any of these units, but their stratigraphic position above the Diamond Creek (?) sandstone, and also the presence of the zone of siliceous and phosphatic mudstone between thick units of prominently bedded cherty carbonate rocks, are typical of the Park City formation as described by Baker, Huddle, and Kinney (1949, p. 1188–1189) in the southern Wasatch Range. According to Cheney (McKelvey and others, 1946, p. 2840), the cherty carbonate-rock units in this part of Utah are properly termed the Park City formation, but the intervening phosphatic mudstone unit is probably continuous with the phosphatic shale member of the Phosphoria formation and should be called the Meade Peak phosphatic shale tongue of the Phosphoria (fig. 54).

The upper part of the upper cherty dolomite unit of the Park City formation and the next overlying formation are not exposed in the East Tintic Mountains, the youngest exposed beds of the Park City being in fault contact with the Bluebell dolomite at a point about 1 mile north of Jericho Pass.

DISTRIBUTION, THICKNESS, AND LITHOLOGIC CHARACTER

In the East Tintic Mountains the Park City and Phosphoria formations are exposed only in the area between Sandstone Gulch and a point about 1 mile north of Jericho Pass in the southwestern part of the range. The beds here dip steeply to the south, and the Park City and Phosphoria formations crop out in a relatively narrow, east-trending band that extends across the southwestern spur of the range from Tintic Valley to Furner Valley. The total thickness of the part of the combined formations exposed in the East Tintic Mountains is about 1,620 feet. The lower cherty dolomite unit of the Park City is about 750 feet thick, the Meade Peak phosphatic shale tongue of the Phosphoria is about 330 feet thick, and the incomplete section of the upper carbonate unit of the Park City is about 540 feet thick. These thicknesses are not greatly different from the thicknesses of the three members of the Park City formation exposed in the Right Fork of Hobble Creek in the southern Wasatch Range (Baker, Huddle, and Kinney, 1949, p. 1188–1189), where the lower member is 883 feet thick, the middle phosphatic member—which is now considered a tongue of the Phosphoria formation—is about 200 feet thick, and the upper member is 830 feet thick. In the Hobble Creek area the upper member is overlain unconformably by the Price River formation of Late Cretaceous age, but in areas nearby it is overlain, also unconformably, by the Woodside formation of Triassic age.

The lower member of the Park City formation is chiefly medium- to thin-bedded, medium- to light-gray dolomite which commonly has a bluish or brownish cast. It contains abundant nodular and layered chert and many fragments of fossils that are not well enough preserved for identification. The base of the member grades into the Diamond Creek(?) sandstone through 50–100 feet of interlayered sandstone, dolomite, and white chert beds. The basal contact is placed, however, at the top of the highest sandstone bed that is more than 2½ feet thick. Siliceous mudstone, which is nearly identical to that of the Meade Peak phosphatic shale tongue, is interbedded with cherty dolomite through a zone about 250 feet thick just above the middle of the member. Some beds of low-grade phosphorite occur in this shaly zone, which suggests a relationship with the Meade Peak, but inasmuch as the beds of phosphorite are relatively thin and few in number, this zone is not here included with the Meade Peak. Future work, however, may indicate the desirability of designating all of the shaly and phosphatic beds in the Park City formation as tongues of the Meade Peak member of the Phosphoria.

The dolomites of the lower member contain abundant chert below the siliceous mudstone zone and relatively little chert above it, but otherwise are similar to each other in color, texture, and thickness of beds. Fossils were probably abundant in these rocks prior to dolomitization, but for the most part they now occur only as vague outlines or indeterminate fragments. The few fossils that are recognizable have been preserved through silicification; these are believed to be chiefly rynchonelloid and compositoid brachiopods, but most of them are not well enough preserved for even generic identification. The sandstones of the lower member of the Park City are generally confined to the shaly zone and the dolomites below it and they average less than 12 inches in thickness. These sandstones are darker brown and coarser grained than the sandstones of the Diamond Creek(?) but closely resemble the quartzites of the Oquirrh formation.

The Meade Peak phosphatic shale tongue of the Phosphoria formation is a nonresistant unit which forms a topographic low between two ridges of steeply dipping dolomite. The soil and rock debris at the surface above the near vertical beds of the Meade Peak is characterized by an accumulation of chips and small fragments of iron-stained, siliceous mudstone, buff to brown sandstone, medium-gray dolomite and coal-black chert. Scattered fragments of black phosphatic shale and phosphorite occur here and there in the float, but, owing to the thickness of the surface debris, a quantitative estimate of the grade and thickness of the phosphorite beds in the bedrock was not made. The siliceous mudstone beds are a few inches to several feet thick. They are brownish black on fresh fracture but weather light brown, tan, or buff. Thin layers and nodules of black chert are abundant; commonly the nodules have indefinite borders and grade imperceptably into siliceous mudstone. The phosphatic beds are brownish black on freshly broken surfaces but weather reddish gray to grayish brown; some of them are oolitic. A bed of brown-weathering, medium-grained sandstone,

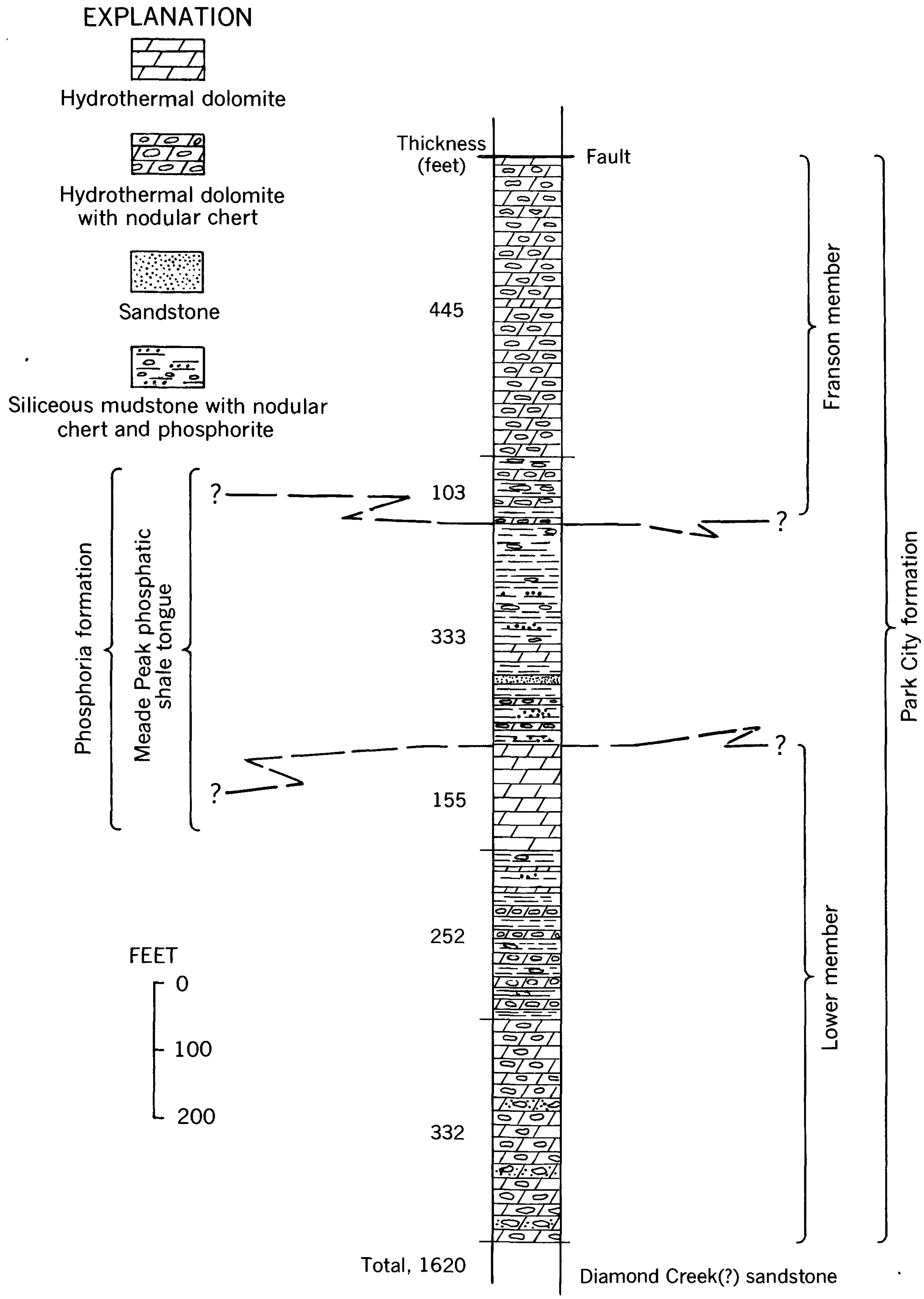

FIGURE 54.—Generalized section of hydrothermally dolomitized Permian Park City and Phosphoria formations in the southern East Tintic Mountains, Utah.

about 15 feet thick, and a prominent bed of light-gray, medium-grained, fossiliferous dolomite, about 25 feet thick, are interbedded with the siliceous mudstone in the lower half of the tongue. Thin beds of cherty dolomite, most not more than 6 inches thick, are also common in the lower half or more of this member.

The upper member of the Park City formation has been given the name Franson member by Cheney (McKelvey and others, 1956, p. 2842–2843). It is a prominently bedded, medium-grained, medium-gray to blue-gray cherty dolomite. No sandstone was found in the Franson member in the East Tintic Mountains, but the equivalent unit in the Wasatch Range, according to Cheney (McKelvey and others, 1956, p. 2843), contains a middle unit of light-gray and grayish-brown carbonatic sandstone about 85 feet thick. Many of the dolomite beds of the Franson member in the East Tintic Mountains contain fragments of fossils, but most of these have been dolomitized and are not identifiable, although some are recognizable as compositoid brachiopods and solitary corals.

The following section of the Park City and Phosphoria formations was measured across the exposures in the southwestern part of the East Tintic Mountains, between Sandstone Gulch and Jericho Pass. The section is continuous with that of the Diamond Creek(?) sandstone. Much if not all of the dolomite is considered to be of hydrothermal origin.

Incomplete stratigraphic section of Park City and Phosphoria formations measured southward from south side of Sandstone Gulch, southern East Tintic Mountains, in the southwesternmost part of T. 13 S., R. 2 W. (loc. 20, pl. 3)

	Thickness (feet)	Distance above base (feet)
Fault, which terminates the upper part of the Park City formation and brings it against the middle part of the Bluebell dolomite		1,620
Park City and Phosphoria formations:		
Franson member of Park City formation:		
11. Dolomite, medium- to light-gray on weathered surface, darker on fresh fracture. Contains many nodules and some 2-in.-thick beds of chert, some of which is light gray, brown, pink, and white. Fragments of fossils abundant, but mostly indeterminable because of dolomitization. Upper part sheared and brecciated adjacent to fault	445	1,175
10. Dolomite, medium- to light-gray, thin-bedded, cherty; interlayered with a few thin beds of siliceous, somewhat phosphatic mudstone	103	1,072
Park City and Phosphoria formations—Continued		
Meade Peak phosphatic shale tongue of Phosphoria formation:		
9. Mudstone, siliceous and phosphatic, black on fresh fracture but weathers medium olive brown; in beds 1–3 in. thick, but unit contains a few 3- to 12-in. beds of cherty dolomite, especially near top	185	887
8. Dolomite, light-gray, medium-grained; contains poorly preserved fossil fragments	23	864
7. Shale, medium- to dark-brown, cherty; some beds phosphatic	20	844
6. Sandstone, medium-brown, medium-grained, quartzitic	15	829
5. Mudstone, dark-brown to black on fresh fracture, medium to light olive-brown on weathered surfaces; some beds phosphatic. Many beds contain indefinite segregations of coal-black chert. Near base and top, unit is interbedded with cherty dolomite	90	739
Lower member of Park City formation:		
4. Dolomite, medium-gray on fresh fracture, lighter gray on weathered surfaces; medium bedded. Contains relatively few chert nodules but many fragments of poorly preserved fossils	155	584
3. Mudstone, siliceous, somewhat phosphatic, cherty; in thin beds alternating with medium-gray, medium-grained, cherty dolomite and a few beds of sandstone. Fault of small displacement may be concealed in unit	252	332
2. Dolomite, medium-gray on freshly broken surfaces, medium- to light-gray on weathered surfaces, medium-grained; contains many nodules of white, brown, and black chert 1–2 in. thick and 6–18 in. long	230	102
1. Dolomite, medium- to light-gray, medium-grained; contains much chert. Some chert nodules in lower half are 6–48 in. thick and several feet long. Interlayered, especially near base, with a few beds of dolomitic sandstone or quartzite	102	
Total Park City and Phosphoria formations	1,620	
Contact conformable.		
Diamond Creek(?) sandstone (upper beds only):		
Sandstone, yellow to pale-brown, with a few interlayered beds of cherty, sandy dolomite. Top taken at top of uppermost thick sandstone of a dominantly sandy unit.		

Fault.—The fault that cuts out the topmost beds of the Park City and the formations that overlie it and brings the Bluebell dolomite against the upper part of the Franson member has a stratigraphic displacement of approximately 21,500 feet. However, it is not prominently marked at the surface and is easily overlooked, inasmuch as the fault plane is nearly parallel with the bedding of the Bluebell and Park City and is bordered by not more than a few feet of healed fault breccia. The dolomitization of the carbonate rocks of the Park City has produced near the fault a medium- to dark-gray dolomite that closely resembles the dolomites of the Bluebell, and it is only by delineation of the Colorado Chief member marker bed and recognition of the sparse but characteristic fossils of the Bluebell that the fault zone may be located with any precision. This fault is one of several steeply dipping, east-trending faults of large magnitude that are alined with similar structures in the Gilson Mountains (John Costain, oral communication, October 1958); these structures may be part of a zone of faults that form the principal tear faults associated with the Nebo thrust fault of the southern Wasatch Range (Eardley, 1934, p. 381–383).

AGE AND CORRELATION

The rocks assigned to the Park City formation in the East Tintic Mountains are correlated with the Park City formation in the southern Wasatch Range (Baker, Huddle, and Kinney, 1949, p. 1188–1189; Cheney, 1957, p. 19–29) on the basis of the many lithologic similarities of the two formations and their occurrence above the distinctive friable crossbedded sandstone of the Diamond Creek(?) sandstone. Baker and Williams (1940, p. 624) describe a fauna of Kaibab and Toroweap (Permian) age that is probably Leonard equivalent, containing *Dictyoclostus ivesi* s. l. from the lower member of the Park City in the Hobble Creek area. This suggests that the lower member is in part equivalent to the Kaibab limestone of the Colorado Plateau (Darton, 1910, p. 21, 28, 32; and Baker, 1946, p. 52–53).

The shaly phosphatic mudstone member of the original Park City formation (Boutwell, 1907, p. 443–446) has been correlated with the Meade Peak phosphatic shale member of the Phosphoria formation by Cheney (1957, p. 24–27), and in the Wasatch Range is termed by him the Meade Peak phosphatic shale tongue of the Phosphoria formation. According to Williams (McKelvey and others, 1956, p. 2857), the Meade Peak member is probably—but not definitely—Word in age. However, on the basis of a newly recognized genus of cephalopods, collected from the upper part of the Meade Peak member 10 miles west of Sublette Ridge in western Wyoming, Miller, Furnish, and Clark (1957, p. 1057) have stated that the Meade Peak is of Leonard age. The Word age assignment by Williams was made largely because Miller and Cline (1934) had previously correlated the Meade Peak with the Word (Williams *in* McKelvey and others, 1957, p. 2857), using all the same genera and species of cephalopods except the new one described from the locality 10 miles west of Sublette Ridge. Because Miller and his coworkers did not thoroughly discuss their reasons for changing the age of the Meade Peak from Word to Leonard, it does not appear possible at this time to state definitely whether the Meade Peak is Leonard or Word, or both, in age.

Williams (McKelvey and others, 1956, p. 2858) reports that the faunas from the upper or Franson member of the Park City are not definitely known to be younger than Word age, but some may be younger. Regionally the combined Meade Peak and Franson members are partly correlative with the Gerster and Edna Mountain formations in eastern Nevada and western Utah (Williams McKelvey and others, 1956, p. 2859).

TERTIARY(?) SYSTEM

APEX CONGLOMERATE OF EOCENE(?) AGE

The Apex conglomerate, which is here named from exposures at the type locality in the Apex Standard No. 2 shaft in the NW¼NE¼ sec. 22, T. 10 S., R. 3 W., unconformably overlies the folded, faulted, and deeply eroded Paleozoic rocks and is overlain by volcanic rocks of middle Eocene age. This conglomerate has a considerable range in composition. A mile west-southwest of Packard Peak it consists of angular to rounded fragments of quartzite with some shale and limestone in a well-lithified red sandy calcareous matrix. In the Eureka quadrangle it is represented by a prevolcanic talus deposit of angular to subrounded limestone and quartzite cobbles covered by the Packard quartz latite along the northern and eastern slopes of Godiva Mountain, and by a conglomerate several tens of feet thick that underlies the Packard quartz latite in the type locality in the Apex Standard No. 2 shaft. The Apex conglomerate nowhere contains fragments of volcanic rocks and is therefore believed to consist of pervolcanic talus or colluvial deposits which accumulated on the structurally deformed per-Tertiary rocks following the principal movements of the Laramide orogeny.

Small masses of red conglomerate exposed in the Boulter Peak quadrangle near the east entrance to Twelvemile Pass and in the Fivemile Pass quadrangle near the east entrance to Fivemile Pass, are similar in composition, color, and other respects to the Apex conglomerate. However, these deposits are not overlain by volcanic rocks and, therefore, cannot be assigned to the Apex with any degree of certainty.

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TERTIARY SYSTEM

MIDDLE EOCENE IGNEOUS ROCKS

The igneous rocks exposed in the East Tintic Mountains are the deeply eroded remnants of a large composite volcano that virtually buried a preexisting structurally complex mountainous area. These igneous rocks include intrusive bodies and thick lava flows as well as the bedded tuffs, breccias, agglomerates, and volcanic gravels that can be considered to be, in part at least, sedimentary deposits. The eruptive centers of the volcanic rocks were approximately in the center of the range and are now marked by stocks, plugs, and dikes that engulfed the principal volcanic conduits and invaded the earliest eruptive rocks.

The effusive rocks are subdivided into three formations: (a) the Packard quartz latite and Fernow quartz latite, oldest; (b) the Laguna Springs latite, an intermediate sequence of latite (and possibly andesite) tuffs, flows, agglomerates, and volcanic gravels; and (c) a late sequence of basalt flows and associated rocks that crop out in the northeastern part of the area (pl. 2) and in the Fox Hills and Lake Mountains.

The intrusive rocks consist of quartz monzonite, monzonite, monzonite porphyry, lamprophyre, andesite, and diabase. Associated with the monzonite and monzonite porphyry intrusive bodies are pebble dikes, which are dikelike bodies of injection breccia consisting chiefly of rounded or subrounded fragments of Tintic quartzite and disk-shaped pebbles of shale, and, less commonly, limestone and dolomite—all embedded in a matrix of quartz fragments, carbonate rock flour, or monzonite. These intrusive rocks and injection breccias have been described elsewhere (Morris, 1957, p. 34–40; Lovering and others, 1949, p. 11–12; and Lindgren and Loughlin, 1919, p. 42–70), and inasmuch as they do not directly bear on the problems of the sedimentary rocks of the East Tintic Mountains except where they metamorphose or cut them, they are not further described in this report. The following descriptions of the extrusive rocks emphasize the lithologic character of the tuffaceous and other rocks, which may be considered to be sedimentary deposits.

VOLCANIC ROCKS

PACKARD QUARTZ LATITE AND FERNOW QUARTZ LATITE

The oldest effusive rocks at present recognized in the East Tintic Mountains were named the Packard rhyolite by Tower and Smith (1899, pl. 74), from extensive exposures at Packard Peak. Tower and Smith also named a closely similar effusive rock that crops out in the southern part of the range south of Tintic Mountain the Fernow rhyolite from exposures near Furner Canyon (pl. 1), which is shown as Fernow Canyon or Ferner Canyon on some maps. Recent studies have shown that the Packard and Fernow are evidently parts of the same volcanic series that have been geographically separated by the overlying latite volcanic rocks. Because of the long usage of the two names, and because of the difficulty of demonstrating that both the Packard and Fernow originated from the same eruptive centers, both names are retained in this report. The lavas of both the Packard and Fernow contain as much plagioclase (andesine) as orthoclase (sanidine) and about 5–20 percent of quartz, as well as biotite, some hornblende, and minor amounts of magnetite, apatite, and sphene, and thus have the composition of quartz latite, the designation which is given them in this and other reports (Morris, 1957, p. 30).

The Packard quartz latite is subdivided into: (a) a basal tuff, (b) a lower vitrophyre, (c) a massive flow unit, and (d) an upper vitrophyre. The basal tuff of the Packard is a massive unit, a few inches to perhaps several hundred feet thick, but it is absent in many areas. It is chiefly fine grained but locally contains fragments as large as 2 inches or more in diameter. It is a dense, well-lithified rock described by Loughlin (Lindgren and Loughlin, 1919, p. 45) as being "composed of distinct grains of feldspar, quartz, and biotite, and fragments of glassy rhyolitic and latitic groundmass." Because of its high porosity and its position at the base of the volcanic series, the tuff was extensively altered by hydrothermal solutions; as a result, the groundmass ranges in color from a bleached white or pale green through various shades of brown, red, and purple. In hand specimens the only distinct grains are euhedral or subhedral crystals of quartz embedded in an aphanitic groundmass. These crystals have the stubby, doubly terminated, hexagonal-dipyramidal form of high-temperature quartz. As seen in thin sections, the unaltered tuffs are composed of fragments and subperfect crystals of quartz, andesine, sanidine, biotite, and magnetite in a groundmass of glass shards that show typical bogen structure. The crystal fragments are 0.5–1 mm in diameter and make up less than 10 percent of the rock. Although the ratio of plagioclase to orthoclase and the percentage of quartz varies from thin section to thin section, they are sufficiently constant to allow classification of the rock as quartz latite. Microscopic examination of layered tuffs that crop out near the Central Standard shaft show the alteration to be confined almost wholly to the groundmass and to be characterized by the development of montmorillonite, which is cut in turn by veinlets of calcite. In other areas the tuffs are kaolinized and silicified.

As exposed near Furner Valley, the Fernow quartz latite consists of a basal tuff bed of irregular thickness and an overlying unit of vitrophyre and porphyritic quartz latite. The basal tuff unit is massive and ranges in texture from fine grained to coarsely fragmental. At many exposures the massive tuff unit merges almost imperceptibly with the overlying vitrophyre unit, which is equally massive, suggesting that the vitrophyre is a welded tuff rather than a flow rock.

LAGUNA SPRINGS LATITE

The latite effusives, which disconformably overlie the Packard quartz latite, are here named the Laguna Springs latite from exposures at the type locality near Laguna Springs in the lower part of the Canyon of Pinyon Creek, in the W½NW¼ sec. 35, T. 9 S., R. 2 W. The different types of volcanic rocks that make up the Laguna Springs latite exhibit a wide range of textures, but they are all similar in mineralogic composition and therefore are believed to be the product of only one general series of volcanic eruptions. To facilitate mapping and description, the Laguna Springs latite is subdivided on the basis of rock type into: (a) a basal tuff, (b) a lower flow series, (c) an intermediate tuff and agglomerate, (d) an upper flow series, and (e) a thick and extensive agglomerate. The flow rocks are described in other reports (Morris, 1957, p. 32–33, Lindgren and Loughlin, 1919, p. 56–64) and are not further considered here.

The basal tuffs are thickest near Ruby Hollow and Diamond Gulch, but they occur at nearly every exposure of the lower latite flows in the East Tintic Mountains, being especially well exposed near Laguna Springs. The tuffs are both fine and coarse grained, and in some areas are agglomeratic. Near Laguna Springs, the lower tuffs are imperfectly layered but include distinct beds of very fine, soft sandy tuffs, and other beds of conglomerate containing cobble-size fragments of vitrophyre from the Packard quartz latite. On Volcano Ridge, Tower and Smith (1899, p. 653–654) describe thick beds of fine and coarse greenish tuffs that dip 10°–20° and contain interbedded sheets of andesite. The tuffs are also associated with agglomerate containing fragments of rhyolite, andesite, quartzite, limestone, and shale, embedded in a matrix of glass shards. On the extreme western edge of Volcano Ridge, the agglomerate contains large masses of quartzite and is not unlike the agglomerate near the Pinyon Queen shaft, in the canyon of Pinyon Creek, which contains blocks of porphyritic latite 6–8 feet in diameter.

The flow rocks of the lower flow series are mostly dark purplish red or dark gray to black and are coarsely porphyritic. Phenocrysts, which make up from 10 to about 30 percent of the rock, consist of orthoclase, plagioclase (calcic oligoclase to labradorite), hornblende, biotite, augite, magnetite, and quartz. Hypersthene occurs instead of hornblende in some flows. Examination of thin sections under the microscope revealed that part of the quartz represents partly digested fragments of the Tintic quartzite. The rocks therefore have the composition of latite.

The pyroclastic and sedimentary rocks of the intermediate tuff and agglomerate unit of the Laguna Springs latite closely resemble the rocks of the basal unit and, in the absence of the lower series of flows, cannot everywhere be separated from them. In general, however, the intermediate tuffs and agglomerates are coarser grained, more prominently bedded, and less resistant to erosion. Near the mouth of the canyon of Pinyon Creek the intermediate tuff and agglomerate unit is well exposed in a railroad tunnel and the cuts associated with it, and in the seasonally dry channel of Pinyon Creek. In these exposures the unit consists chiefly of gravelly tuff composed of rounded fragments ranging from fine sand to bounders. It is distinctly bedded throughout, individual beds ranging from 1 to 4 feet in thickness. Some beds consist almost wholly of fine ash and small fragments; others contain both fine and coarse fragments. Near the edge of the mountain range east and southeast of Laguna Springs, the gravelly beds intertongue with latite flows.

The lavas of the upper flow series are closely similar to those of the lower flow series; in places where the intermediate tuff and agglomerate unit is absent, or not well exposed, the two flow series cannot be separated.

The thick agglomerate unit at the top of the Laguna Springs latite is the most widespread of the latitic rocks. It covers broad areas of the northeastern and southeastern parts of the East Tintic Mountains and large parts of Long Ridge and nearby areas. It consists of a heterogeneous assemblage of angular to subrounded fragments of latite ranging from silt-sized particles to huge blocks of lava weighing several tons. The deposits are poorly stratified and weather to rounded slopes covered by lava boulders.

BASALT

The basalt flows in the northeastern part of the East Tintic Mountains and adjacent areas are fine to medium grained, porphyritic, and nearly black. The phenocrysts are 5 mm or less in length and consist of labradorite, augite, and olivine; the accessory minerals are magnetite and apatite. The rock is most commonly vesicular but ranges from dense to scoriaceous. In the limited exposures in the East Tintic Mountains it is not associated with basaltic tuffs or other volcanic-sedimentary deposits.

AGE AND CORRELATION OF VOLCANIC ROCKS

In the west-central part of Long Ridge, about 10 miles east of the Tintic mining district, volcanic conglomerates and breccias equivalent to units of the Laguna Springs latite are found in the Goldens Ranch formation of Muessig (1951, p. 234). This formation also contains quartz-crystal tuffs and bentonites possibly equivalent to units of the Packard and Fernow quartz latites. The Goldens Ranch formation grades downward into bentonite-bearing shales of the lower and middle Eocene Green River formation. About 820 feet above the base of the Goldens Ranch formation a relatively pure limestone occurs—the Sage Valley limestone member of Muessig (1951, p. 234)—which contains plant stems and leaves that have been identified by Roland W. Brown as being late Green River in age. Muessig (1951, p. 234) compared thin sections of boulders from the volcanic conglomerates below the Sage Valley limestone member with thin sections of the flow rocks of the Laguna Springs latite in the East Tintic Mountains and found them to be essentially identical. Further, it is possible to trace the volcanic conglomerates of the Goldens Ranch formation laterally into agglomerates and breccias of the Laguna Springs latite. These stratigraphic relations indicate that the volcanic rocks of the East Tintic Mountains were erupted during late middle Eocene time.

The lead-alpha age of zircons concentrated from the monzonite stocks of the Tintic and East Tintic mining districts gave ages of 46.5 million years and 38 million years respectively, according to Howard Jaffe (written communication, 1954; report No. IWM 629).

UNNAMED TERTIARY LIMESTONE AND ARGILLIZED TUFF

Scattered small exposures of limestone and fresh and argillized tuff in the extreme northeastern part of the East Tintic Mountains are parts of an unnamed sequence of limestone and clay, believed to be of early Tertiary age, that is extensively exposed in the Fox Hills and the southern part of the Lake Mountains. This group of rocks has been described by Stringham and Sharp (1950, p. 726–733) as consisting of a lower limestone, an intermediate lens of clay that is locally known as the Fox Clay deposit and an upper limestone. The clay and the upper limestone were not definitely recognized in the Mosida Hills part of the East Tintic Mountains, but isolated masses of tuff and breccia associated with the lower limestone member in this area may be equivalent to the Fox clay. In the Fox Hills the upper limestone unit is overlain with moderate angular unconformity by the basalt flows described in the section of this report dealing with the middle Eocene igneous rocks.

The limestone bed exposed in the Mosida Hills is fine grained to medium grained rock that is white on fresh fractures but weathers pale blue. It is about 100 feet thick and is overlain by tuffs and breccias of latitic composition and by debris from the basalt flows. The Fox clay in the Fox Hills is described by Stringham and Sharp (1950, p. 727) as a lenticular bed having a maximum thickness of 18 feet and thinning rapidly to the east and southeast. It consists largely of a type of halloysite that contains more water than typical halloysite, and varied amounts of detrital quartz. Stringham and Sharp (1950, p. 732) believe that the clay deposit was formed from transported endellite clay, which became partly dehydrated during transport, thus changing to halloysite. In a later study of the same deposit, Ames and Sand (1957, p. 1857) concluded that the halloysite and montmorillonite, which is associated with it but was not described by Stringham and Sharp, is the product of hydrothermal alteration of lenticular beds of volcanic tuff accomplished by hot springs.

AGE AND CORRELATION

The limestone and associated clay deposits in the Fox Hills and nearby areas have not yielded fossils of any kind, but they are similar in several respects to the Eocene Sage Valley limestone member of the Goldens Ranch formation of Muessig (1951, p. 234) and are probably correlative with it. They have not been deformed except for simple tilting and are therefore younger than the youngest compressive movements of the Laramide orogeny. The limestone and clay deposits are, in turn, overlain by basaltic lavas that are considered to be the youngest of the late middle Eocene effusive rocks of the East Tintic Mountains. The halloysite and montmorillonite deposits associated with the limestones appear to be altered tuffs that are probably equivalent to some of the pyroclastic units of the Laguna Springs latite. All these structural and stratigraphic relations indicate an early Tertiary—probably late middle or early late Eocene—age, and thus a temporal if not stratigraphic equivalence with the Sage Valley limestone member.

SALT LAKE(?) FORMATION

Deposits of marly limestone, bentonitic tuff, sandy silt, and gravel, which are provisionally correlated with the Salt Lake formation of Pliocene age exposed about 20 miles south of Salt Lake City at Jordan Narrows (Hunt, Varnes, and Thomas, 1953, p. 13–14; and Slentz, 1955), crop out over wide areas in Rush and Tintic Valleys. Similar deposits are also presumed to underlie Pleistocene lake beds or detrital deposits in Cedar, Goshen, and other valleys adjacent to the East Tintic Mountains. These Pliocene deposits have been studied only incidentally, and not in the detail warranted by their importance.

The deposits here included under the Salt Lake(?) formation are poorly consolidated and, where weathered, cannot be readily distinguished from adjacent and overlying Pleistocene and Recent deposits. The marly limestones are especially well exposed in railroad and highway cuts, and along gullies near Boulter Pass. They are medium bedded to massive, and weather chalky white, being grayish white to creamy white on fresh fractures. Some beds contain moderately well preserved shells of ostracodes and spired gastropods. The bentonitic tuffs chiefly underlie the marly limestones and crop out less prominently. On a freshly broken surface they are pale grayish green and dense, texturally resembling bar soap. Small flakes of lustrous black biotite are readily identified with a hand lens, but the feldspar fragments and the original matrix of vitric shards are altered to clay. The weathered exposures of the bentonitic tuff beds are characteristically a loose, fluffy soil.

Overlying the bentonitic tuff and marly limestone beds is a buff to reddish-brown, gravel-streaked, sandy silt, which is comparatively unconsolidated but which appears to be generally conformable with the underlying beds. A sandy bed near the base of the silt unit contains fan-shaped shards of clear volcanic glass determined by E. J. Young of the U.S. Geological Survey to have an index of refraction of 1.496 ± 0.004, which indicates a rhyolitic composition.

Near Boulter Pass the limestone and bentonitic tuff beds strike almost due north and dip 14°–22° E., however, dips of 35° W. were observed in similar beds that crop out in railroad cuts about 9 miles northwest of Boulter Pass. No folds or structures related to folding were observed in the marly limestones and bentonites, and it is believed that the large and diverse dips are the result of the tilting and displacement of the valley fault blocks that took place during the early part of the Pleistocene epoch. Owing to the possible repetition of beds by faulting, no estimates of the total thickness of the bentonitic tuff and marly limestone section were made.

The upturned edges of the beds of marly limestone, bentonitic tuff, and sandy silt along the eastern parts of Tintic and Rush Valleys are truncated by a broad bajada that extends westward from the East Tintic Mountains. Several of the alluvial fans that form this bajada retain their original topographic characteristics and thus are presumed to be of Pleistocene age. The beds of the Salt Lake(?) formation that underlie the west half of Tintic Valley are beveled by a dissected pediment surface that slopes to the southeast at 3° to 5°. This pediment surface is covered by an irregular thickness of gravel, also of probable Pleistocene age, composed of subangular and subrounded fragments of chiefly Precambrian rocks derived from the Sheeprock and West Tintic Ranges. This pediment was not observed near the East Tintic Mountains.

The fossils in the marly limestone beds together with the fine grain and the even bedding of the bentonitic tuffs indicate that parts of the Salt Lake(?) formation were deposited in a freshwater lake. The fragments of volcanic glass in the sandy silt shows that it also is—at least in part—of volcanic origin, or that the source material contained much fresh unweathered tuff.

AGE AND CORRELATION

In the Jordan Narrows, the Salt Lake formation, as described by Hunt (Hunt, and others, 1953, p. 13), consists in part of "alternating dark-gray silt, and white or light-gray firm, ledge-forming beds that probably are cemented, reworked tuffs. The individual beds range from 2 to 20 feet in thickness; included with them are a few, very thin, clay partings." Overlying these beds unconformably is "a series of buff beds with a basal conglomerate which dips 5° less than the underlying light-colored fine-textured beds." The ledge-forming beds are fossiliferous and effervesce strongly in acid.

The buff tuffaceous silts exposed near Boulter Pass are coarse grained at the base and overlie several fossiliferous limestone beds about 10 feet thick. Although the unconformity observed by Hunt at the top of the ledge-forming beds was not recognized with any certainty above the marly limestone in the Boulter area, there is a sharp lithologic change between the limestone and the overlying silt deposits. The lack of induration of the silt as contrasted to the moderately indurated bentonitic tuffs and marly limestones also suggests that the silts are somewhat younger than the beds they overlie.

Some freshwater ostracode shells were collected by H. D. Goode (1955 written communication), from the fossiliferous limestone near Boulter Pass, and were examined by I. G. Sohn of the U.S. Geological Survey. Sohn reported that they range through the Tertiary and Quaternary, and that their presence therefore has no stratigraphic significance. Sohn compared the amount of the noncarbonate residue of these shells, however, with that of a known Pliocene sample from Malheur County, Oreg., and he infers from the comparison that the sediments may be lower Pliocene or older. Such an age would fit beds of the Salt Lake formation, and would be in keeping with their stratigraphic position below the oldest Pleistocene gravel, but Sohn points out that this method of age determination may not be accurate.

On the basis of the suggested age of the fossils and the lithologic similarity of these beds to the marls and bentonites exposed at the Jordan Narrows, these beds are assigned, at least provisionally, to the Salt Lake formation.

HISTORY OF PRE-QUATERNARY SEDIMENTATION

The geologic history of the area now occupied by the East Tintic Mountains includes long periods of submergence beneath marine waters, interspersed with shorter periods of uplift and erosion. There is no evidence of any strong deformation during the entire Paleozoic era, but regionally important uplifts took place during the middle part of the Ordovician period, during the Late Devonian in the area just to the north of the East Tintic Mountains now occupied by the Uinta and central Wasatch Ranges and the Oquirrh and Stansbury Mountains, and again following the deposition of the Oquirrh formation during the Permian.

During the latter part of late Precambrian time the East Tintic region received arenaceous and argillaceous sediments that appear to have been deposited in shallow waters of rapidly sinking regional basins. No Precambrian glacial deposits of the type recognized elsewhere in north-central Utah are exposed in the East Tintic Mountains, but they may have been stripped off by erosion during the long time interval represented by the unconformity between the Big Cottonwood formation and the Tintic quartzite.

A gradually deepening sea invaded the area during the Early Cambrian time, and by early Middle Cambrian time it was depositing predominantly carbonate rocks in the East Tintic area. Deposition of this type persisted almost without interruption through the Early Ordovician. During at least part of Middle Ordovician time the area was emergent and underwent erosion.

An invasion of the sea during Late Ordovician time is indicated by the abrupt contact between the Upper Ordovician Fish Haven dolomite and the Lower Ordovician Opohonga limestone. These relations also suggest that the Middle Ordovician positive area was a broad zone arched up with comparatively little deformation, eroded, and swept clean of debris before the incursion of the Late Ordovician seas.

Rocks of Middle Silurian age are apparently conformable with the underlying Upper Ordovician dolomites and the overlying Devonian dolomites and are virtually indistinguishable from them; yet the Middle Silurian rocks are separated from both by hiatuses in the fossil record that suggest considerable lapses of geologic time. No contributing evidence of uplift, erosion, or nondeposition during the Silurian is recognized in the East Tintic Mountains, although it is recorded in adjoining areas.

Early, Middle, and perhaps the earliest part of Late Devonian time was probably a period of nondeposition if not emergence and erosion in the area of the East Tintic Mountains, inasmuch as no Lower and only doubtful Middle Devonian beds are known in the range. However, during early Late Devonian time the dolomite beds of the upper Bluebell dolomite and the dolomite and quartzite and quartzite breccia beds of the Victoria formation were deposited. The clastic deposits of the Victoria were chiefly derived from the Late Devonian positive area north of the East Tintic Mountains, and their texture suggests that they may have been emergent at times during the general period of their deposition.

During the latter part of Late Devonian time, a broad area in northern and central Utah—including the East Tintic Mountains and the area of the Late Devonian uplift to the north—was invaded by the Three Forks–Madison sea; deposition of limestone was renewed in this sea and continued into Late Mississippian time. Clastic sediments were deposited during the latter half of the Late Mississippian.

Sedimentation continued from Late Mississippian to Early Pennsylvanian time with the deposition of the Manning Canyon shale. However, coarse sandstones, fine- to medium-grained angular conglomerates in the Manning Canyon shale exposed in the East Tintic Mountains, and plant fossils from the Manning Canyon in the nearby Lake Mountains indicate at least brief emergence of the land during this interval.

The remainder of the Pennsylvanian and the early part of the Permian was a time of continued marine deposition, resulting in the accumulation of a tremendous thickness of limestone and fine- and medium-grained sandstones of the Oquirrh formation. Cross-bedding and other features in the sandstones and clastic limestones indicate deposition in relatively shallow waters that filled a downwarping trough, within which deposition kept pace with subsidence.

During the latter part of early Permian time, the area gradually emerged and received deposits of wind-blown sand now constituting the Diamond Creek(?) sandstone. Submergence followed in the later Permian with the invasion of the Park City sea.

The record of sedimentation during the Mesozoic era has been lost in the East Tintic Mountains but is voluminous in the Wasatch Range and Wasatch Plateau, 30 miles to the east and southeast, and in the southern part of Long Ridge, about 20 miles south-southeast of

Eureka. In these areas, Triassic red beds and limestone, and Middle Jurassic gypsiferous shales and crossbedded sandstones overlie the limestone of the Park City formation, which implies chiefly continental deposition under arid conditions during the greater part of these periods. In the area east of Salt Lake City, however, early Late Jurassic limestone records the invasion of the Sundance sea and a brief return to marine sedimentation, which may have extended southwestward to the East Tintic area. Thick marine Jurassic shales about 50 miles to the south must have been laid down in a deep basin that may have bordered or included some of the southern part of the area now occupied by the East Tintic Mountains.

During Early Cretaceous time and persisting through the Late Cretaceous, east-west compressional forces acted upon the area of the East Tintic Mountains, uplifting the land and folding and faulting the sedimentary rocks. As a result of this orogenic activity, large thrust and tear faults developed, and highlands formed that shed coarse debris to the east, thus forming the extensive conglomerates of the Indianola, Price River, and younger formations of central and eastern Utah.

Intensive volcanic activity began in the middle Eocene and possibly extended into the late Eocene, probably culminating before Oligocene time. Extrusion of thick lava flows, tuffs, and agglomerates of quartz latite and latite took place, accompanied by intrusion of quartz monzonite, monzonite, and other rocks. During this time extensive mineralization occurred near several centers of hydrothermal activity. At the time the volcanic rocks were erupted, calcareous and argillaceous sediments of the upper part of the Green River formation were being deposited in a shallow lake whose shoreline was probably somewhere between the present site of the East Tintic Mountains and Long Ridge. The flow rocks and coarse pyroclastic deposits of the eruptions were probably deposited on the steep sides of the volcanic pile, while the finer airborne tuffs were deposited alternately with other sediments in the Green River lake. The coarse pyroclastic rocks were later transported by mudflows and stream action to the east, where they were deposited as volcanic conglomerates over the fine sediments of the Green River. During the later part of the period of volcanic activity, a small body of water accumulated in the central part of Long Ridge; in this local lake the Sage Valley limestone member of the Goldens Ranch formation of Muessig (1951, p. 234) was deposited. However, continued volcanic activity caused the burial of the lake sediments by more volcanic conglomerate and tuffs. According to Muessig (oral communication, 1949) these conglomerates were in turn overlain by clay and silts of unknown but probably Tertiary age. Deposits of limestone and clay with stratigraphic relations similar to the Sage Valley limestone member was also deposited in the area northeast of the East Tintic Mountains during this general interval of time.

No rocks of Oligocene or Miocene age are found in the East Tintic Mountains or contiguous areas, but it seems likely that deposits of this age may be concealed beneath the extensive Pliocene and younger accumulations in the intermontane valleys. It is possible, however, that the present Great Basin may have been high land with exterior drainage during the Oligocene as it was during the Cretaceous and Eocene, but the absence of Oligocene deposits in adjacent areas makes this interpretation difficult to assess.

During the Pliocene epoch the terrestrial and lacustrine deposits that make up the Salt Lake (?) formation accumulated in the basins adjacent to the East Tintic Mountains. Bentonitic tuffs interlayered with these deposits indicate some volcanic activity during this interval, but the fine-grained texture of the tuffs suggests that the eruptive centers were probably many miles distant.

QUATERNARY SYSTEM

By H. D. Goode

The Quaternary deposits of the East Tintic Mountains are subdivided into four groups: (a) lacustrine clay, silt, sand, and gravel; (b) loess, alluvium, and fan gravel; (c) colluvium, talus, and landslide debris; and (d) eolian sand and silt. The lacustrine sediments were deposited in the freshwater Lake Bonneville during the Wisconsin glacial stage. The loess and the alluvial and colluvial deposits of the mountains formed chiefly prior to Lake Bonneville time but are in part contemporary with, or younger than, the Lake Bonneville lacustrine deposits. The eolian sand and silt deposits are post–Lake Bonneville in age, but sparse remnants of thick loess indicate widespread eolian activity in pre–Lake Bonneville time.

DEPOSITS OF PRE–LAKE BONNEVILLE AGE

LOESS

One of the oldest Quaternary deposits in the area is a loess deposit, but it has been identified at only two exposures. At the caved portal of the Tetro tunnel, on the north slope of Godiva Mountain, a 40-foot-thick stratum of medium-brown loess overlies about 1 foot of colluvium on lava bedrock and underlies silt that grades upward into angular limestone colluvium on which a pre-Wisconsin soil (see p. 131–132) has developed. Near the Iron King No. 1 shaft, 2.2 miles east-southeast of Eureka, a similar loess underlies a stream gravel on which a pre-Wisconsin soil had developed, but the thickness of this loess is not known.

The loess consists principally of quartz grains, but also contains vienlets of calcium carbonate (caliche), shards of clear volcanic glass, and a few rock fragments near the base. Fewer than 1 percent of the grains are as large as 0.5 mm.

The loess is not indurated, tilted, or faulted as is the Salt Lake(?) formation; it is therefore probably younger. Futhermore, the shards of volcanic glass have similar habit and the same index of refraction as shards from the tuffaceous beds of the Salt Lake(?) formation; the shards are more abundant in the tuffaceous beds than in the loess, and most shards in the loess appear more broken than those in the Salt Lake(?) formation, many of which have a fanlike habit that appears to be their original structure. These relations suggest that the shards in the loess were derived from the Salt Lake(?) formation.

The lime content and the silt-size and smaller quartz grains in the loess may also have been derived from the tuffaceous sandstone of the Salt Lake(?) formation. Whatever its source, the loess indicates that a large amount of wind-blown silt was deposited in the area, probably early in Quaternary time. The loess in turn was probably an important source of the silt now contained in nearly all the younger deposits of the area.

ALLUVIUM AND COLLUVIUM

In the East Tintic Mountains, alluvium and colluvium of pre-Lake Bonneville age are widely distributed as alluvial terraces in canyons, as slopewash, and as alluvial-colluvial fans in wide valleys and along the mountain fronts. The deposits are heterogeneous in size, shape, bedding, sorting, cement, and in the composition of rock fragments. The flat-lying, stream-laid alluvium intertongues with, and grades into, the steeper creep and slopewash colluvium.

The alluvial deposits range from inconspicuous lag gravels, through well-developed canyon terrace gravels, to large thick fans covering several square miles. Remnants of lag gravel—represented by a sparse scattering of foreign pebbles on bedrock spurs—are well illustrated by the gravel on a bedrock spur 500 feet south of the Apex Standard No. 1 shaft 2½ miles southeast of Eureka, and on the bench one-fourth mile north of Eureka; excellent samples of terrace gravels are preserved in the middle reaches of Broad Canyon; large thick fans are especially well developed along the mountain front west of Boulter Peak.

Similarly, the colluvial deposits range from tiny remnants plastered high against bedrock cliffs, as on the south face of Pinyon Peak, to large fanlike bodies such as may be seen lower on the same slope. (fig. 55.)

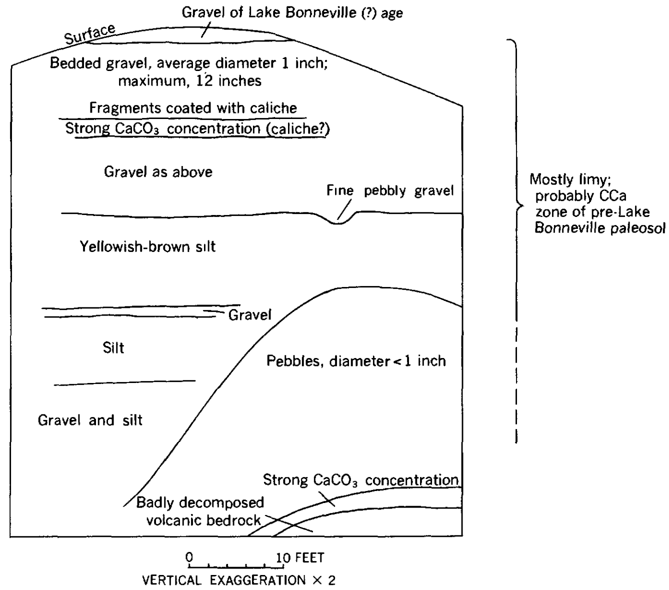

FIGURE 55.—Generalized composite cross section of alluvial-colluvial fan of pre-Lake Bonneville age south of Pinyon Peak, Eureka quadrangle. Composite section, both sides of railroad cut 400 feet N. 25° E. of Central Standard shaft, SW¼ sec. 3, T. 10 S., R. 2 W.

Some colluvial deposits are more extensive than the area supplying their detritus. The most prominent are on the east side of Broad Canyon, where detrital material from the west side of Gardison Ridge covers an area about half again as great as the area that supplied the material. The surface here has a gradient of 8°. The exact thickness of the deposit is unknown, but exposures along gullies indicate that it is more than 50 feet thick.

Locally the alluvial-colluvial deposits are partly cemented with calcium carbonate (fig. 56). Near the

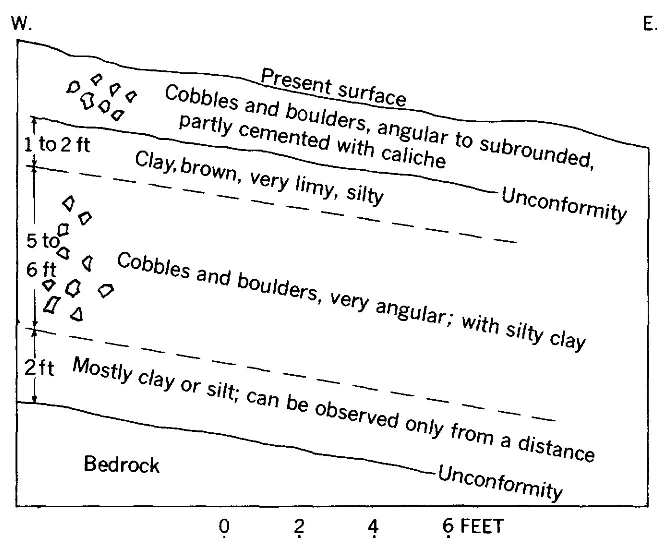

FIGURE 56.—Generalized cross section of partly cemented colluvium, probably of two pre-Lake Bonneville ages. Section in pit at altitude 6,500 feet in Burriston Canyon. Eureka quadrangle, northern part sec. 20, T. 10 S., R. 2 W.; looking north.

surface, the caliche is hard and forms lenses 1–5 feet thick and many square feet in area, or forms irregular plates a few to several inches square and commonly less than 1 inch thick. It also coats pebbles and larger rock fragments. Commonly the lenses, plates, and coated pebbles are surrounded by powdery calcite and silt. Other caliche-cemented lenses occur as much as 10–30 feet below the surface.

In areas where the volcanic rocks are pyritized, some lenses at the base of gravels lying on bedrock are cemented by oxides of iron and of manganese. Examples may be seen on the spur 500 feet southwest of the Water Lily shaft, on the ridge 1,500 feet west of the North Lily shaft, and in the valley 1,500 feet north of the North Lily shaft. This gravel is commonly a porous, multicolored conglomerate one to several feet thick, consisting of light- to dark-colored rock fragments lying in a dark-gray, black, reddish-brown, or yellowish-brown matrix. It contains chiefly volcanic rock fragments, but carbonate rocks are present in the Water Lily shaft near the gravel. The cement consists of oxides of iron and manganese and little or no lime is present. The few carbonate fragments are much decomposed.

Most of the gravels contain only rock fragments from bedrock nearby. One exception, however, is an alluvial gravel in Rush Valley in the northwest corner of Boulter Peak quadrangle. It contains minor amounts of volcanic rock, and green quartzite that probably came from the West Tintic Mountains.

Shells of gastropods and ostracodes are abundant locally in the pre-Lake Bonneville alluvium-colluvium, as in the exposure about 50 feet above the present stream channel in Burriston Canyon (fig. 57). All specimens collected at this location are from the upper part of the deposits; according to J. P. E. Morrison of the U.S. National Museum the fossils range in age from Yarmouth to Recent.

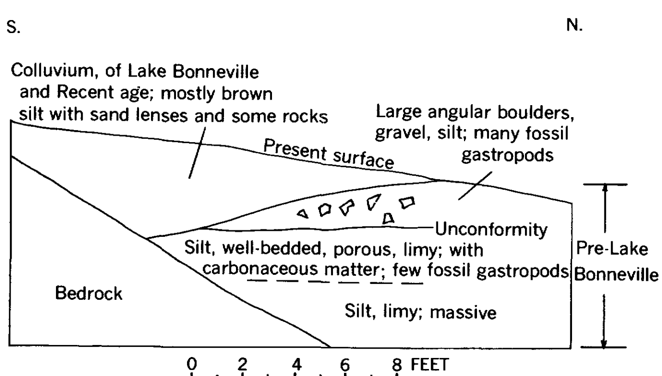

FIGURE 57.—Generalized cross section showing alluvium of pre-Lake Bonneville age overlain by younger colluvium. Section in Burriston Canyon, Eureka quadrangle, about 50 feet above stream channel, NE¼ sec. 20, T. 10 S., R. 2 W.; looking west, altitude about 6,375 feet.

No fossils older than Yarmouth have been found in the unconsolidated deposits lying above the Salt Lake(?) formation, and the age of most of them is evidently Pleistocene or younger. However, in the Oquirrh Mountains, 50 miles to the north, Slentz (1955, p. 23) has assigned to the Pliocene part of his Salt Lake group the 300-foot-thick Harkers fanglomerate of lower Jordan Valley, a formation that appears to be similar to the old alluvial fans in the East Tintic Mountains. Slentz reported no fossils from the Harkers fanglomerate but based his age determination principally on geomorphic evidence. His description that the Harkers has been "truncated and buried beneath the sediments of Lake Bonneville and more recent stream gravels" (Slentz, 1955, p. 28) fits the fans on the eastern flank of the East Tintic Mountains. It seems likely that extensive fan deposits of the Oquirrh Mountains and East Tintic Mountains are of the same age, unless there is a marked difference in the Pliocene and Pleistocene tectonic history of these ranges, which are in the same tectonic belt and are less than 20 miles apart. In the East Tintic Mountains similar fans, which are assigned to the Pleistocene, unconformably overlie beds of the Salt Lake(?) formation that are tilted more than 15°. Although the fans have been faulted in many places along the mountain fronts, none have been tilted like the underlying Salt Lake(?); apparently a marked hiatus occurred after the deposition of the sediments of the Salt Lake(?) formation and before the deposition of the overlying fans.

In some places more than one alluvial deposit of pre-Lake Bonneville age can be distinguished. In Burriston Canyon near the Apex Standard No. 1 shaft, for example, three separate alluvial gravels of pre-Lake Bonneville age can be recognized. The oldest is a gravel of quartzite, limestone, and dolomite boulders lying on a hilltop about 170 feet above the present channel. About one-fourth mile downstream from this gravel there are 2 alluvial terrace gravels—one about 80 feet and the other about 35 feet above the present channel. Both younger gravels consist mostly of volcanic rock fragments; the higher one contains 2–10 percent carbonate rock fragments and the lower one contains 10–25 percent. The lower of these gravels can be traced in almost continuous exposures to the Bonneville shoreline, where it is overlain by gravel of the Bonneville formation.

PRE-WISCONSIN SOIL

Pre-Wisconsin soil—called paleosol by Hunt and Sokoloff (1950, p. 109)—is less strongly developed in

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the East Tintic Mountains than in many places in the Rocky Mountain region. In its typical development elsewhere, the paleosol consists of 5–20 feet of lime-enriched, weathered parent material overlain by about 10 feet of lime-free, reddish-brown clay, the lower part of which locally contains tiny veinlets of calcium carbonate (op. cit., p. 110). This soil has been developed about equally well on a wide variety of parent materials, although the zone that is normally enriched in lime has little calcium carbonate where formed on nonlimy parent materials (Hunt, Varnes, and Thomas, 1953, p. 44). In the East Tintic Mountains area, the typical reddish-brown clay of the pre-Wisconsin paleosol occurs only in a few localities and is rarely as thick as 18 inches. Commonly, only residual remnants a few inches thick remain; the clay has not been found on any of the large fans that are cut by lake-shore erosion and overlain by lake deposits. If the paleosol was once well developed on these deposits in the East Tintic Mountains, the clay zone has been almost entirely removed. However, a surface or near-surface zone rich in calcium carbonate is a distinguishing character of all deposits described here as of pre-Lake Bonneville age. This zone consists mainly of powdery lime carbonate mixed with fine silt, and in it caliche coatings are common on gravel fragments, and it may or may not have hardpan caliche near the surface. Most of the pre-Lake Bonneville gravel deposits contain high proportions of silt (20–90 percent), either mixed with coarse fragments or as distinct beds or lenses several feet thick. The calcium carbonate is disseminated through this fine material to depths of 15 to 20 feet, and is surprisingly uniform in amount regardless of whether the gravel contained is limestone or volcanic rock. In fact, the small amount of gravel in many deposits and the freshness of the pebbles in the gravel suggest that the lime carbonate may be more closely related to the silt than to the gravel associated with the silt.

This lime-rich zone is tentatively correlated with the lime-enriched zone of the pre-Wisconsin paleosol, and deposits in which it is found are assigned a pre-Lake Bonneville age. Many Lake Bonneville and younger deposits also contain appreciable amounts of calcium carbonate, but where the two are otherwise similar lithologically, deposits of pre-Lake Bonneville and post-Pliocene age contain much more lime than the younger deposits. Deposits of pre-Lake Bonneville age contain sufficient lime to lighten the color of the silt, locally making it white or cream colored, whereas the Lake Bonneville deposits do not contain enough lime to affect appreciably the color of the fine portions. The lime zone of the older deposits is 3 to 5 times as thick as that in the younger deposits; it has been found in strong concentration in all deposits cut by lake shore erosion or overlain by lake sediments, but not in deposits younger than the lake.

The sparse, thin remnants of the characteristic reddish-brown clay of the pre-Wisconsin paleosol indicate that the old soil was not so strongly developed in the East Tintic Mountains as in the Wasatch Range and elsewhere, or that subsequent erosion has removed most of the clay. The vast quantities of caliche and finely disseminated calcium carbonate in the deposits of pre-Lake Bonneville age could be the result of pedologic processes, as is the reddish-brown clay; but the absence of a clay zone on the thick lime-rich alluvial fans of undoubted pre-Lake Bonneville age suggests that the carbonate was concentrated in part at least by other than the pedologic processes that produced the red clay and its caliche zone.

The following measured stratigraphic sections show part of the range in composition and thickness of some of the alluvial-colluvial deposits of pre-Lake Bonneville age.

Stratigraphic section A. Colluvium of pre-Lake Bonneville age overlain by silt and colluvium of Provo and Recent age in adit about three-fourths mile northwest of North Standard shaft in SW¼ sec. 27, T. 9 S., R. 2 W., at altitude of 6,600 feet.

	Thickness Ft	In
Provo and Recent colluvium:		
Gravel and silt; fragments chiefly volcanic rock. Limy at base. Base strikes N. 25° W., dips 15° NE	2	6
Provo and Recent silt:		
Silt and clay, yellowish-brown. Contains sparse angular tuff fragments. Probable loess	3	6
Pre-Lake Bonneville colluvium:		
Chiefly of flat fragments of limestone less than 1 in to 1 ft long. Top surface strikes N. 40° W., dips 25° NE	1	
Base covered.		

Stratigraphic section B. Colluvium of pre-Lake Bonneville age overlain by colluvium of Lake Bonneville and Recent age, along road 350 feet north-northwest of Beck Tunnel No. 2 shaft in the NW¼ sec. 20, T. 10 S., R. 2 W., at altitude of about 7,025 feet.

	Thickness Ft	In
Lake Bonneville and Recent colluvium:		
Silt, dark-brown; and angular rock fragments having no caliche	1	6
Pre-Lake Bonneville colluvium:		
Silt, very limy; and angular rock fragments covered with caliche	3	

Stratigraphic section C. Colluvium of pre-Lake Bonneville age with younger colluvium at surface, measured on north face of Sunrise Peak, NW¼ sec. 17, T. 11 S., R. 2 W.

	Thickness (feet)
Surface material:	
Cobbles and boulders.	
Pre-Lake Bonneville colluvium:	
Clay, brown, silty	1
Silt, yellowish-brown, clayey, very limy. Scattered small angular cobbles and boulders occur near base	10
Silt, brown, clayey, with angular cobbles and boulders throughout. Bedrock surface dips about 15°; bedding in colluvium approximately parallel to bedrock surface	20

Stratigraphic section D. Alluvium(?) of pre-Lake Bonneville age, measured in shaft a mile west-northwest of Laclede mine at boundary between secs. 1 and 12, T. 11 S., R. 3 W., at altitude of about 6,025 feet.

	Thickness (feet)
Surficial material:	
Pebbles and cobbles of volcanic rock, partly covered with caliche (post-Lake Bonneville).	
Pre-Lake Bonneville alluvium(?):	
Silt, tan- to cream-colored, very limy	6
Silt, sand, and gravel; cobbles to 6 inches in diameter apparently filling channels	2
Silt, tan, very limy; with few or no pebbles; possibly of loessic origin. Basal contact fairly sharp	9
Gravel with pebbles to 2 in. in diameter partly imbricated	2
Base concealed.	

DEPOSITS OF PRE-LAKE BONNEVILLE AND LAKE BONNEVILLE AGE

LANDSLIDES

Landslides of pre-Lake Bonneville or early Lake Bonneville age are present in the East Tintic Mountains on east-, northeast-, and north-facing slopes; they involve Tertiary volcanic rocks but not Paleozoic sedimentary rocks. The most important slides are in the Eureka quadrangle: (a) on the east face of Lime Peak; (b) on the north slope of Homansville Canyon south of Lime Peak; (c) a mile south-southeast of the Zuma mine in the SW¼ sec. 28, T. 10 S., R. 2 W.; (d) on the north slope of Big Hill, about a mile west of Dividend; and (e) a mile south of the Apex Standard No. 1 shaft near the center of sec. 27, T. 10 S., R. 2 W. All the landslides occur below steep scarps and have more or less hummocky, nearly horizontal surfaces.

Some of the features of the landslide south-southwest of the Zuma mine in the SW¼ sec. 28, T. 10 S., R. 2 W., indicate its approximate age. This landslide appears on the map of the Eureka quadrangle as a relatively flat bench above the 6,800-foot contour. Two soils were found on the slide; the lower soil has a very strong lime-carbonate zone covered by a red-brown clay, typical of a pre-Wisconsin paleosol (Hunt and Sokoloff, 1950, p. 109–110) and the overlying soil has a much less limy zone and appears to correspond to a Wisconsin soil. This relationship is shown in stratigraphic section E. The scarp above the landslide has only the Wisconsin soil developed on it, but at several places on the same slope north of the scarp, remnants of both red-brown clay and the strong lime zone occur. The presence of only the Wisconsin soil on the scarp, although the pre-Wisconsin soil is developed on the slope nearby and is present on the slide, indicates that the slide must have occurred in the interim between the development of the two soils, and thus it is probably late pre-Lake Bonneville or early Lake Bonneville in age.

Stratigraphic section E. Section showing pre-Lake Bonneville soil overlain by soil of probable Lake Bonneville age on landslide block 3,500 feet N. of Silver Pass in SW. corner sec. 28, T. 10 S., R. 2 W., at altitude of about 6,700 feet.

	Thickness Ft	Thickness In
Surficial material:		
Loose angular cobbles and boulders up to 4 ft in diameter.		
Lake Bonneville(?) soil:		
Silt, light yellowish-brown, slightly limy at base		6
Silt, gray to black; not limy		3
Silt, red-brown, clayey; not limy	1	3
Pre-Lake Bonneville soil:		
Silt, red-brown; moderately limy at top and grading downward into very limy zone	>2	
Base not exposed.		

The other slides have not been studied in detail, but their relation to other nearby Quaternary deposits suggests that they also are late pre-Lake Bonneville or early Lake Bonneville in age.

The landslides of the East Tintic Mountains provide evidence that a period of strong erosion either preceded or accompanied the early filling of Lake Bonneville. Probably the landslides occurred during one of the periods when the pre-Lake Bonneville fans and older colluvium were deeply dissected. Since that time, colluvial deposits having surfaces as steep as 26° and 31° have remained relatively stable. Probably the dry climate, good drainage, and the absence of lubricating materials such as clay are all factors that have permitted unconsolidated deposits to maintain steep slopes throughout post-Lake Bonneville time.

DEPOSITS OF LAKE BONNEVILLE AGE

Lake Bonneville bordered the East Tintic Mountains area on the east, filled most of Cedar Valley, extended into Rush Valley, but did not invade the Tintic Valley north of Jericho (lat. 39°45′ N.). The lake cut shorelines at many different levels, but the highest shoreline, named Bonneville by Gilbert (1890,

p. 93–94), is the most prominent. The shorelines were cut in both bedrock and alluvial fans, and lacustrine silt, sand, and gravel were deposited on both bedrock and fans. After the lake receded, the shorelines and lake deposits were in turn cut by stream channels and partly covered by younger alluvial and colluvial deposits.

ALPINE FORMATION

At its type locality in northern Utah Valley, the Alpine formation, which has a maximum thickness of about 150 feet, consists of a gravel member, a sand member, and a silt and clay member (Hunt and others, 1953, p. 17–18).

In the East Tintic Mountains area, the deposit correlated with the Alpine formation is principally gray silt and very fine sand. It is well sorted, moderately well bedded, and contains abundant remains of gastropods and ostracodes. It is well exposed one-half mile south of U.S. Route 6 near the eastern edge of the Eureka quadrangle, below an altitude of about 5,075 feet. Here streams drained eastward from the relatively low-lying east-central part of the quadrangle and carried fine detritus into the ancient lake. Lake currents evidently carried the material southward and westward, depositing it as an L-shaped embankment around the bedrock headland. These deposits of the Alpine formation are probably thicker than others along the eastern edge of the mountains, but the base is concealed, and the estimated thickness—25 feet—is little better than a guess.

In the northeast corner of the Boulter Peak quadrangle the Alpine formation is exposed over an area of about 200 acres. There it is unconformably overlain by alluvial gravelly silt thought to be of Provo age.

ALLUVIAL SILT OF ALPINE AGE

A yellowish-brown alluvial silt is correlated with lake silt of the Alpine formation. This silt has little or no coarse material, but contains veinlets of caliche. The silt has been traced far enough above the Lake Bonneville shoreline to preclude the possibility that it is a lake deposit.

In the Fivemile Pass quadrangle, about 3½ miles east of the Topliff quarry in the NW¼ sec. 1, T. 8 S., R. 3 W., a yellowish-brown silt of probable Alpine age is exposed in an arroyo (fig. 58). It extends downstream in a continuous exposure to a point where it grades into highly fossiliferous silt of the Alpine formation. At an altitude of about 5,090 feet no caliche veinlets are recognized, and the color of the silt is between the yellowish brown of the alluvial silt and the light gray of the Alpine formation. Lying above this apparently transitional zone is a 1-foot-thick gravel of partly decomposed discoidal pebbles. Overlying the gravel is gravelly silt of Provo(?) age.

Small erosion remnants of a yellowish-brown silt were found in a few canyons of the area. The occurrence of these remnants on bedrock or on gravel of pre-Lake Bonneville age is of little help in correlation, but because they include little or no coarse material, locally contain some clay, and have tiny veinlets of caliche, they are tentatively correlated with the alluvial silt of Alpine age.

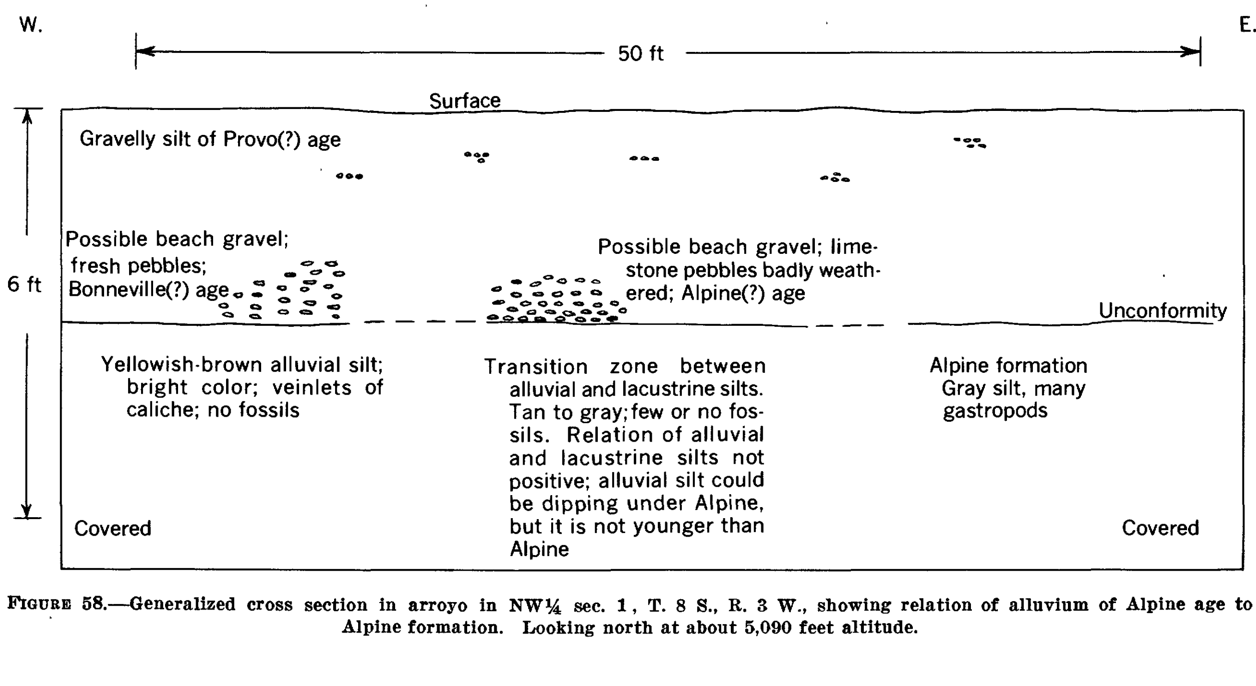

FIGURE 58.—Generalized cross section in arroyo in NW¼ sec. 1, T. 8 S., R. 3 W., showing relation of alluvium of Alpine age to Alpine formation. Looking north at about 5,090 feet altitude.

BONNEVILLE FORMATION

The Bonneville formation includes gravel and sand at, or just below, the Bonneville shoreline, but its deposits are as sparse in this area as in other parts of the Lake Bonneville basin. In the northeast corner of the Boulter Peak quadrangle, the gravel forms a dissected curving beach at about 5,140 feet altitude. Along the eastern edge of the Eureka quadrangle, the gravel and sand extend for about 9 miles, occurring here and there as beaches, benches, bars, and spits.

The gravel consists of rounded fresh pebbles and small cobbles, many of them flattened or discoidal from wave action on the Bonneville beach, but fine-grained slope wash or windborne material of later age commonly is mixed into the upper few inches of the gravel. In many places the gravel may be identified by pebbles that are different from the nearby source rocks. For example, the beach deposits in sec. 25, T. 10 S., R. 2 W., contain limestone pebbles which moved southward by shore drift across the mouths of local streams that drained only volcanic rocks.

Most of the gravel deposits are close to the Bonneville shoreline; but about one-half a mile south of U.S. Route 6 in sec. 13, T. 10 S., R. 2 W., and eastward, several parallel benches of gravel overlie the embankment deposit of silt of the Alpine formation through a vertical range of at least 200 feet. The gravel benches are L-shaped, convex toward the lake, and evidently are beach deposits, showing that the lake stood at many levels below 5,140 feet. In other places the gravel occurs as bars, as in the SW¼ sec. 1, T. 10 S., R. 2 W., and as spits, as in sec. 1, T. 11 S., R. 2 W. The base of the gravel is not exposed, but the thickness of the gravel probably nowhere exceeds 20 feet.

Two exposures of dissected parts of a once-continuous sand bar were found in sec. 12, T. 10 S., R. 2 W., north of U.S. Route 6. The sand averages 1–2 mm in diameter, but some pebbles are as large as 15 mm. The sand and pebbles are finer grained southwestward, indicating shore drift in that direction. The bar is 10–12 feet thick and rests on bouldery fanglomerate or tuff.

GRAVELLY SILT OF PROVO(?) AGE

Unconformably overlying the Alpine formation is an alluvial gravelly silt similar in color to yellowish-brown alluvial silt of Alpine age, but more drab. It is probaby the most extensive unconsolidated unit of the region, covering large areas in Rush, Cedar, and Tintic Valleys, and smaller areas in the large canyons.

In the basins, the gravelly silt is remarkably uniform, consisting principally of silt and fine sand with sparse lenses of pebbles, which make up only 1–2 percent of the whole. Although unconsolidated, it crops out along the sides of small gullies as nearly vertical cliffs. The silt is only faintly bedded, but contains lenses of gravel. In canyons, as near the mouth of Broad Canyon, the gravelly silt contains as much as 75 percent pebbly gravel, and the lime in it is conspicuous.

The gravelly silt deposits are thickest near the head of Rush Valley, about 2 miles west of the Boulter Peak quadrangle, where beds up to 40 feet thick overlap the Salt Lake(?) formation. These gravelly silt deposits can be traced upstream over fan gravel of pre-Lake Bonneville age (fig. 59) to the mountain front, but

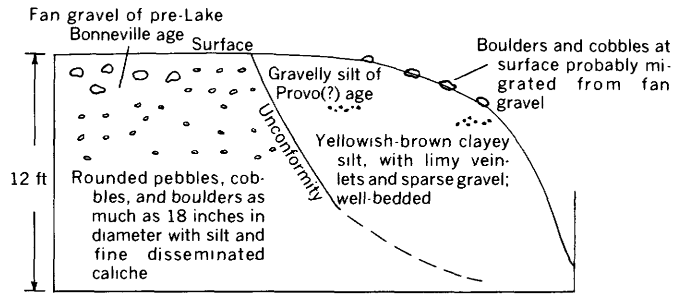

FIGURE 59.—Generalized cross section showing relation of gravelly silt of Provo(?) age to fan gravel of pre-Lake Bonneville age. SE corner sec. 26, T. 9 S., R. 4 W., about 200 feet west of southwest corner of Fivemile Pass quadrangle.

most of the deposits have been removed from the lower canyons, and only sparse remnants of doubtfully similar deposits occur there (fig. 60).

In the northeast corner of the Boulter Peak quadrangle the gravelly silt overlies the Alpine formation, but the relation between it and nearby deposits of the Bonneville formation is not clear. Tentatively, this gravelly silt is regarded as younger than the Bonneville formation.

SILTS OF ALPINE AND PROVO(?) AGES

The age of some deposits that consist principally of silt is difficult to determine. For the most part, the

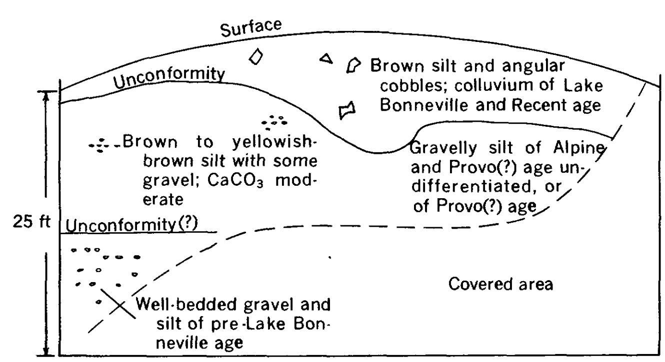

FIGURE 60.—Generalized cross section showing colluvium covering remnants of alluvial deposits of Lake Bonneville and pre-Lake Bonneville age. Scranton Canyon (Barlow Canyon on some maps) near eastern edge sec. 7, T. 9 S., R. 3 W.

alluvial silt of Alpine age is entirely silt, whereas most of the gravelly silt of Provo(?) age has definite lenses of gravel; however, the presence or absence of a small amount of gravel in silts of similar color provides only very tenuous evidence of identity. Gravel-bearing silt deposits that cannot be traced directly to the Lake Bonneville shoreline, such as those in Ruby Hollow and in Diamond Gulch, are given only a Lake Bonneville age designation, signifying that the deposits may be of either Alpine or Provo(?) age.

Other deposits whose age is not readily determined occur in the high, broad parts of some of the westward-draining valleys in the Boulter Peak quadrangle. These deposits consist of brown, clayey, gravelly silt lying topographically below gravel of pre-Lake Bonneville age. Similar deposits occur only sparsely in the intermediate reaches of the canyons and so cannot be traced with certainty to Lake Bonneville lacustrine deposits. In the Boulter Peak quadrangle the clayey gravelly silt is probably the equivalent of the gravelly silt of Provo(?) age, but may be as old as Alpine, and consequently it is placed with the undifferentiated deposits.

GRAVEL OF PROVO(?) AGE

A coarse gravel containing gray silt and boulders as large as 1 foot in diameter fills a channel in the Provo(?) gravelly silt in Broad Canyon. The gravel is well bedded, and its upper 2 feet is principally silt with only sparse, subangular pebbles. Although the base is not exposed, the fill is at least 10–12 feet thick. The lower 8–10 feet consists of moderately well sorted, subrounded pebbles, cobbles, and small boulders with as much as 25 percent gray silt.

This gravel is confined to the main stream channels—having been removed from tributary channels if ever deposited there. At the mouths of canyons the gravel forms alluvial fans that overlap fans of pre-Lake Bonneville age.

DEPOSITS OF LAKE BONNEVILLE AND RECENT AGE

COLLUVIUM

Colluvium of Lake Bonneville and Recent age includes talus, frost-action (congeliturbate) deposits, and the almost ubiquitous slope wash of both steep and gentle slopes.

Talus and rock streams occur on steep slopes on both Paleozoic and Tertiary rock formations but are thicker and more widespread on Tertiary rock. The talus is composed of fresh, angular rock fragments of pebble to large block size with little or no fine material. Rock streams of cobble-size fragments on Paleozoic bedrock commonly surround remnants of pre-Lake Bonneville colluvium. An extensive talus deposit fills the scarp of the landslide on the east side of Lime Peak.

Other related deposits occur in nearly flat, shallow depressions at high elevations. There congeliturbate deposits, consisting of a few feet of angular cobbles mixed with smaller fragments, sand, and silt, are commonly covered by 10–12 inches of silty material that has a weakly developed soil profile. The rubbly material below the silt is not at all stratified, but apparently has been "churned" in place by frost action. The rather sharp contact between the dominantly fine layer and the coarse fragments suggests that the frost action which stirred the lower material became less active at some time in the past, and that fine slope wash later covered the deposit.

The slope wash deposits of Lake Bonneville and Recent age contain gray or brown silt, angular to subrounded pebbles and cobbles, and are moderately well bedded parallel to their slopes. Most of them are only a few feet thick, but partly or completely conceal older alluvial and colluvial deposits which they overlap (fig. 61). In a few localities, however, erosion of the bedrock and deposition of detritus have been more active than in most, and in places the younger colluvium is much as 50 feet thick.

The colluvial cover generally is thicker on north-facing slopes than on south-facing slopes. This is especially evident in the many east-west canyons of the Boulter Peak quadrangle and also in Ruby Hollow in the Eureka quadrangle.

The younger colluvial deposits have little or no caliche and less disseminated lime carbonate than the pre-Lake Bonneville deposits, and they are generally characterized by gray or brown rather than light yellowish-brown silt. No fossils have been found in the deposits of Lake Bonneville and Recent age.

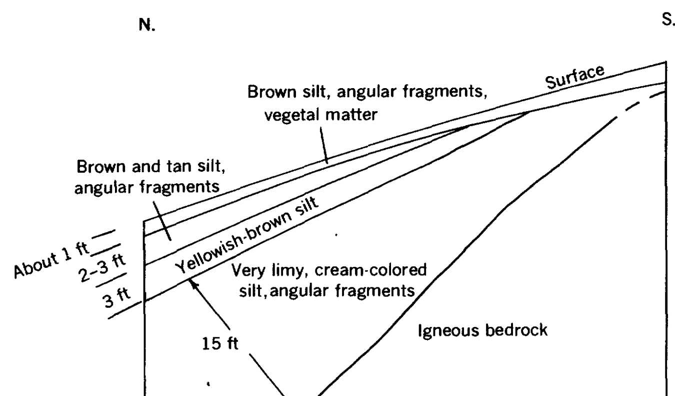

FIGURE 61.—Generalized cross section showing colluvium of Lake Bonneville and Recent age overlying and concealing deposits of pre-Lake Bonneville age. Mine cut south of Mammoth, Tintic Junction quadrangle, NW¼SE¼ sec. 25, T. 10 S., R. 3 W.

The Lake Bonneville and Recent colluvium unconformably overlies the pre-Lake Bonneville alluvium-colluvium. In many places the older deposit is topographically higher than the younger colluvium but is surrounded by it.

The following measured stratigraphic sections show a few of the colluvial deposits of Lake Bonneville and Recent age.

Stratigraphic section F. Colluvium of Lake Bonneville and Recent age, in augered hole about 1,300 feet northwest of Lime Peak, NW¼ sec. 4, T. 10 S., R. 2 W., at altitude of about 6,425 feet

	Thickness Ft	In
Lake Bonneville and Recent colluvium:		
Silt, gray, containing vegetal material; angular pebbles near surface	1	2
Silt, light-yellowish-brown, clayey		10
Silt, light-yellowish-brown, clayey; with moderate lime	1	4
Base not penetrated.		

Stratigraphic section G. Colluvium and alluvium of Lake Bonneville and Recent age, measured in shaft 3,900 feet N. 63° W. of crest of Pinyon Peak, in sec. 33, T. 9 S., R. 2 W., at altitude about 6,050 feet

	Thickness (feet)
Lake Bonneville and Recent colluvium and alluvium:	
Gravel, poorly sorted, angular, coarse- and medium-grained; little or no fine-grained material	4
Gravel, medium-grained, faintly bedded, sparse cobbles	8
Base concealed, but material on the shaft dump shows gravel to be underlain by yellowish-brown silt of probable loessic origin.	

Stratigraphic section H. Colluvium of Lake Bonneville and Recent age overlying older alluvium and colluvium probably of Lake Bonneville age, measured in pit 1 mile N. 66° W. of crest of Pinyon Peak in SE. corner sec. 29, T. 9 S., R. 2 W., at altitude of 5,925 feet

	Thickness (feet)
Lake Bonneville and Recent colluvium:	
Gravel and gray-brown silt; rock fragments poorly sorted, angular, up to 3 in. in diameter	2
Silt, yellowish-brown; with lenses of bedded fine gravel	4
Lake Bonneville(?) alluvium and colluvium:	
Gravel, poorly sorted, angular	4
Silt, yellowish-brown	2
Base concealed.	

RECENT DEPOSITS

ALLUVIUM

The oldest Recent alluvium is gravel that fills or partly fills the present flood plains of most streams; in areas draining volcanic rock, it forms extensive rubbly fan deposits, such as those along the eastern front of the mountains. In the major streams, the gravel consists of small cobbles, pebbles, sand, and silt, and its thickness ranges from a few inches to 15 feet. It is well bedded, but individual beds are not so distinctively sorted as in some of the alluvium of pre-Lake Bonneville age. At the mouths of tributaries and of canyons along the mountain front, gravel composed of coarse pebbles and small boulders occurs as fans that are lithologically like the gravel of Provo(?) age but can readily be distinguished from older fans by their rougher surfaces. These fans are rubbly and cobbles and small boulders are scattered over their surfaces.

Younger alluvial deposits form narrow terraces 2–3 feet above present channel bottom along parts of some major streams. They are of little extent and difficult to correlate.

A striking but restricted and sparsely distributed alluvium consists of angular to subrounded boulders and cobbles which are found in bottoms of steep canyons or near their mouths. This alluvium contains little or no fine material; some deposits contain only fragments 6 inches or more in diameter. The deposits apparently are the remains of mudflows whose fine constituents later were moved downstream.

EOLIAN DEPOSITS

In Cedar Valley about 2 miles south of Fairfield, sand dunes that were once stable are now being reattacked by the wind. The dunes which are more than 15 feet thick, overlie lake or stream deposits of Lake Bonneville age. Vegetation covers their western slopes but is sparse on the eastern slopes, which are now being deflated. A large part of a mammal skull, identified as *Bison bison* by G. E. Lewis of the U.S. Geological Survey, and many flakes and chips, evidently from the activity of Indian tool or weapon makers, have been found in the deflated part of the dunes. Probably the dunes were formed during or immediately after the recession of Lake Bonneville.

Other dunes of fine sand and silt, 2–3 feet high and apparently younger than the dunes south of Fairfield, cover about 2 square miles in the northeast and northwest corners of the Boulter Peak quadrangle. These younger dunes were derived from the deflation of fine-grained alluvial and lacustrine deposits. The dunes in the northwest corner of the quadrangle are evidently the result of cultivation and are less than 100 years old.

COLLUVIUM

Some very recent slump and creep deposits of restricted occurrence have also been found in the East Tintic Mountains. Two such deposits appear on aerial photographs taken in 1952, but not on those taken in 1943. Both are only a few thousand square feet in area. One slump, in sec. 33 near Silver Pass, evidently resulted from the headward erosion of a stream, which effected a capture in Recent, probably historic, time (Goode, 1954, p. 1376). Another slump occurred on the north face of the hill south of Dividend. This slump appeared fresh in the summer of 1952; it may have occurred during the spring thaw after the very heavy snows of the winter of 1951–52, which were about three times the annual average (see p. 5).

REFERENCES CITED

Abbott, W. O., 1951, Cambrain diabase flow in central Utah: Compass, v. 29, no. 1, p. 51–10.

Altschuler, Z. S., Cisney, E. A., and Barlow, I. H., 1953, X-ray evidence on the nature of the carbonate-apatites [abs.]: Geol. Soc. America Bull., v. 63, no. 12, pt. 2, p. 1230–1231.

Ames, L. L., and Sand, L. B., 1957, Genesis of the Fox Clay, Utah County, Utah [abs.]: Geol. Soc. America Bull., v. 68, no. 12, pt. 2, p. 1857.

Baker, A. A., 1946, Geology of the Green River Desert-Cataract Canyon region, Emery, Wayne, and Garfield Counties, Utah: U.S. Geol. Survey Bull. 951, 122 p.

———1947, Stratigraphy of the Wasatch Mountains in the vicinity of Provo, Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Chart 30.

Baker, A. A., Huddle, J. W., and Kinney, D. M., 1949, Paleozoic geology of north and west sides of Uinta Basin, Utah: Am. Assoc. Petroleum Geologists Bull., v. 33, no. 7, p. 1161–1197.

Baker, A. A., and Williams, J. Steele, 1940, Permian in parts of Rocky Mountain and Colorado Plateau regions: Am. Assoc. Petroleum Geologists Bull., v. 24, p. 619–635.

Beeson, J. J., 1927, Mining districts and their relation to structural geology: Am. Inst. Mining Metall. Engineers Trans., v. 75, p. 757–792.

Behre, C. H., Jr., 1953, Geology and ore deposits of the west slope of the Mosquito Range: U.S. Geol. Survey Prof. Paper 235, 176 p.

Billingsley, Paul, and Crane, G. W., 1933, The Tintic mining district, *in* The Salt Lake Region, 16th Internat. Geol. Congress Guidebook 17: Washington, D.C., U.S. Govt. Printing Office, p. 101–124.

Birch, Francis, Schairer, J. F., and Spicer, H. C., eds., 1942, Handbook of physical constants: Geol. Soc. America Spec. Paper 36, 325 p.

Boutwell, J. M., 1912, Geology and ore deposits of the Park City district, Utah: U.S. Geol. Survey Prof. Paper 77, 231 p.

Bulter, B. S., 1913, Geology and ore deposits of the San Francisco and adjacent districts, Utah: U.S. Geol. Survey Prof. Paper 80, 212 p.

Butler, B. S., Loughlin, G. F., Heikes, V. C., and others, 1920, The ore deposits of Utah: U.S. Geol. Survey Prof. Paper 111, 672 p.

Calkins, F. C., and Butler, B. S., 1943, Geology and ore deposits of the Cottonwood-American Fork area, Utah: U.S. Geol. Survey Prof. Paper 201, 152 p.

Cheney, T. M., 1957, Phosphate in Utah and an analysis of the stratigraphy of the Park City and Phosporia formations, Utah—a preliminary report: Utah Geol. Mineralog. Survey Bull. 59, 52 p.

Cook, D. R., 1957, Ore deposits of the main Tintic mining district, *in* Geology of the East Tintic Mountains and ore deposits of the Tintic mining districts; Utah Geol. Soc. Guidebook 12, p. 57–79.

Cook, K. L., and Berg, J. W., Jr., 1955, Regional gravity survey in Salt Lake and Utah Counties, Utah [abs.]: Oil and Gas Jour., v. 54, no. 24, p. 130.

Crane, G. W., 1917, Geology of the ore deposits of the Tintic mining district, Utah: Am. Inst. mining Engineers Trans., v. 54, p. 342–355.

Crittenden, M. D., Sharp, B. J., and Calkins, F. C., 1952, Geology of the Wasatch Mountains east of Salt Lake City, Parleys Canyon to Traverse Range, *in* Geology of the central Wasatch Mountains, Utah: Utah Geol. Soc. Guidebook 8, p. 1–37.

Croft, M. G., 1956, Geology of the northern Onaqui Mountains, Tooele County, Utah: Brigham Young University Research Studies, Geology Ser., v. 3, no. 1, 48 p.

Darton, N. H., 1910, A reconnaissance of parts of northwestern New Mexico and northern Arizona: U.S. Geol. Survey Bull. 435, 88 p.

Deiss, C. F., 1933, Paleozoic formations of northwestern Montana: Montana Bur. Mines and Geology Mem. 6, 51 p.

Deiss, C. F., 1938, Cambrian formations and sections in part of the Cordilleran trough: Geol. Soc. America Bull., v. 49, no. 7, p. 1067–1168.

Dengler, H. F., 1957, Phosphate: Eng. Mining Jour., v. 158, no. 2, p. 122–123.

Disbrow, A. E., 1957, Fivemile Pass quadrangle, Tooele and Utah Counties, Utah: U.S. Geol. Survey Mineral Inv. Map MF–131.

Duncan, D. C., 1953, Reconnaissance investigations for uranium in black shale deposits of the Western States during 1951 and 1952: U.S. Geol. Survey TEI–381, Issued by U.S. Atomic Enegry Comm., Tech. Inf. Service, Oak Ridge, Tenn., 87 p.

Eardley, A. J., 1933, Stratigraphy of the southern Wasatch Mountains, Utah: Michigan Acad. Sci. Arts and Letters (1932 Papers), v. 18, p. 307–344.

——— 1934, Structure and physiography of the southern Wasatch Mountains, Utah: Mich. Acad. Sci. Arts and Letters (1933 Papers), v. 19, p. 377–400.

——— 1938, Sediments of Great Salt Lake, Utah: Am. Assoc. Petroleum Geologists Bull., v. 22, no. 10, p. 1305–1411.

——— 1944, Geology of the north-central Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 55, no. 7, p. 819–894.

——— 1951, Structural geology of North America: New York, Harper and Bros., 624 p.

Eardley, A. J., and Hatch, R. A., 1940, Proterozoic(?) rocks in Utah: Geol. Soc. America Bull., v. 51, no. 6, p. 795–843.

Gilbert, G. K., 1890, Lake Bonneville: U.S. Geol. Survey Mon. 1, 438 p.

Gilluly, James, 1929, Geology and oil and gas prospects of part of the San Rafael Swell, Utah: U.S. Geol. Survey Bull. 806–C, p. 69–130.

——— 1932, Geology and ore deposits of the Stockton and Fairfield quadrangles, Utah: U.S. Geol. Survey Prof. Paper 173, 171 p.

Girty, G. H., 1903, The Carboniferous formations of Colorado: U.S. Geol. Survey Prof. Paper 16, 546 p.

Goode, H. D., 1954, Migrating drainage divide in the East Tintic district, Utah [abs.]: Geol. Soc. America Bull., v. 65, no. 12, pt. 2, p. 1375–1376.

Granger, A. E., 1953, Stratigraphy of the Wasatch Range near Salt Lake City, Utah: U.S. Geol. Survey Circ. 296, 14 p.

Hinds, N. E. A., 1936, Uncompahgran and Beltian deposits in western North America: Carnegie Inst. Washington Pub. 463, p. 53–136.

Hintze, F. F., 1913, A contribution to the geology of the Wasatch Mountains, Utah: New York Acad. Sci. Annals 23, p. 85–143.

Hintze, L. F., 1951, Lower Ordovician detailed stratigraphic sections for western Utah: Utah Geol. Mineralog. Survey Bull. 39, 100 p.

——— 1952, Lower Ordovician trilobites from western Utah and eastern Nevada: Utah Geol. Mineralog. Survey Bull. 48, p. 1–249.

Holland, F. D., Jr., 1952, Stratigraphic details of Lower Mississippian rocks of northeastern Utah and southwestern Montana: Am. Assoc. Petroleum Geologists Bull., v. 36, no. 9, p. 1697–1734.

Huddle, J. W., and McCann, F. T., 1947, Geologic map of Duchesne River area, Wasatch and Duchesne Counties, Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 75.

Hunt, C. B., and Sokoloff, V. P., 1950, Pre-Wisconsin soil in the Rocky Mountain region, a progress report: U.S. Geol. Survey Prof. Paper 221–G, p. 109–123.

Hunt, C. B., Varnes, H. D., and Thomas, H. E., 1953 (1954), Lake Bonneville: Geology of northern Utah Valley, Utah: U.S. Geol. Survey Prof. Paper 257–A, p. 1–99.

Jones, D. J., and Marsell, R. E., 1955, Pleistocene sediments of lower Jordan Valley, Utah, *in* Tertiary and Quaternary geology of the eastern Bonneville Basin: Utah Geol. Soc. Guidebook 10, p. 85–112.

Kazakov, A. V., 1937, The phosphorite facies and the genesis of phosphorites, *in* Geological Investigations of Agricultural ores: Trans. Sci. Inst. Fertilizers and Insecto-Fungicides, No. 142 (published for the Internat. Geol. Cong. 17th) Leningrad, p. 95–113.

Keiser, H. D., 1928, Lime plant of Chief Consolidated near Eureka, Utah, has some unusual features: Eng. Mining Jour., v. 126, no. 8, p. 298–299, August 1928.

Kerr, P. F. and others, 1950, Analytical data on reference clay minerals: Am. Petroleum Inst. Project 49, Clay Minerals Standards, Prelim. Rept. No. 7, New York, Columbia University.

Kinney, D. M. and Rominger, J. F., 1947, Geology of the White rocks, Ashley Creek area, Uintah County, Utah: U.S. Geol. Survey Oil and Gas Inv. Prelim. Map 82.

Krauskopf, K. B., 1956, Factors controlling the concentrations of thirteen rare metals in sea water: Geochemica et Cosmochimica Acta, v. 9, p. 1–32B, London, Pergamon Press Ltd.

Lindgren, Waldmar, and Loughlin, G. F., 1919, Geology and ore deposits of the Tintic mining district, Utah: U.S. Geol. Survey Prof. Paper 107, 282 p.

Longwell, C. R., and Dunbar, C. O., 1936, Problems of the Pennsylvanian-Permian boundary in southern Nevada: Am. Assoc. Petroleum Geologists Bull., v. 20, no. 9, p. 1198–1207.

Lovering, T. S., and others, 1949, Rock alteration as a guide to ore—East Tintic district, Utah: Econ. Geology Mon. 1, 65 p.

McKelvey, V. E., Swanson, R. W., and Sheldon, R. P., 1953, The Permian phosphorite deposits of western United States, in Saint Guilhem, P. L. R., ed., Origine des gisements de phosphates de chaux: Internat. Geol. Cong., 19th, Algiers, Comptes Rendus, sec. 11, fasc. 11, p. 45–64.

McKelvey, V. E., Williams, James Steele, Sheldon, R. P., Cressman, E. R., Cheney, T. M., and Swanson, R. W., 1956, Summary description of Phosphoria, Park City, and Shedhorn formations in western phosphate field: Am. Assoc. Petroleum Geologists Bull., v. 40, no. 12, p. 2826–2863.

Mansfield, G. R., 1927, Geography, geology, and mineral resources of part of southeastern Idaho, with descriptions of Carboniferous and Triassic fossils by Girty, G. H.: U.S. Geol. Survey Prof. Paper 152, 453 p.

Merriam, C. W., 1940, Devonian stratigraphy and paleontology of the Roberts Mountains region, Nevada: Geol. Soc. America Special Paper 25, 114 p.

Miller, A. K., 1930, The age and correlation of the Bighorn formation of northwestern United States: Am. Jour. Sci. 5th ser., v. 20, p. 195–213.

Miller, A. K., and Cline, L. M., 1934, The cephalopods of the Phosphoria formation of northwestern United States: Jour. Paleontology, v. 8, p. 281–302.

Miller, A. K., Furnish, W. M., and Clark, D. L., 1957, Permian ammonoids from western United States: Jour. Paleontology, v. 31, p. 1057–1058.

Moore, G. W., 1954, Extraction of uranium from cold water solutions by coal and other materials: Econ. Geology, v. 49, p. 652–658.

Morris, H. T., 1957, General geology of the East Tintic Mountains, Utah, *in* Geology of the East Tintic Mountains and ore deposits of the Tintic mining districts: Utah Geol. Soc. Guidebook 12, p. 1–56.

Muessig, S. J., 1951, Eocene volcanism in central Utah: Science, v. 114, no. 2957, p. 234.

Nolan, T. B., 1935, The Gold Hill mining district, Utah: U.S. Geol. Survey Prof. Paper 177, 172 p.

——— 1943, The Basin and Range province in Utah, Nevada, and California: U.S. Geol. Survey Prof. Paper 197–D, p. 141–196.

Nolan, T. B., Merriam, C. W., and Williams, J. Steele, 1956, The stratigraphic section in the vicinity of Eureka, Nevada: U.S. Geol. Survey Prof. Paper 276, 77 p.

Olmstead, S. G., 1921, Economic geology of the Ophir mining district, Utah: Econ. Geology, v. 16, p. 433–456.

Olson, R. H., 1956, Geology of the Promontory Range, *in* Geology of parts northwestern Utah: Utah Geol. Soc. Guidebook 11, p. 41–75.

Osmond, J. C., 1954, Dolomites in Silurian and Devonian of east-central Nevada: Am. Assoc. Petroleum Geologists Bull., v. 38, p. 1911–1956.

Pettijohn, F. J., 1949, Sedimentary rocks: New York, Harper and Brothers, 526 p.

Proctor, P. D., and Clark, D. L., 1956, The Curley limestone—an unusual biostrome in central Utah: Jour. Sed. Petrology, v. 26, no. 4, p. 313–321.

Rankama, Kalervo, and Sahama, T. G., 1950, Geochemistry: Chicago, Univ. Chicago Press, 912 p.

Richards, R. W., and Mansfield, G. R., 1912, The Bannock overthrust, a major fault in southeastern Idaho and northeastern Utah: Jour. Geology, v. 20, p. 681–709.

Richardson, G. B., 1913, The Paleozoic section in northern Utah: Am. Jour. Sci., 4th ser., v. 36, p. 406–416.

——— 1941, Geology and mineral resources of the Randolph quadrangle, Utah-Wyoming: U.S. Geol. Survey Bull. 923, 54 p.

Rigby, J. K., 1958, Geology of the Stansbury Mountains, *in* Geology of the Stansbury Mountains, Tooele County, Utah: Utah Geol. Soc. Guidebook 13, p. 1–134.

Ross, R. J., Jr., 1949, Stratigraphy and trilobite faunal zones of the Garden City formation, northeastern Utah: Am. Jour. Sci., v. 247, p. 472–491.

——— 1951, Stratigraphy of the Garden City formation in northeastern Utah, and its trilobite faunas: Yale Univ., Peabody Mus. Nat. History Bull. 6, 161 p.

Slentz, L. W., 1955, Salt Lake group in lower Jordan Valley, Utah, *in* Tertiary and Quaternary geology of the eastern Bonneville Basin: Utah Geol. Soc. Guidebook 10, p. 23–36.

Spencer, A. C., 1917, The geology and ore deposits of Ely, Nevada: U.S. Geol. Survey Prof. Paper 96, 189 p.

Spurr, J. E., 1895, Economic geology of the Mercur mining district, Utah: U.S. Geol. Survey 16th Ann. Rept., pt. 2, p. 343–455.

Spurr, J. E., 1923, The ore magmas, v. 2: New York, McGraw-Hill Book Co., 915 p.

Stokes, Wm. Lee, and Arnold, D. E., 1958, Northern Stansbury Range and the Stansbury formation, *in* Geology of the Stansbury Mountains, Tooele County, Utah: Utah Geol. Soc. Guidebook 13, p. 135–148.

Stringham, B. F., and Sharp, B. J., 1950, The Fox Clay deposit, Utah: Am. Jour. Sci., v. 248, no. 10, p. 726–733.

Tower, G. W., and Smith, G. O., 1899, Geology and mining industry of the Tintic district, Utah: U.S. Geol. Survey 19th Ann. Rept. (1897–98), pt. 3, p. 601–767.

U.S. Weather Bureau, 1954, Climatological data, annual summary 1953, Utah, v. 55, no. 13, p. 160–167, Kansas City.

Waggaman, W. H., and Bell, R. E., 1950, Western phosphates—Factors affecting development, comparison of sulfuric acid and thermal reduction processing, potential markets: Indus. Eng. Chemistry, v. 42, p. 269–292.

Walcott, C. D., 1891, Correlation papers—Cambrian: U.S. Geol. Survey Bull. 81, 447 p.

——— 1908, Cambrian geology and paleontology: Smithsonian Misc. Coll. 53, 431 p.

——— 1912, Cambrian brachiopods: U.S. Geol. Survey Mon. 51, pt. 1, 872 p., pt. 2, 363 p.

Webb, G. W., 1956, Middle Ordovician detailed stratigraphic sections for western Utah and eastern Nevada: Utah Geol. Mineralog. Survey Bull. 57, 77 p.

Westgate, L. G., and Knopf, Adolph, 1932, Geology and ore deposits of the Pioche district, Nevada: U.S. Geol. Survey Prof. Paper 171, 79 p.

Wheeler, H. E., 1940, Revisions in the Cambrian stratigraphy of the Pioche district, Nevada: Nev. Univ. Bull., v. 34, no. 8, 40 p.

——— 1943, Lower and Middle Cambrian stratigraphy in the Great Basin area: Geol. Soc. America Bull., v. 54, p. 1781–1822.

——— 1948, Late pre-Cambrian–Cambrian stratigraphic cross section through southern Nevada: Nevada Univ. Bull., v. 42, no. 3, 58 p.

Wichman, F. M., 1920, The Ophir mining district, Utah: Eng. Mining Jour., v. 110, p. 560–563.

Williams, J. Stewart, 1943, Carboniferous formations of the Uinta and northern Wasatch Mountains, Utah: Geol. Soc. America Bull., v. 54, p. 591–624.

——— 1948, Geology of the Paleozoic rocks, Logan quadrangle, Utah: Geol. Soc. America Bull., v. 59, p. 1121–1163.

Williams, N. C., 1953, Late pre-Cambrian and early Paleozoic geology of western Uinta Mountains, Utah: Am. Assoc. Petroleum Geologists Bull., v. 37, no. 12, p. 2734–2742.

Young, J. C., 1955, Geology of the southern Lakeside Mountains, Utah: Utah Geol. Mineralog. Survey Bull. 56 (October 1955), 116 p.

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Part of illustrative matter in pocket.

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(Continued on next card)

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Stratigraphy of the East Tintic Mountains, Utah. 1961. (Card 2)

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