Bedrock, Surficial, and Economic Geology of the Sunnyside Coal-Mining District, Carbon and Emery Counties, Utah

GEOLOGICAL SURVEY PROFESSIONAL PAPER 1166

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By FRANK W. OSTERWALD, JOHN O. MABERRY, *and* C. RICHARD DUNRUD

With a section on EARLY MAN IN THE SUNNYSIDE AREA

By JAMES O. DUGUID, JR.

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Description of the geologic setting and economic potential of an east-central Utah coal-mining district

UNITED STATES GOVERNMENT PRINTING OFFICE, WASHINGTON : 1981

UNITED STATES DEPARTMENT OF THE INTERIOR

JAMES G. WATT, *Secretary*

GEOLOGICAL SURVEY

Doyle G. Frederick, *Acting Director*

Library of Congress Cataloging in Publication Data
Osterwald, Frank W.
Bedrock, surficial, and economic geology of the Sunnyside coal-mining district, Carbon and Emery Counties, Utah.
(Geological Survey Professional Paper 1166)
Bibliography: p. 63
Supt. of Docs. no.: I 19.16:1166
1. Geology–Utah–Carbon County. 2. Geology–Utah–Emery Co. I. Maberry, John O., joint author.
II. Dunrud, C. Richard, joint author. III. Title. IV. Series: United States Geological Survey Professional Paper 1166.
QE170.C37084 557.92′566 79–607177

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

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BEDROCK, SURFICIAL, AND ECONOMIC GEOLOGY OF THE SUNNYSIDE COAL-MINING DISTRICT, CARBON AND EMERY COUNTIES, UTAH

By FRANK W. OSTERWALD, JOHN O. MABERRY, and C. RICHARD DUNRUD

ABSTRACT

The Sunnyside mining district is in the western Book Cliffs of Utah, at the north end of the Colorado Plateau. The region has been inhabited by humans since pre-Basket-Maker time. Bituminous coal, which forms the economic base for much of east-central Utah, has been mined extensively from the district since about 1900. Most of the coal is used to make metallurgical coke for the steel industry in the Western United States. Mining is difficult in much of the district, but the importance of the coal to the steel industry provides the stimulus for mining it. Among the difficulties that hamper mining in the district, the most important is coal-mine bumps (rockbursts in the coal), which are continuing hazards to life and property in the mines.

A sedimentary sequence more than 10,000 feet (3,050 meters) thick, ranging in age from Jurassic to Eocene, crops out in the district and dips gently northeastward into the Uinta Basin. Rocks ranging in age from Precambrian to Early Jurassic in the district are known only from drill records. The exposed sedimentary rocks represent deposition in both continental and marine environments, under a wide variety of local conditions. The Blackhawk Formation, the major coal-bearing unit, was deposited in a dominantly deltaic environment during the retreat of the Late Cretaceous sea. Most Tertiary rocks were formed in continental depositional environments. A large freshwater lake occupied much of the area during Tertiary time. Sedimentation largely ceased by the end of late Eocene time.

A complex sequence of nonindurated sedimentary materials of Quaternary age yielded much information on the geomorphic and structural history of the district. These materials range from stream alluvium of probable early Pleistocene age high in the Book and Roan Cliffs to man-induced talus that formed after 1959. The lower Pleistocene alluvial deposits probably were deposited in old strike valleys by strong southward-flowing streams of an earlier drainage pattern. Range Creek, Little Park Wash, and parts of Whitmore and Horse Canyons probably are remnants of this earlier pattern. Scattered boulder deposits near the top of West Ridge may be remnants of pre-Wisconsin glacial deposits. Three levels of pediments were cut along the base of the Book Cliffs during pre-Wisconsin time, following a great amount of erosion when the lower Pleistocene alluvium and glacial materials were deposited. Surficial deposits of early Wisconsin(?) age are widespread at high elevations in the district. The most widespread is a unit composed of slope mantle, colluvium, and landslide debris. Some Pleistocene landslides in this unit were reactivated by modern construction activities. Materials of late Wisconsin(?) age consist mostly of various types of stream alluvium related to major modern drainage courses. Some of these alluvial materials are valuable sources of ground water and forage for livestock, although much alluvium in the southern part of the district, derived mostly from Mancos Shale, is mostly dry and nearly barren of vegetation. Surficial deposits of Holocene age consist mostly of small talus cones along tributary drainages, small alluvial fans, and alluvium along modern streams. A few large masses of talus north of Dragerton formed after 1959 as a result of tremors and ground motion related to mining. These Quaternary materials indicate that many of the structural features observed underground in the coal mines may have resulted from differential stresses set up by erosion during and after the cutting of pre-Wisconsin pediments. These stresses have a direct relationship to occurrence of coal-mine bumps. Three large mine-waste dumps constitute another Holocene surficial unit.

The geologic structure of the district is simple. The beds dip northeastward less than 20°, except in some fault zones. Steeply dipping joints occur in three major sets, one trending west-northwest, one trending north to north-northwest, and one trending east-northeast. The most consistent orientation of faults is nearly parallel to these joint directions. Stratigraphic separation on all faults exposed at the surface in the mining area is less than 200 ft (60 m); horizontal separation on a fault west of the mining area is about one-half mile (0.8 km). A pronounced belt of west-northwest-trending faults in the central part of the district probably is the crest of a collapsed anticline. Most folds in the district are broad and gentle. Locally, steepened dips of the coal beds near the Book Cliffs suggest folding as a result of elastic rebound of Mancos Shale during erosional unloading. Minor structural features in the coal, such as cleavages and fracture zones, which are known to be important factors controlling coal-mine deformation, probably were formed by the same stress system that caused the joints.

Coal is the only commodity now mined in the district, but gypsum, methane, and asphalt-impregnated sandstone are present in potentially economic quantities. Water is a valuable commodity in the district, because it is so scarce. A few shows of oil have been found in wells in the district and uranium prospecting formerly was widespread, but no commercial production of either commodity is known. Minor occurrences of metallic sulfide minerals were found along a few faults.

INTRODUCTION

The Sunnyside coal-mining district, as defined here, is in east-central Utah and is a part of the Book Cliffs Coal Field which extends from Castle Gate, Utah, eastward for about 150 miles (240 km) to Palisade, Colo. (fig. 1). The Book Cliffs Coal Field is geologically coextensive with the Wasatch Plateau Coal Field, which extends southward from Castle Gate for about 75 miles (120 km); these fields are separated mainly for convenience (Spieker, 1925, p. 17). Fisher (1936, p. 3) referred to all of the Book Cliffs Coal Field west of the

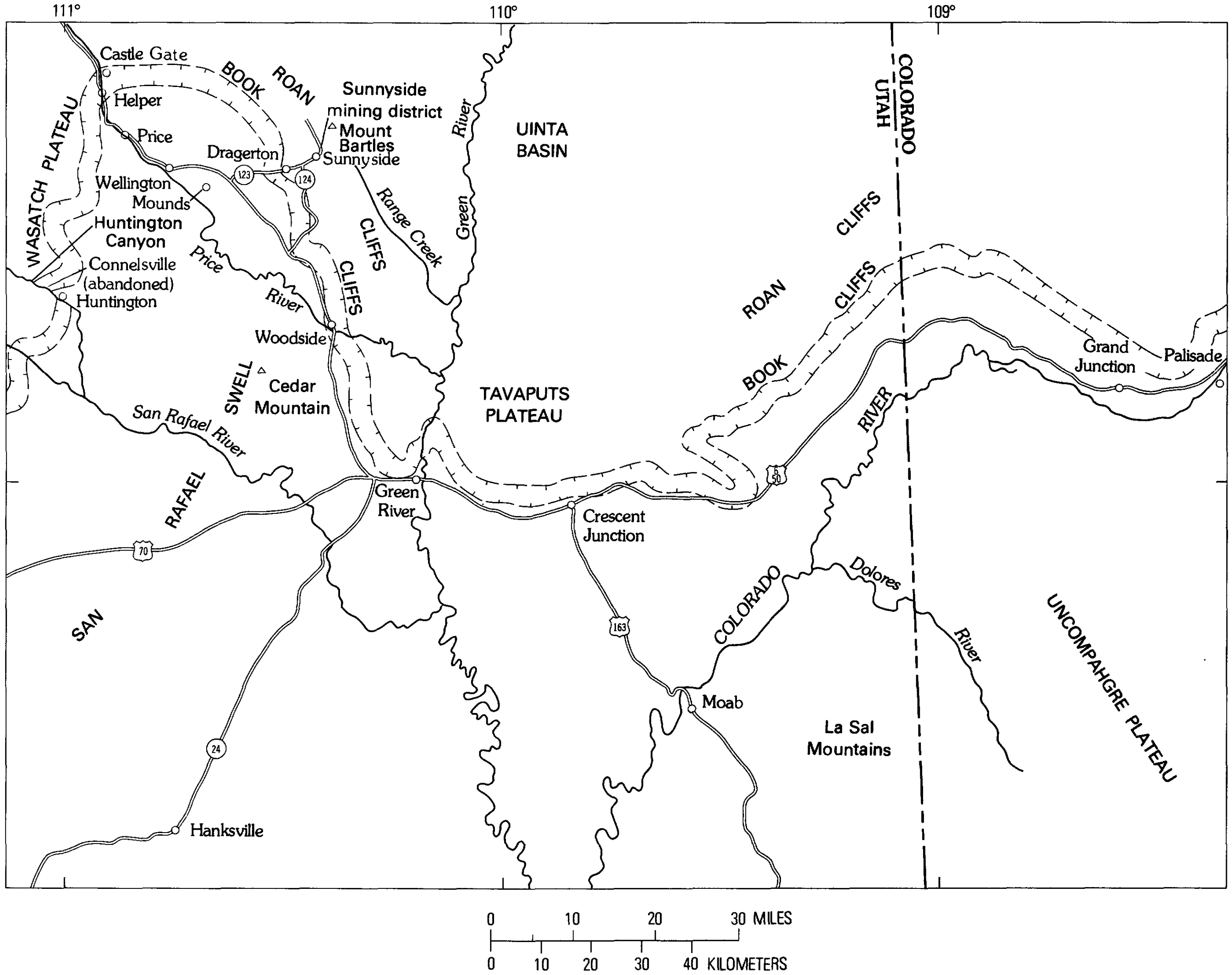


FIGURE 1.—Index map of eastern Utah and western Colorado.

Green River (fig. 1) as the "Sunnyside district," a usage at variance with ours. The coal-mining area near Castle Gate, 25 miles (40 km) west of Sunnyside, is separate geologically, geographically, economically, and technologically from that near Sunnyside and is not considered to be within the district. The Sunnyside district, from which high-volatile bituminous coking coal is mined from the Blackhawk Formation of Cretaceous age, includes the Sunnyside mines of Kaiser Steel Corp., the Geneva (formerly Horse Canyon) and Columbia Mines of United States Steel Corp., and the Book Cliffs Mine of the Book Cliffs Coal Co., and is within the Sunnyside and Woodside 15-minute topographic Quadrangles (fig. 1).

Nearly all the coal currently mined (1972) in the Sunnyside district is shipped to steel plants at Provo, Utah, and Fontana, Calif.; these plants depend upon the mines as major sources of metallurgical coke. Mining difficulties in the district have increased steadily because of the ever-increasing depths to which mining is pursued so that large tonnages of coal can be produced rapidly. The value of the remaining coal adds economic incentive to mine coal in the district, in spite of many physical difficulties.

Among the difficulties which have plagued mining in the Sunnyside district are coal-mine bumps. Bumps—which are spontaneous and commonly violent releases of energy stored in coal or rock in mine ribs, floors, roofs, and faces, resulting in sudden ejections of coal and rock—have been a continuing problem in the district since the mines were first opened in 1899. Bumps are frequent in the mines of the district, and even small ones may slightly damage equipment or injure personnel. Deaths have occurred when single football-size pieces of coal were suddenly ejected from highly stressed ribs. Large bumps have caused large areas of some mines elsewhere in central Utah to be closed and sealed (John Peperakis, Kaiser Steel Corp., oral commun., 1965).

Our investigations were concerned primarily with bumps and began in 1958 at the request of and in cooperation with the U.S. Bureau of Mines. Members of the Bureau staff had studied engineering problems related to coal-mine bumps for many years, but wanted supplemental information concerning geologic factors that might influence the occurrence of bumps. Because of its economic importance, history of frequent bumps, and accessible surface geology, we selected the Sunnyside No. 1 Mine for our initial study. The study later was expanded to include most mines in the Sunnyside district. Active cooperation with the Bureau of Mines continued until 1961; after 1961 the work was carried on by the Geological Survey, with continuing informal cooperation with the Bureau in the field.

This report presents the results of our surface geologic investigations in the district from 1958 through 1969 and serves as an introduction to a series of reports on various specialized facets of our studies. Much additional research will be needed before the mechanics of coal-mine bumps can be fully understood and before all the geologic, engineering, and topographic factors that influence them can be evaluated fully. The application and extension of our research to the study of mine failures in other areas as described in this series of reports may lead eventually to general principles which can be used to make mining safer and more economical than at present. Application of geologic studies to design of mines will effectively increase the minable reserves of many commodities. The geologic features discussed in this report provide the basic information for our engineering-geologic studies of bumps that will be presented in future reports.

FIELDWORK AND ACKNOWLEDGMENTS

Underground and surface geologic mapping of the Sunnyside No. 1 Mine area was begun by Osterwald and R. E. Eggleton in 1958. Few, if any, guidelines were available for this work, so mapping scales were made large enough to depict any possible but obscure relations between geologic features and failure of coal and rock in underground workings. Underground mapping of selected areas in which details of coal failure could be closely studied was at the scale of 1 in. to 40 ft (1:480). After pertinent features were delineated by this detailed mapping, large areas of the mine were mapped, using standardized mining engineering maps as bases, at the scale of 1 in. to 200 ft (1:2,400). Surface mapping in the field was done on enlarged aerial photographs, delineating all beds more than 10 ft (3 m) thick. Information plotted on the photographs in the field later was transferred in the office by photogrammetric methods to specially prepared topographic base maps having a scale of 1 in. to 500 ft (1:6,000), and a 20-ft (6-m) contour interval (Osterwald, 1961, 1962a; Osterwald and others, 1969; Dunrud and Barnes, 1972). The bases were prepared by extending horizontal and vertical control from mining company surveys, so that maps of underground workings could be fitted accurately to the surface geologic maps.

The surface and underground mapping of the Sunnyside No. 1 Mine area was completed in 1959 by Osterwald and Harold Brodsky. Brodsky (1960) also independently studied the stratigraphy of the Mesaverde Group and the coal beds at Sunnyside. During the 1960 field season a simple mechanical three-component seismograph was operated in the office building of Kaiser Steel Corp. to determine whether earth tremors, which are commonly felt in the region, could be recorded and related to known bumps. Brodsky continued his stratigraphic work in 1960, and both men collected additional surface geological information for the Sunnyside No. 1 Mine-area map (Osterwald, 1961, 1962a). Vertical and horizontal control also was extended from mining company surveys in preparation for mapping parts of the Sunnyside No. 2 and Columbia Mines.

Osterwald and Dunrud began mapping surface and underground geology of the Sunnyside No. 2 and Columbia Mines, at a scale of 1 in. to 200 ft (1:2,400), in 1961. The surface geology was mapped on enlarged aerial photographs and transferred to a special topographic base having a scale of 1 in. to 500 ft (1:6,000) and a 20-ft (6-m) contour interval. This work was largely completed in June 1962, when construction of a fixed seismic-monitoring network encompassing the entire district was begun. James O. Duguid, Jr., Barton K. Barnes, and Jerome Hernandez helped with construction of the network and installation of the instruments. Dunrud and Duguid measured stratigraphic sections near the Geneva Mine in preparation for geologic mapping in that area. Maberry constructed structure-contour and overburden-thickness maps for the area of the Sunnyside No. 2 and Columbia Mines, and participated in the final surface and underground work, which began in the fall of 1963 (Osterwald and others, 1969).

Modification and debugging of the seismic system and interpreting records occupied most of our time during 1963, although Dunrud and Barnes began to map surface geology at the Geneva Mine. Mapping at

the Geneva Mine was done at the same scales as at the Sunnyside No. 1 mine but with emphasis on different details because of the different geology and mining practices. A topographic base map also was specially prepared (Dunrud and Barnes, 1972). Mapping at the Geneva Mine was essentially completed in 1966, although subsidence cracks and fault movements were measured at irregular intervals after that time.

The seismic recording system was completely redesigned and modified by Electronics Engineer John B. Bennetti, Jr., in 1963. Bennetti also designed and built special transistorized preamplifiers for the system in 1964, and in 1965 he installed a 14-channel FM magnetic-tape-recording system, using specially modified equipment. The seismic system operated almost continuously from 1963 to 1977, largely through the efforts of Jerome Hernandez, and was a valuable tool in avoiding casualties from bumps, as well as a valuable research tool. Dunrud, Barnes, and Hernandez interpreted most of the seismic records (Barnes and others, 1969; Dunrud and others, 1970, 1973).

A continuously recording tiltmeter was installed at the seismic recording station near Sunnyside in 1962. Bennetti modified and redesigned both the transducer and recorder sections of the tiltmeter several times. A microbarograph and two recording thermographs were operated continuously until 1977 at the recording station to determine whether ground tilt or changes of seismic activity patterns are related to changes of air pressure or temperature (Osterwald and Dunrud, 1966, p. 104-107).

Maberry began an independent study of sedimentary structures, stratigraphy, and trace fossils in the Blackhawk Formation in 1966, to determine whether such features could be used to predict mining conditions before actual mining. His results are contained in a separate report (Maberry, 1971).

Osterwald began mapping the geology of the Woodside 15-minute Quadrangle in 1962 so that regional structural and stratigraphic changes could be related to deformational patterns in the coal mines. This work was recessed in 1963 and 1964 because of the large amount of time required to operate the instrumentation systems, but was resumed in 1965 and completed in 1968. Maberry, aided in 1968 by J. L. Stevenson, mapped the eastern part of the quadrangle, where much unmined coal exists, in an attempt to predict mining conditions on the basis of work at Sunnyside.

Responsibility for the material in this report is divided among us. Osterwald assembled much of the material gathered from various facets of the fieldwork and wrote most of the sections on Quaternary geology, structure, and economic geology. Maberry wrote the material pertaining to pre-Pleistocene stratigraphy and to characteristics of the coal, utilizing his own measured sections as well as those by R. E. Eggleton, Harold Brodsky, Dunrud, and Osterwald, and V. H. Johnson (written commun., 1962). Dunrud supplied much information on stratigraphy and structure of the Horse Canyon area, and contributed importantly both to the investigations of structural features in the coal and its associated rocks, and to the interpretation of many features.

The work upon which this report is based could not have been done without the help and interest of many persons. We are particularly indebted to David J. Varnes of the Geological Survey, who originally outlined possible geologic problems that could be investigated and who planned the original work at the Sunnyside No. 1 Mine. His continuing interest and guidance in later phases of the work were invaluable.

Many employees of the mining companies contributed greatly to the investigation through discussion of problems and by providing logistical and moral support. John Peperakis of Kaiser Steel Corp. and R. M. von Storch of United States Steel Corp. gave ready access to the properties under their control and were always ready to discuss problems or new developments. Members of the engineering staffs of their companies, particularly R. J. Bowen, J. T. Taylor, Lynn F. Huntsman, and J. B. McKean, were very helpful in contributing their knowledge of the area to our study.

We greatly appreciate the many courtesies and the assistance given by many miners and local residents. We are particularly grateful to the Ray Wilcox, Waldo Wilcox, and Don Wilcox families, who gave us free access to their lands along Range Creek. Elwin Rasmussen of Dragerton, Utah, devoted much time, energy, and skill to keep our field vehicles and other mechanical equipment in good operating condition.

PHYSIOGRAPHY AND GENERAL GEOLOGY

The Sunnyside district is along the southern margin of the Uinta Basin (Fenneman, 1931, p. 304), which is formed by the Book Cliffs (figs. 1, 2), an imposing southwestward- and westward-facing escarpment of alternating siltstones and sandstones of Late Cretaceous and Tertiary age. These rocks make up a series of light-brown cliffs which are separated by narrow slopes of nonresistant siltstones and mudstones. Above the Book Cliffs, a series of reddish cliffs and slopes made up mostly of sandstones, siltstones, and mudstones of early Tertiary age constitutes the Roan Cliffs. The Roan Cliffs are capped by an irregular surface which is called the Tavaputs Plateau. The Tavaputs Plateau, cut into extremely rough topography by many canyons, slopes gently northward and eastward into the central part of the Uinta Basin. The desert floor at the base of the Book Cliffs is as much as 4,500 ft (1,370 m) below the level of the Tavaputs Plateau. This desert floor, made up of the Castle Valley and the Clark Valley, is a lowland underlain by as much as 3,500 ft (1,070 m) of Mancos Shale of Cretaceous age.

Early explorers named the Book Cliffs for the open-book appearance of the evenly bedded Cretaceous strata between reentrants. The Roan Cliffs and Roan Plateau were named for the reddish-brown color of the Tertiary rocks that form their features.

The Book Cliffs and Roan Cliffs are a rough, remote, mountainous area. Steep cliffs and deep canyons make many places difficult to reach, even on foot. Local thick forests of aspen and spruce alternate with open areas covered by sagebrush and grasses at high elevations. Thick stands of juniper, mountain mahogany, and pinon-pine commonly grow on slopes in the Book Cliffs and on extensive pediments that extend from the base of the cliffs. Thickets of mountain mahogany at intermediate elevations are extremely dense and hard to pass through on foot. In many of these thickets individual plants are large and commonly reach the size of trees, in contrast to typically small mountain mahogany shrubs in many other western localities.

The climate in the district is arid to semiarid and generally is mild except for a few weeks in midsummer when high temperatures are common. Temperatures above 100°F (38°C) are rare, however, except for local areas beneath west- or southwest-facing cliffs. Spring and fall seasons are commonly dry and mild. Rainfall is about 6 in. (15 cm) per year at low elevations and as much as 20 in. (51 cm) per year above 8,000 ft (2,440 m); most of the precipitation occurs during winter and spring. During the summer months violent thunderstorms cause local floods that sometimes constitute hazards to field parties working in valleys and gulches. Cool winds, known locally as "canyon winds," resulting from convective overturns, blow down many canyons at night, particularly near the town of Sunnyside. As a result of these winds, local nighttime temperatures as low as 45°F (7°C) are common during the summer months.

U.S. Highways 6 and 60 traverse the lowland near the base of the Book Cliffs, and connect Price, Utah, with Provo, Utah, and Grand Junction, Colo. Utah Highways 123 and 124, built during World War II, connect Sunnyside and Dragerton to U.S. Highways 6 and 50 and also link the Geneva Mine and Columbia to Dragerton. A paved county road extends southwestward from the Geneva Mine to U.S. Highways 6 and 50. Except for a few access roads built by mining companies, most other roads in the district are steep, rough, and poorly maintained.

EARLY MAN IN THE SUNNYSIDE DISTRICT

By JAMES O. DUGUID, JR.

Artifacts and campsites left by prehistoric man are common in the Sunnyside district and surrounding areas. Most of the campsites were opened by amateur pot hunters, and, as a result, much historically valuable material has been lost. A few new sites were found during fieldwork, and the following discussion is based on my examination of articles from these sites and of identifiable articles from the Prehistoric Museum at Price, Utah. Only a few of the most diagnostic remains are described. All dates referred to these remains are approximate and were determined by analogy with similar artifacts from other localities; the dates are presented only to give the general range of ages.

Campsites are common under overhanging cliffs in many of the canyons at locations that now are far from known sources of water. Similarly, a large campsite extends for several miles along Grassy Trail Creek westward from the mouth of Whitmore Canyon near Sunnyside. The size, abundance, and locations of the campsites suggest that water was much more abundant when the sites were occupied than it is at present and that rainfall was formerly much greater.

The oldest known artifact found in the Sunnyside district is an Agate Basin–type weapon point discovered by the Wilcox family on their ranch on Range Creek. These points represent a culture more than 9,000 years old, but this specimen may have been carried into the area by a later people.

Most campsites and artifacts appear to be of a Basket-Maker culture, which ranges in age from 1,500 to 3,500 years B.P. (before present). These people probably were similar to the Pinto Basin (Uncompahgre) people (Alice Hunt, 1956) who inhabited the Uncompahgre Plateau region of western Colorado during this time. Most sites are under overhanging sandstone ledges, many of which are smoke blackened. We found three red pictographs of human figures under a large overhang in Whitmore Canyon, and numerous pictographs can be seen at the base of the cliffs at the mouth of Whitmore Canyon. An overhang in Horse Canyon has fire-blackened walls, and the floor is thickly covered with juniper bark. A pictograph of an arrow passing through a circle can be observed beneath an overhang east of Range Creek near the mouth of Sheep Canyon, about 1 mile (1.6 km) east of the eastern boundary of plate 1. We found several bone implements, some chipped-stone artifacts, and part of an atlatl shaft beneath the Range Creek overhang. Near the overhang we found two metates, one mano, and two broken corner-notched weapon points, which, with the atlatl shaft, suggest a Basket-Maker culture.

The most recent archeological remains in the Sunnyside district are of Pueblo culture, which ranges in age from historic time to about 1,500 years B.P. Artifacts of this culture, reported to be from the Sunnyside area, are in the Prehistoric Museum at Price. We found ruins of a few crudely constructed buildings (fig. 2), probably of an early Pueblo culture, beneath a large overhanging cliff of Bluecastle Sandstone Member of the Price River Formation southeast of Sunnyside. Crude cleared areas on a nearly level surface about 100 ft (30 m) above the ruins may be sites of former fields, although no water is nearby at present. If these cleared areas are former fields, rainfall was probably much greater at the time they were worked than it is at present. Factory sites, where projectile points were made, are common near Little Park Wash on dip slopes of Bluecastle Sandstone Member. The sites are marked by abundant chips of quartzite, quartz, and chert, and broken projectile points are common.

A small storage bin under an overhanging sandstone ledge in the Sunnyside Member of the Blackhawk Formation in a wash about 2 miles (3.2 km) east of Sunnyside is shown in figure 3. This bin was made of sandstone slabs cemented together with crude adobe mortar. A pictograph above the bin (fig. 4) shows a crude atlatl shaft or arrow impacted in the center of an arch-topped figure. This pictograph was painted on the rock face in red, yellow, and black; the colors persist, having been protected from weathering by the overhang.

We were shown outlines of several unexcavated early Pueblo pit houses along Range Creek, about 1.5 miles (2.4 km) east of the Woodside quadrangle, by the Wilcox family.

The abundant archaeological sites indicate that the district has been inhabited for a very long time and

FIGURE 2.—Crudely constructed building of probable early Pueblo culture beneath overhanging cliff of Bluecastle Sandstone Member of the Price River Formation, 2.5 miles (4 km) southeast of Sunnyside, Utah. Building outline marked by one standing wall, fallen sandstone blocks, and juniper logs.

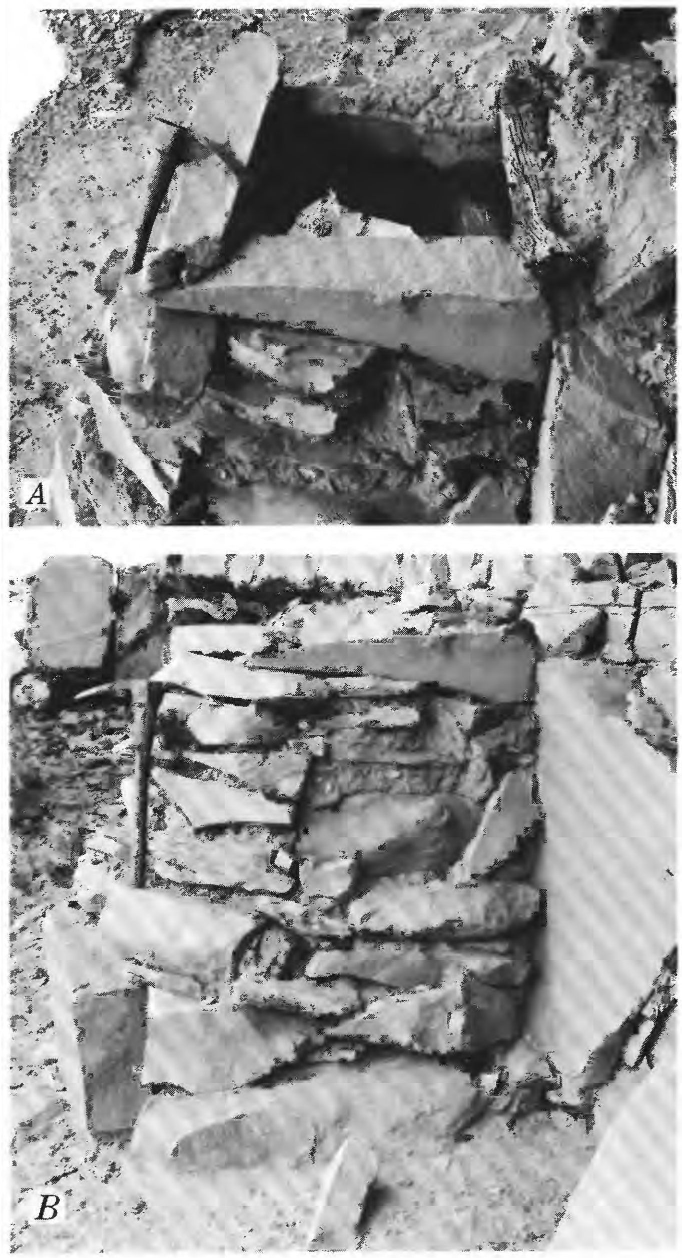


FIGURE 3.—Small storage bin beneath ledge of Sunnyside Member of the Blackhawk Formation, 2.5 miles (4 km) southeast of Sunnyside. *A*, Top view, showing shape and size of bin. *B*, Side view, showing crude mortar construction. Pick handle is 18 in. (46 cm) long.

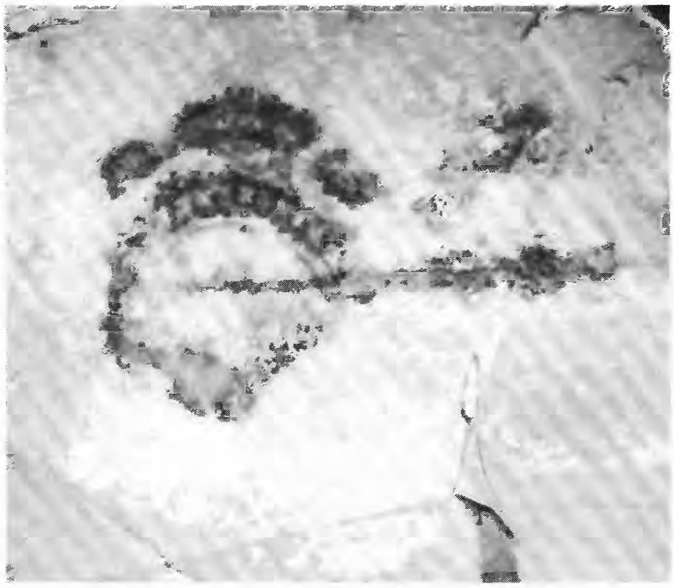


FIGURE 4.—Pictograph of atlatl shaft or arrow impaling a figure, found on sandstone face above storage bin, about 2.5 miles (4 km) southeast of Sunnyside, shown in fig. 3. Shaft or arrow is red and is about 25 in. (64 cm) long; interior of figure and box-like areas on its top are yellow; outlines are black.

that it supported a large population. The reasons are probably similar, except for coal mining, to the reasons that attract people to the Book Cliffs and Roan Cliffs today—pleasant climate, scenic views, good hunting, and abundant berries and pinon-pine nuts—although water probably was more abundant in prehistoric times. There is no evidence, however, that in prehistoric times the inhabitants used coal in any way.

EARLY EXPLORATION AND DEVELOPMENT OF COAL IN EAST-CENTRAL UTAH

Many of the early Spanish and American exploring expeditions passed through the lowlands at the base of the Book Cliffs because they were easy to travel. The main route of the Spanish Trail from Santa Fe, N. Mex., to California passed a few miles south of the Woodside Quadrangle. That trail is now marked by a Utah State Historical Society sign. Some of the early explorers probably noticed the coal beds, but the members of the Gunnison expedition in 1853 (Beckwith, 1855, p. 65) made the first mention of the coals in what is now east-central Utah. Beckwith and James Schiel, a geologist, examined and described coal which probably came from Rock Canyon in what is now known as the Wasatch Plateau Coal Field (fig. 1). The first mines in the area were opened at Connelsville, in upper Huntington Canyon (western Emery County, fig. 1), in 1874 (Morton, 1877).

Economic development of east-central Utah, of which coal mining is an integral part, was closely related to development of good transportation systems. The first railroad in east-central Utah, the narrow-gage Utah and Pleasant Valley, was built in 1878 from Springville to newly opened coal mines near Scofield, in northwestern Carbon County. This railroad was absorbed by the narrow-gage Denver and Rio Grande Western Railway, which was completed from Ogden, Utah, to Grand Junction, Colo. in 1883 (Beebe and Clegg, 1962, p. 372). The D&RGW Ry. became the Rio Grande Western in 1889 and was rebuilt to standard gage in 1890, when about 10 miles (16 km) of track in the canyons of Price River and Grassy Trail Creek in the southern part of the district were rerouted because of numerous floods (Denver and Rio Grande Western Railroad, written commun., 1965). Remains of the abandoned grade can still be seen in the river canyons. The Carbon County Railroad, originally a subsidiary of both the Utah Fuel Co. and the Rio Grande Western Railroad, was built from Mounds Station to Whitmore Canyon in 1899 as a result of the discovery of coal (Beebe and Clegg, 1962, p. 374). This subsidiary became the Sunnyside branch of the Denver and Rio Grande Western Railroad, which was formed in 1908 by consolidation of the Rio Grande Western with the Denver and Rio Grande; the Sunnyside branch was extended to Columbia in 1924. During World War II, part of the Sunnyside branch was realined to reduce grades and was extended southward from Columbia to the Geneva Mine. The track from Columbia Junction near Dragerton to the Geneva Mine presently (1977) is operated by the Carbon County Railway, a subsidiary of United States Steel Corp.

STRATIGRAPHY

Rocks exposed at the surface in the Sunnyside district were deposited in continental and marine environments, and range in age from Middle Jurassic to Eocene (pl. 1). Nonindurated sediments of Pleistocene and Holocene age cover large areas, but deposition was not continuous in the area throughout the Pleistocene and Holocene. Rocks as old as Mississippian age occur in the subsurface above Precambrian basement rocks.

Deposition of the rocks exposed near Sunnyside took place in varied environments. Flood plains and restricted lagoonal and paludal areas occupied the region during Late Jurassic time, receiving sediments from a low positive area in west-central Colorado (McKee and others, 1956, pl. 9). These conditions progressed to marine deposition with the advance of a Cretaceous seaway that flooded most of the Western Interior of the United States (Reeside, 1957, p. 506). Later withdrawal of the sea caused offlap deposition of marine, transitional, and continental sediments. There was no significant sedimentation in the area after late Eocene time, although younger sedimentary rocks occur a few miles to the north. Rocks of the Colton Formation of early and middle Eocene age are the youngest described in this report, although rocks of the Green River Formation of Eocene age crop out a few miles north and east of Sunnyside (pl. 1).

Chemical composition of the rocks described herein varies widely because of their different depositional environments; lithologically, however, the rocks are sandstone, coal, mudstone, and limestone. Gypsum, silica, clay, and calcium carbonate are common cementing agents, and some formations contain distinct layers of gypsum, clay, and limestone. Composition of the rocks governs their physiographic expression. Erosion forms strike valleys in mudstones and prominent dip slopes, ledges, bluffs, and cliffs in sandstones. Limestones generally are resistant to erosion, forming a series of retreating ledges having valleys or stripped surfaces between them. Where they were burned extensively at their outcrop, most coal beds are indicated by red baked zones in the Book Cliffs.

Rock color in the Sunnyside district covers a wide spectrum. Jurassic rocks are dominantly red, with secondary shades of green, brown, white, and yellow. Cretaceous mudstones and most limestones are gray, whereas sandstones tend to be yellowish except near burned coals, where they are red and white. Tertiary rocks mostly are variegated pastel shades of red, gray, brown, and yellow.

Many formation names in the area are based on lithologic similarity to units that were established elsewhere. As a result, some names do not carry the same age connotation as they do at other locations, but to explore the history and correlation of each name is beyond the scope of this report. Excellent and comprehensive nomenclature histories are contained in Stokes and Holmes (1954) (Jurassic); Fisher, Erdmann, and Reeside (1960) (Cretaceous and Tertiary); and C. B. Hunt (1956) (Cenozoic). Many Upper Cretaceous units are named for towns and coal mines in the Wasatch Plateau and Book Cliffs Coal Fields.

JURASSIC SYSTEM

CARMEL FORMATION

The Carmel Formation is of Middle Jurassic age (Imlay, 1952, p. 963); it comprises the oldest rocks that crop out in the Sunnyside district. The Carmel consists of thin beds of evaporite, mudstone, siltstone, sandstone, and limestone that form low, rolling topography having low bluffs, ledges, and stripped dip slopes. The Carmel was named by Gilluly and Reeside (1928, p. 73) during their investigations of oil and gas possibilities in the San Rafael Swell.

The formation consists of two general facies, a lower arenaceous limestone facies and an upper silty sandstone facies containing mudstone and anhydrite. The lower facies of the Carmel is composed of about 80 ft (24 m) of gray, flaggy, somewhat oolitic limestone, interbedded with thin lenses of gray mudstone, siltstone, and sandstone (fig. 5). Fossils of shallow-water pelecypods are common in the limestone beds, indicating that the lower facies of the Carmel was deposited in shallow marine water.

The upper facies of the Carmel consists of 150–200 ft (45–60 m) of soft, easily eroded, gray to white gypsum and anhydrite, interbedded with red and some gray, shaly mudstone and sandstone. The rocks of the upper facies were deposited in shallow coastal lagoons when the rate of regional subsidence was only slightly slower than the rate of sedimentation.

Some Carmel gypsum beds are of economic significance. The Carmel is exposed in the San Rafael Swell, in the southwestern part of the district.

ENTRADA SANDSTONE

The Entrada Sandstone, of Middle Jurassic age, is a bright pastel-red series of sandstone beds that forms rounded bluffs and dip slopes in the southwestern part of the area. The sandstone was named by Gilluly and Reeside (1928, p. 76) for a locality about 25 miles (40 km) southwest of Sunnyside, in the San Rafael Swell.

In the map area of this report, the Entrada is 300 ft (90 m) thick; it is as thick as 850 ft (260 m) in the section described by Gilluly and Reeside.

FIGURE 5.—Northward view of the Carmel Formation in T. 18 S., R. 13 E., unsurveyed. Gently rolling slopes of Carmel (Jca) are below resistant ledges of Entrada Sandstone (Je).

The lower part of the sandstone is impure, silty, and clayey, but is better sorted upward and becomes nearly pure quartz sand, cemented by iron oxide and silica. Quartz grains are well rounded and frosted, and the Entrada is almost universally regarded to be of eolian origin.

The lower part is softer and less resistant to erosion than the upper part and so forms rounded bluffs along its outcrop. The upper part forms bold cliffs and steep escarpments (fig. 6). The upper surface of the Entrada is cut by stream-channel deposits and shows the effects of subaerial erosion prior to deposition of the Curtis Formation.

CURTIS FORMATION

The Curtis Formation, of Middle Jurassic age, is a soft slope-forming series of sandstone and shale beds of pastel-green hues. The formation was named by Gilluly and Reeside (1928, p. 78) for exposures at Curtis Point in the San Rafael Swell, about 30 miles (48 km) south of Sunnyside. At this type locality, the Curtis is 190 ft (60 m) thick; it thickens northward over a distance of 2 miles (3 km) to 250 ft (75 m) at Summerville Point. This increase in thickness over a short lateral distance is due to deep erosion of the Entrada surface upon which the Curtis was deposited. The Curtis thins rapidly to the south and east.

Rocks of the formation were deposited in shallow marine waters; Gilluly and Reeside (1928, p. 79) collected crinoid and crustacean fossils from the Curtis. In addition, they found sedimentary structures such as a discontinuous basal pebble conglomerate, bicuspate ripple marks, and foreset crossbedding. These features indicate shallow-water conditions during deposition. Curtis rocks are soft and relatively easily eroded; they form rounded knolls and gently rolling dip slopes atop the Entrada bluffs.

SUMMERVILLE FORMATION

The Summerville Formation, of Middle Jurassic age, consists of interbedded sandstone and laminated gypsiferous mudstone. The overall color of the unit is dark brownish red. The formation crops out as rounded bluffs in the southwestern part of the Sunnyside district.

The Summerville was named by Gilluly and Reeside in their 1928 study (p. 80) for exposures at Summerville Point in the San Rafael Swell, about 25 miles (40 km) south of Sunnyside. They included it as the upper formation in their San Rafael Group (pl. 1).

Gypsum is ubiquitous throughout the formation, both as intergranular cement and as discrete beds. The bedded gypsum commonly is somewhat silty. Bedding is remarkably even and persistent in the Summerville (fig. 7). The alternation of beds probably is due to a form of cyclic sedimentation in shallow water. Stokes and Holmes (1954, p. 38) postulated that the depositional environment of the Summerville was a playa lake or shallow embayment. Fossils are extremely rare in the Summerville, indicating that hostile ecologic conditions persisted in the depositional environment. We believe that hot, dry, sometimes subaerial conditions existed and that the water of Summerville deposition was usually hypersaline.

The Summerville is a facies in a continental to marine sedimentational progression. The unit becomes much sandier southward, and passes eastward into the beach sandstone of the Moab Tongue of the Entrada Sandstone (Stokes and Holmes, 1954, p. 38).

The contact between the Summerville and the overlying Morrison Formation is gradational (Gilluly and Reeside, 1928, p. 79), and is without apparent unconformity. Although the Summerville appears to be nonresistant to weathering and structurally weak in outcrops, an abandoned narrow-gage railroad tunnel built in about 1883 along the Price River, about 3.25 miles (5.2 km) northwest of the Silvagni Ranch, was still in good condition in 1977. Timbering was used only near the south portal, and only minor roof caving had occurred elsewhere. Trenching of the tunnel floor about 6 ft (2 m) deep since 1969 for irrigation water has weakened the sills, and some inward movement of the lower walls was observed in 1977. This inward movement has caused some related fracturing in the rocks above the tunnel roof (fig. 8).

MORRISON FORMATION

The Morrison Formation, of Late Jurassic age, comprises a series of sandstone and mudstone beds of many pastel colors. These strata form slope-and-bluff topography near the Price River in the western part of the Sunnyside district, where they are about 400 ft (122 m) thick.

The Morrison was named originally by G. H. Eldridge (*in* Emmons and others, 1896) for a partly exposed section near Morrison, Colo. The formation subsequently was revised by Waldschmidt and LeRoy (1944, p. 1097).

The Morrison is one of the most widespread suites of rocks in the Western Interior of North America. It crops out in the United States from Montana to Arizona and from Texas to North Dakota. It underlies almost the entire Colorado Plateau.

The lower part of the Morrison contains important uranium and vanadium deposits, and many of the uranium districts of the eastern part of the Colorado


Jc
Jc
Je
A

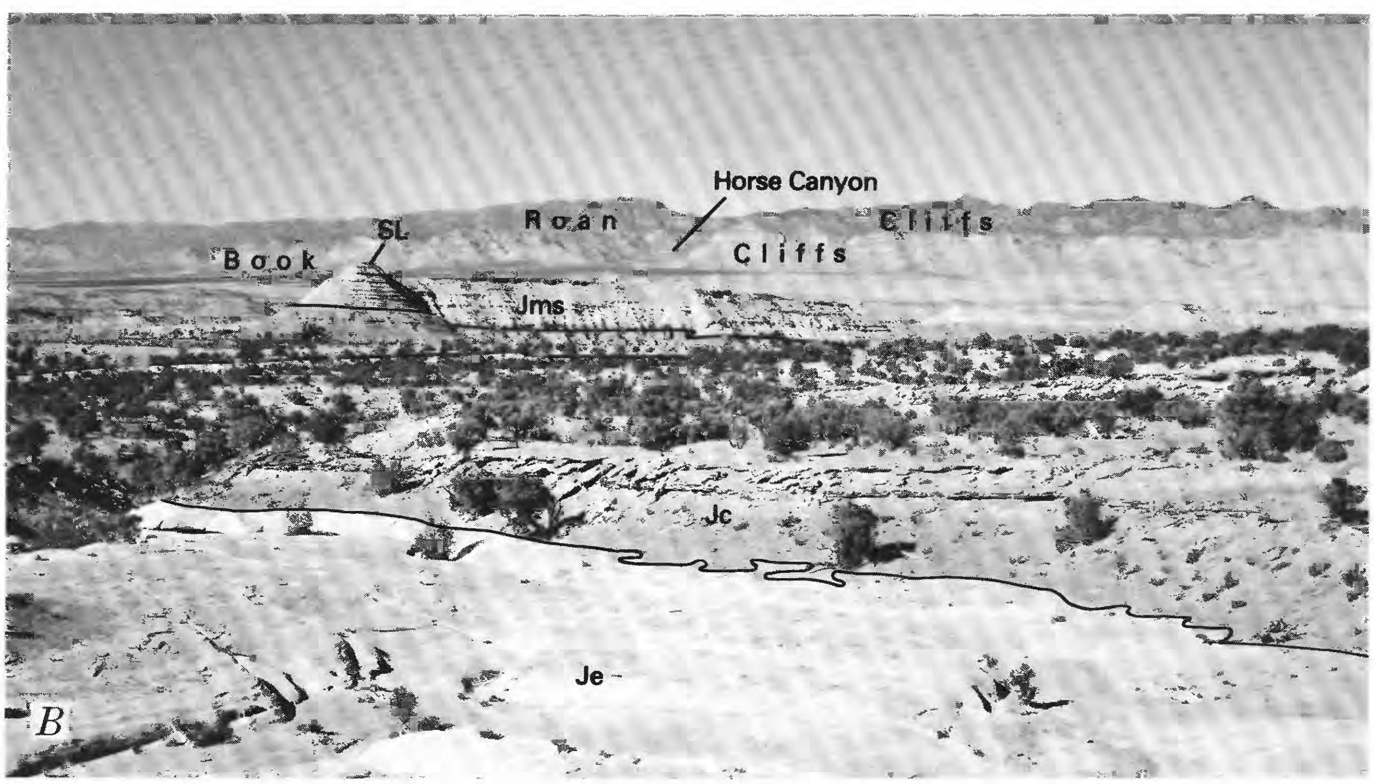

Horse Canyon
SL
Roan
Cliffs
Book
Cliffs
Jms
Jc
Je
B

FIGURE 6 (facing page).—Views of the Entrada Sandstone and associated strata. *A*, Northward view of a bluff in sec. 29, T. 17 S., R. 13 E., showing erosional forms of resistant sandstone and shale beds of Entrada Sandstone (Je), overlain by a thin erosional remnant of the less well cemented Curtis Formation (Jc). *B*, Northeast view from top of the bluff (*A*) showing the soft, crossbedded, easily eroded sandstones of the Curtis Formation (Jc) overlying Entrada Sandstone (Je). Shales of the Summerville Formation (Js) underlie sandstones of the Salt Wash Member of the Morrison Formation (Jms) in the Sugarloaf (SL). Mouth of Horse Canyon in Book Cliffs and Roan Cliffs shown in background. Photographs by Vard H. Johnson.

Plateau are in this part. The formation also contains many deposits of well-preserved dinosaur and other vertebrate-animal remains.

The Morrison is composed of two members in the Sunnyside district, the Salt Wash Sandstone Member (Lupton, 1914, p. 117) at the base and the overlying Brushy Basin Shale Member (Gregory, 1938, p. 59). Age-diagnostic fossils are rare in the Morrison, and this lack of fossils has led to a long controversy over the age of the formation. From its definition in 1896 until 1936, the Morrison was considered to be Early Cretaceous or Late Jurassic in age. Baker, Dane, and Reeside (1936, p. 31) included "under the name Morrison all the Jurassic continental sediments deposited subsequent to the deposition of the San Rafael Group." Cobban (1945, p. 1270) found distinctive algae and ostracodes indicative of Late Jurassic age in the Morrison, and Imlay (1952) included the formation in the Upper Jurassic of North America.

SALT WASH SANDSTONE MEMBER

The Salt Wash Sandstone Member in the Sunnyside district comprises 50–200 ft (15–60 m) of sandstone containing minor lenses of mudstone. The sandstones dominantly are brownish red in color, and the enclosed mudstones are shades of red, brown, gray, and green. The member as a whole forms cliffs, ledges, and bluffs along its outcrop in the southwestern part of the district. Fluviatile channel-fill deposits having prominent crossbedding are the dominant sedimentary units, and crossbedding studies of the channel fills indicate depo-

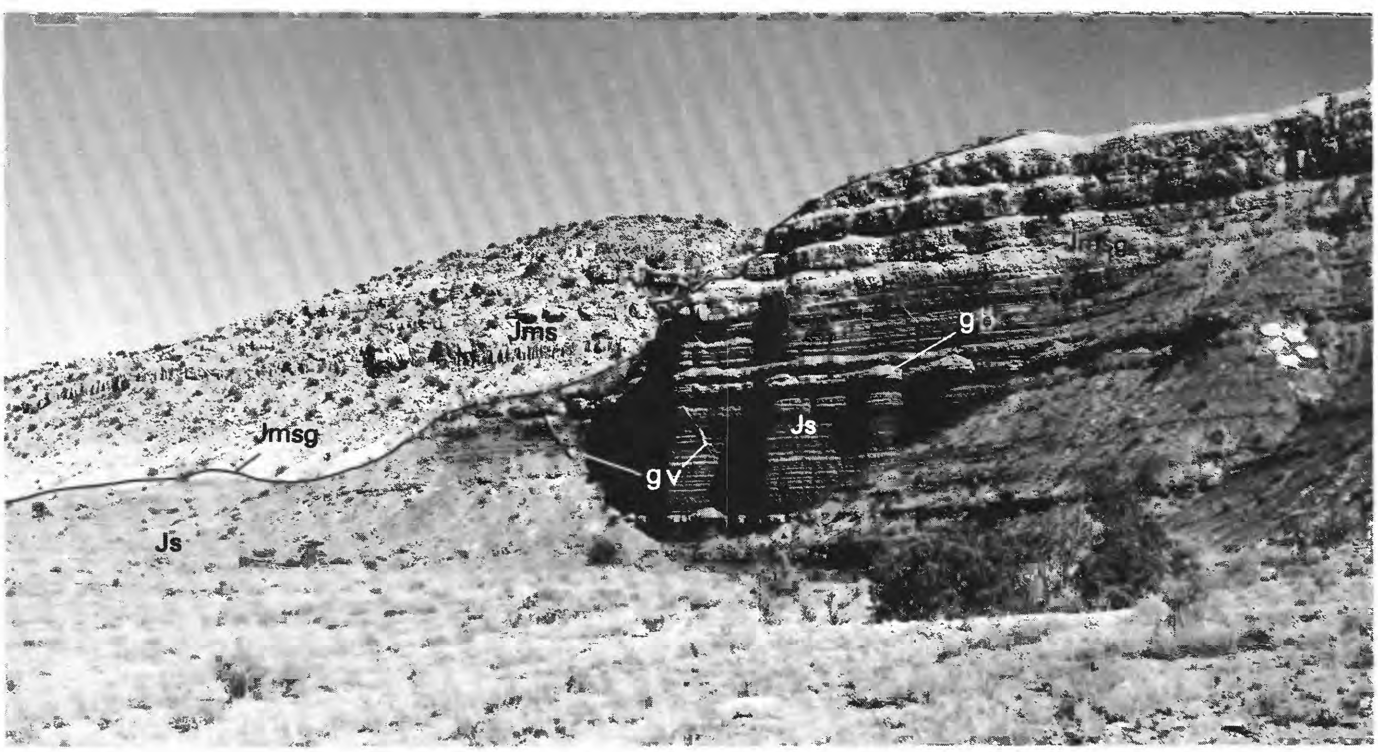


FIGURE 7.—Summerville Formation (Js) on the east side of Camel Wash in sec. 27, T. 17 S., R. 13 E., showing Summerville shales capped by thick gypsum beds (Jmsg) that are at the base of the Salt Wash Sandstone Member of the Morrison Formation (Jms). Gypsum beds (gb) showing pinch-and-swell structure and thin impure gypsum veins (gv) are characteristic of the Summerville. Section above top of Summerville Formation is measured section of Gilluly and Reeside (1928, p. 80). Photograph by Vard H. Johnson.

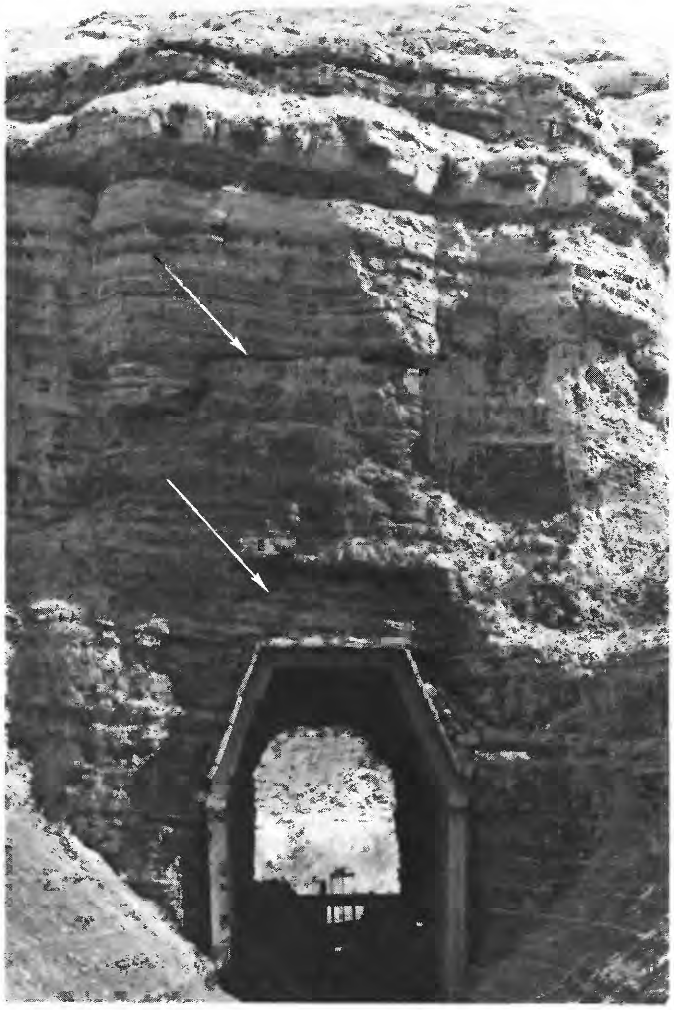


FIGURE 8.—South portal of abandoned narrow-gage railroad tunnel in cliff of Summerville Formation along Price River, about 3.25 miles (5.2 km) northwest of Silvagni Ranch. Inward movement of walls and timber sills, resulting from digging of irrigation ditch, allowed arch-shaped tension fractures (arrows) to form in rocks as much as 10 ft (3 m) above tunnel roof. Headgate for irrigation ditch is in distance, near north portal.

sition by east-flowing streams from highlands or mountainous regions in western Utah and eastern Nevada (Cadigan, 1967, p. 44).

The mechanism of transport and deposition of the Salt Wash was a system of aggrading braided streams (Cadigan, 1967, p. 46) flowing across a broad alluvial plain. Grain sizes in the individual channels vary from pebbles to fine sand and become finer toward the upper part of the channel fill.

BRUSHY BASIN SHALE MEMBER

The Brushy Basin Shale Member of the Morrison in the Sunnyside district is a unit about 200 ft (60 m) thick, composed of interbedded mudstones, siltstones,

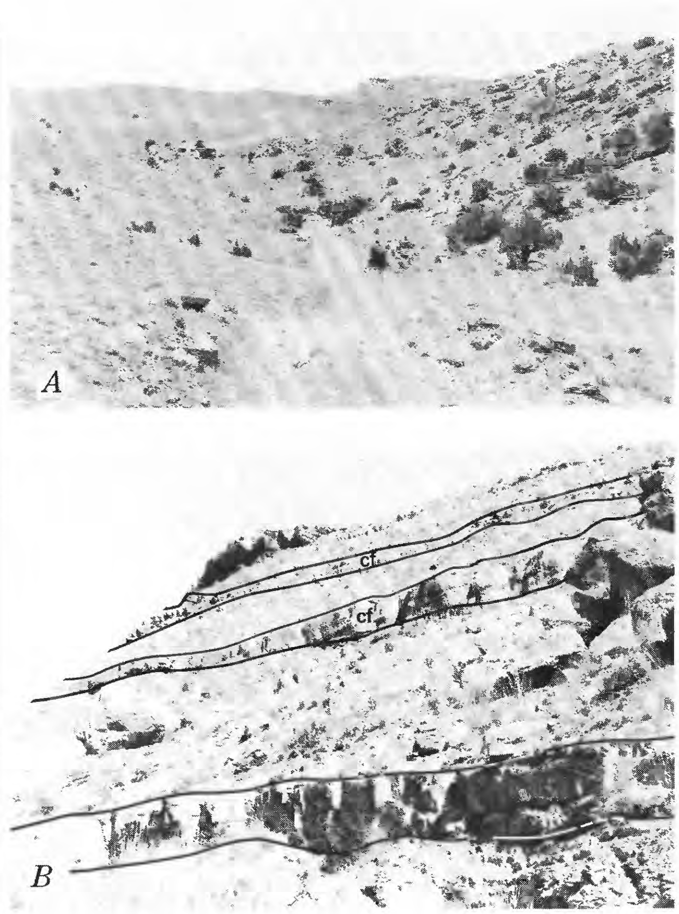


FIGURE 9.—Views of the Morrison Formation. *A*, Northwest view, sec. 4, T. 17 S., R. 13 E., of rounded slopes (foreground) characteristic of the easily eroded Brushy Basin Member of the Morrison Formation. Blocks on slope at right are derived from Buckhorn Conglomerate Member of the Cedar Mountain Formation, which caps cuesta to right. *B*, Southward view of east-dipping channel-fill deposits (cf) (outlined) of chert-pebble conglomerate in the Brushy Basin Member of the Morrison Formation, cropping out above the Price River near Silvagni Ranch in sec. 23, T. 17 S., R. 13 E. These conglomerates closely resemble the overlying Buckhorn Conglomerate Member, which, however, contains relatively few pebbles in this vicinity. Compare those resistant ledges with the easily eroded beds in the Brushy Basin Member in *A*.

claystones, and limestone lenses (fig. 9*A*). The most conspicuous feature of the member is its variegated colors. Limestone layers generally are gray, and other lithologies are various bright shades of red, green, brown, yellow, and gray. Thin discontinuous channel siltstones indicate continued deposition by very sluggish streams on a nearly featureless but extensive flood plain. Much of the claystone is bentonitic, the bentonite having been deposited by ashfall on the Morrison flood plain and mixed with terrigenous sediments. The limestone lenses formed in small lakes scattered over the low-lying flood plain. A group of channel-fill deposits of chert-pebble conglomerate occurs in the Brushy Basin on the Price River, near Silvagni Ranch in sec. 23, T. 17 S., R. 13 E. (fig. 9*B*).

Fragments of mineralized dinosaur bone occur in many outcrops of the Brushy Basin Member throughout central Utah. Excellent dinosaur fossils are contained in the Brushy Basin about 20 miles (30 km) southwest of Sunnyside, in the San Rafael Swell. Many complete skeletons of carnosaurian dinosaurs were recovered from this locality (Stokes, 1944, p. 964). At Humbug Wash (pl. 1), Gilluly and Reeside (1928, p. 81) recovered poorly preserved fossil gastropods.

Tectonism in the Sunnyside area, as in most of the Colorado Plateau during Jurassic time, was limited mostly to slow subsidence of the region. Gilluly (1929, p. 111) reported that the sandstones of the Salt Wash Member thin to as little as 5 ft (1.5 m) on the west side of the San Rafael Swell, and this thinning has been found to be due to a change of facies from sandstone to mudstone. During our field investigations, we observed channel directions in the Salt Wash that deviate from the normal streamflow direction, which was from the northwest across the Morrison coastal plain. These anomalous, arcuate, convex-northeastward trends of relict channel structures indicate deflection of streamflow by a topographically high area. These trends suggest that a slight topographic high on an otherwise relatively featureless plain resulted from slight arching of the swell during deposition of the Salt Wash Member.

CRETACEOUS SYSTEM

Our field studies indicate that between deposition of the Morrison Formation and deposition of the Cedar Mountain Formation the Sunnyside district was part of a slowly subsiding low-lying coastal plain having little relief. No widespread erosion or sedimentation took place here, and only a few sluggish streams meandered eastward to the sea. In western Utah, the Sevier Arch and other north-trending positive areas began to re-emerge after earlier erosion. These areas furnished sediment eastward to the encroaching seaway throughout Cretaceous time.

The San Rafael Swell apparently was quiescent during much of the Cretaceous, because Cretaceous rocks do not thin noticeably toward the swell. Later uplift and erosion removed all Upper Cretaceous rocks from the structure, and so there is no direct sedimentational evidence of tectonism in the swell during the Cretaceous. The swell probably arched slightly in Campanian time.

Sedimentation in the region resumed quietly; emergence of highlands to the west brought surges of deposition of a widespread pediment-gravel veneer on the Morrison sediments, followed by more variegated silts and muds on a coastal plain (Katich, 1954, p. 42).

CEDAR MOUNTAIN FORMATION

The Cedar Mountain Formation was originally assigned group status (Stokes, 1944, p. 958) but was later designated a formation by Stokes (1952, p. 1774). The type locality is on the southwest flank of Cedar Mountain, about 10 miles (16 km) west of Woodside. The formation is composed of two members in the district: the Buckhorn Conglomerate Member and an overlying unnamed shale member.

BUCKHORN CONGLOMERATE MEMBER

The Buckhorn Conglomerate Member crops out in patches atop the Morrison Formation and forms a distinctive lithologic break from the fine-grained Brushy Basin deposits. The type section (Stokes, 1944, p. 966) is at Buckhorn Flat in sec. 9, T. 18 S., R. 10 E., in Emery County, Utah. In the Sunnyside district it varies in thickness from 0 to 60 ft (0 to 18 m) and forms ledges, ridges, and long dip slopes on the east flank of the San Rafael Swell (fig. 10*A*).

The Buckhorn is a conglomerate composed of chert pebbles, feldspar, quartz, quartzite, siliceous limestone, and rare dinosaur-bone fragments. We observed no multilithic rock fragments. Silica and clay are the most common cements. The conglomerate occurs both as extensive sheet deposits and as channel deposits (fig. 10*B*). It is widespread in the northern part of the district but is less abundant in the southern part. Channel forms are discontinuous; they show graded bedding and crossbedding and contain large pieces of silicified plant material (fig. 10*C*). Field measurements of internal sedimentary structures indicate that the dominant transport direction was eastward. Channel structures are preserved in a matrix of fine- to coarse-grained clay-cemented sandstone. Leaf imprints and silicified small plant fragments occur in the sandstone.

Individual channel structures are common in the lower part of the member, and many channel and tabular bodies coalesce in the upper part. Lithologies change abruptly both laterally and vertically throughout the member. Stokes (1944, p. 976) determined that the Buckhorn was derived from upper Paleozoic rocks to the west and southwest of the San Rafael Swell. Stokes (1952, p. 1774) also postulated that this unit is a Cretaceous pediment gravel on the basis of comparison with Holocene pediment gravels.

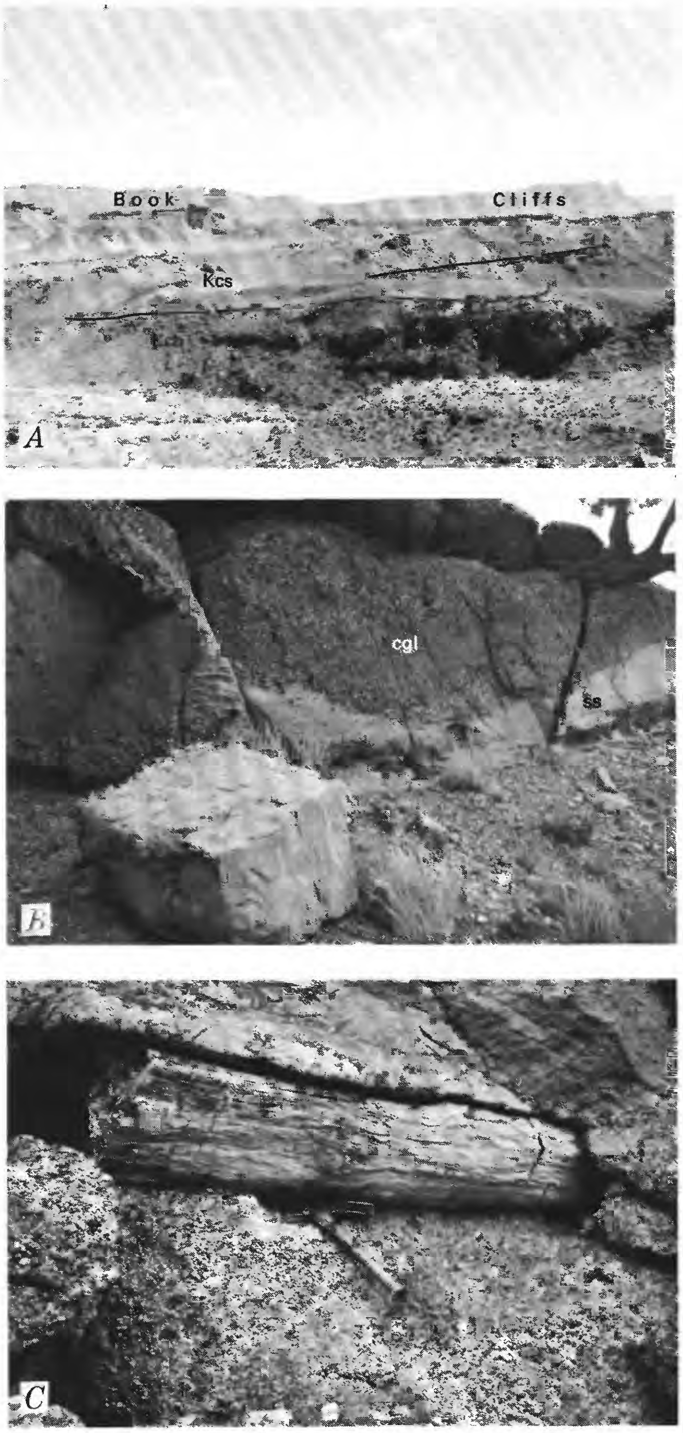


FIGURE 10.—Views of the Buckhorn Conglomerate Member of Cedar Mountain Formation. *A*, Southeast view of the Buckhorn Conglomerate Member in a tributary of the Price River, sec. 23, T. 17 S., R. 13 E. Buckhorn (Kcb) is overlain by the unnamed shale member of the Cedar Mountain Formation (Kcs); higher Cretaceous units in the Book Cliffs are on the skyline. *B*, Southeast view of conglomeratic channel deposit cut into sandstone in the Buckhorn Conglomerate Member, sec. 14, T. 17 S., R. 13 E. Conglomerate (cgl) tongues out just beyond the locality of the right edge of the photograph (southwest), and is wholly replaced by sandstone facies (ss). Most of the pebbles in the conglomerate facies are chert. *C*, Large silicified log in Buckhorn Conglomerate Member. Orientation of log is N. 70° W. Log diameter above pick is 19 in. (48 cm). Most of pebbles in conglomerate are chert. Photograph taken in north-trending tributary to Price River, sec. 14, T. 17 S., R. 13 E.

UNNAMED SHALE MEMBER

The best exposure of the unnamed shale member is on Cedar Mountain, about 10 miles (16 km) west of Woodside, in the northern part of the San Rafael Swell. The shale member unconformably overlies the Buckhorn Member, as shown by channels and other erosion features at the top of the Buckhorn. The member is 272 ft (83 m) thick at Cedar Mountain, but thins eastward and is only 25 ft (7.6 m) thick in western Colorado (Stokes, 1944, p. 989). In the Sunnyside area, the member forms smooth slopes between ledges of more resistant rocks (fig. 10*A*).

The unnamed shale member consists of variegated mudstones and lenticular sandstones and siltstones that commonly contain nodules of chert or siliceous limestone. The unnamed shale may have been derived from reworked Morrison sediments under conditions of deposition similar to those prevailing during Morrison deposition. The two units are very similar in composition and color, but whereas Morrison colors are dominantly bright red and purple, the colors of the unnamed shale member are pastel shades of those colors. Field comparisons showed that nodules of chert and siliceous limestone are more rounded in the unnamed shale than in the Morrison.

Rare fossils in the unnamed shale member indicate late Early Cretaceous (Aptian-Albian) age (Katich, 1954, p. 44). Katich postulated that the member was formed on an alluvial plain, where slow, uniform mud and silt deposition occurred between shallow channels of sluggish streams. A few freshwater lakes and ponds dotted the plain, and vegetation was limited to grass, rushes, and low-growing bushes; only a few large fragments of plants occur in the member. Climatic conditions during deposition of the unnamed shale member probably were warm and humid, or subtropical.

The upper contact of the unnamed shale member is placed at the top of the highest variegated mudstone. This surface is interpreted to be on an unconformity, because it is irregular and incised by fluviatile channels of the Dakota Sandstone.

DAKOTA SANDSTONE

The Dakota Sandstone was extended into central Utah by Richardson (1909, p. 14), who applied the name to an interbedded, ledge-forming, coal-bearing sequence of sandstones and mudstones below the Mancos Shale. In the Sunnyside district the Dakota forms cuestas or hogbacks, or caps mesas of rocks less resistant than itself to erosion. The Dakota is of Early(?) and Late Cretaceous age in the Sunnyside district.

The Dakota varies in thickness from about 20 to 65 ft (6 to 20 m) in the Sunnyside district and is composed of two facies: a lower conglomerate and coarse-grained sandstone and an upper medium- and fine-grained sandstone interbedded with shale.

The lower facies consists of 5–15 ft (1.5–4.5 m) of siliceous chert- and quartzite-pebble conglomerate and arkosic coarse-grained sandstone. The beds commonly are cemented by silica and comprise channel-fill deposits (fig. 11). This facies closely resembles the conglomerate in the Buckhorn Member of the Cedar Mountain Formation. Katich (1954, p. 45) found that Dakota conglomerate consists of 70 percent quartzite and 30 percent chert.

The upper facies consists of 15–50 ft (4.5–15 m) of greenish-brown medium- to fine-grained arkosic sandstone that contains interbeds of light-gray to pale-greenish-gray shale. The shale commonly forms small strike valleys between low sandstone cuestas. The sandstone beds are crossbedded and have irregular upper and lower boundaries. Although we observed no distinct channel-fill structures during our study, we interpret the overall environment of deposition of the Dakota to be fluviatile.

Fossils in the Dakota are uncommon, and only plant fossils are known from the Dakota in the Sunnyside district. Richardson (1909, p. 14) collected Dakota

FIGURE 11.—Channel-fill sandstone deposit of Dakota Sandstone (Kd), cut into unnamed shale member (Kcs) of Cedar Mountain Formation as preserved on a ridge crest in sec. 24, T. 17 S., R. 13 E., above the Price River near Silvagni Ranch. View is eastward and direction of sediment transport in the channel was southeastward. Scale is indicated by thickness of Dakota (about 20 ft or 6 m).

plant fossils near Woodside, and Rushforth (1969) found several genera of fossil ferns in the Dakota. The ferns seem to be good indicators of paleoenvironment, inasmuch as they are related to modern taxa of ferns that grow only in tropical areas, under climatic conditions of high rainfall and humidity.

The uppermost part of the Dakota becomes increasingly finer grained upward, and is conformable with the Mancos Shale.

MANCOS SHALE

The Mancos Shale has been recognized over vast areas of the Western Interior. Because the Mancos interfingers with other formations, its age range is different in different areas. Mancos sediments were deposited in the Western Interior from latest Early Cretaceous to late Late Cretaceous time. In the Sunnyside area, deposition of the Mancos took place throughout most of the Late Cretaceous; it correlates with the middle and upper parts of the Colorado Group and the lower part of the Montana Group reference section of the northern Western Interior (Cobban and Reeside, 1952).

The Mancos is as thick as 4,400 ft (1,340 m) near Sunnyside. Thickness throughout the area is variable, however, owing to varied physiographic conditions during deposition and local postdepositional erosion prior to or concurrent with deposition of Mancos sediments, and to the intertonguing of the upper contact.

Abundant fossils and trace fossils indicate that the formation was deposited in offshore marine environments in the Western Interior seaway. Trace fossils constructed by worms and other benthonic organisms are abundant in the shales, and cephalopod and pelecypod shells are common in ferruginous Mancos concretions (J. R. Gill, oral commun., 1969). The entire Mancos fauna indicates marine deposition.

As a distinctive lithologic unit, the Mancos extends westward as broad outcrop bands across the Colorado Plateau from the Rocky Mountains, and northward from northeastern Arizona to northern Colorado. Although the Mancos in Utah contains several members, near Sunnyside only the Ferron Sandstone Member (Lupton, 1913, p. 16–17) exists as a discrete mappable unit. We concur with R. C. Moore (*in* Longwell and others, 1923, p. 15) that the Tununk Shale (Gilbert, 1877, p. 4), Ferron Sandstone, and Blue Gate Shale (Gilbert, 1877, p. 4) Members of the Mancos in the Henry Mountains area correlate approximately with the entire Mancos section in east-central Utah. Therefore, our map (pl. 1) shows only the main body of the Mancos Shale, the Ferron Sandstone Member, and the lower and upper sandstone members.

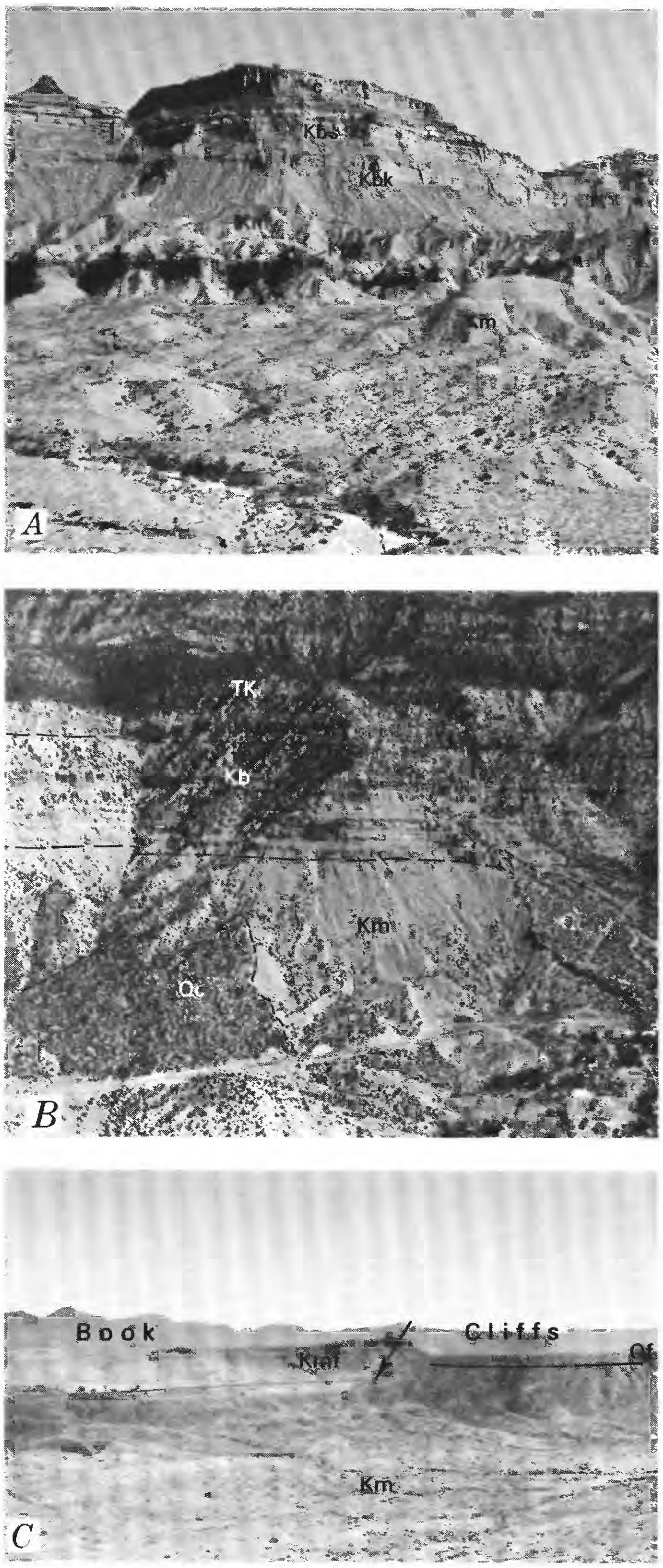


FIGURE 12.—Physical characteristics of the Mancos Shale and associated strata. *A*, View eastward toward the Book Cliffs of badland topography carved in the Mancos Shale, southern part of the district. Resistant ledge, Kba, in middle ground is tongue of Aberdeen Member of Blackhawk Formation; Kbk, Kenilworth Member, and Kbs, Sunnyside Member of Blackhawk Formation; Kc, Castlegate Sandstone, Km, Mancos Shale. *B*, Oblique aerial view of the cliff front near Columbia, Utah, showing steep slopes of Mancos Shale (Km) protected from erosion by the overlying Blackhawk Formation (Kb) and Cretaceous and Tertiary rocks (TK). Qc, colluvium derived from Mancos and Blackhawk sediments. Town of Columbia in lower right corner. Eastward view, sec. 20, T. 15 S., R. 14 E. *C*, Ferron Sandstone Member (Kmf) bluff on the east flank of the San Rafael Swell, near Cedar Siding. The Ferron is cut by a west-northwest-trending zone of faults, having total upward relative displacement of 110 ft (34 m) to the north (left in the photograph). Denver and Rio Grande Western Railroad track passes through the bluff in the fault zone (arrow). Bluff in the middle foreground is Mancos Shale (Km) that was protected from erosion by a remnant of alluvial fan gravel (Qf). Faults cut the Ferron Member behind the middle foreground bluff. Southeastward view in sec. 2, T. 17 S., R. 13 E.

The Mancos Shale in the Sunnyside district forms a wide valley between the San Rafael Swell and the Book Cliffs (fig. 12*A*), where it has been eroded into extensive and intricately carved badlands and broad swales (fig. 12*B*). Badland topography becomes more common near the Price River. Badland formation is strongly influenced by salts, particularly mirabilite ($Na_2SO_4 \cdot 10H_2O$) and thenardite (Na_2SO_4), which inhibit plant growth on the Mancos and also undergo hydration and dehydration as humidity changes. These hydration changes cause swelling and contraction of the sediment particles and contribute much to the weathering process (Buss, 1956, p. 19). In the badlands area, ephemeral streams that drain into the Price River from the Book Cliffs have cut deep, vertically walled trenches in the Mancos. Farther north, however, the Mancos forms broad, gently sloping valleys that extend to the foot of the cliffs. At the foot of the Book Cliffs, the Mancos Shale is protected from erosion by overlying sandstones, and it rises in steep slopes above the valley floors (fig. 12*B*). Although seemingly soft and able to easily absorb water, the Mancos contains much very fine grained mixed-layer clay that allows water only slight penetration below the surface and forces much of the precipitation to run off. For example, during heavy rains Mancos surfaces normally are impassable to vehicles, due to formation of mud on the surface, but the rocks may be dry a few inches down. The surfaces generally dry out within a few hours after a drenching rainstorm.

The lower part of the Mancos Shale comprises about 500 ft (150 m) of medium-gray to bluish-gray, locally fissile mudstone that contains discontinuous lenses and stringers of ferruginous siltstone and claystone. This lower part of the Mancos also contains stringers and veinlets of crystalline gypsum (selenite), and weathered masses of crystals are abundant on mudstone slopes where they sparkle and shine in the sunlight. Thin discontinuous sandy zones occur locally and form low cuestas or support low knolls.

The Ferron Sandstone Member is 800 ft (250 m) thick at its type locality, about 50 miles (80 km) southwest of Sunnyside, near the Wasatch Plateau. In the Sunnyside district, however, the Ferron is only 20–50 ft (7–15 m) thick, where it comprises thin beds of interbedded reddish-brown siltstone and very fine to fine-grained sandstone. The Ferron forms rounded bluffs on the flanks of the San Rafael Swell (fig. 12*C*).

We found only trace fossils in the Mancos in this area. We have found trace fossils of the cruziana and zoophycos facies of Seilacher (1964, p. 310) in some of the siltstone and sandstone beds. According to Seilacher, these fossils indicate an offshore marine environment of deposition for this part of the Ferron; therefore, this unit may be interpreted as the offshore facies of a beach sand that was deposited farther to the west. The arenaceous sediments were transported eastward into the Sunnyside district during a limited regression of the Cretaceous sea. Following this, westward advance of the shoreline resulted in deposition of offshore deep-sea muds above the Ferron.

The upper part of the Mancos Shale resembles the lower part. In lithology, color, and other details, the units generally are similar, but have minor local variations. The upper part contains more gypsum crystals and veins than the lower part; it also contains calcium carbonate and other salts; weathered slopes that look as though they were dusted with flour are common throughout the upper part of the Mancos as a result of weathering of the gypsum and calcium carbonate. Discontinuous tongues of thin sandstone and siltstone, probably offshore extensions of the Aberdeen Sandstone Member of the Blackhawk Formation that is present west of the Sunnyside district, crop out in the Mancos in the southern part of the district near the base of the Book Cliffs.

The Mancos grades upward into and intertongues with sandstone units of the Blackhawk Formation. The contact is conformable, indicating continuing sedimentation during regression of the sea. Because of the intertonguing in these regressive deposits of the Blackhawk and Mancos, the upper contact of the Mancos is placed at successively higher stratigraphic positions (or levels) as one progresses southeastward across the district.

MESAVERDE GROUP

The term "Mesa Verde Group" originally was applied to a group of coal-bearing sandstone and shale units between thick marine shale units (Holmes, 1877, p. 245). The type locality is near Mesa Verde in southwestern Colorado, and the name was used for similar rocks throughout a large part of the Western Interior. So indiscriminately has the name been used that "Mesaverde" is now applied to many rock units in different parts of the Western Interior that are lithologically similar to those at the type locality but that may be of different ages.

In the Sunnyside district the Mesaverde Group comprises three Upper Cretaceous formations. In ascending order, these are the Blackhawk Formation, Castlegate Sandstone, and Price River Formation. Spieker and Reeside (1925, p. 445) named the Blackhawk and Price River (in which they included the Castlegate as Castlegate Sandstone Member) Formations, and Fisher, Erdmann, and Reeside (1960, p. 14) raised the Castlegate to formation rank.

The basal contact of the Mesaverde Group is gradational and intertongues with the Mancos Shale. Because of this relationship, the contact rises stratigraphically eastward into Colorado so that none of the Mesaverde units at Sunnyside are present at the eastern terminus of the Book Cliffs. Thus, all of the Mesaverde Group in western Colorado is younger than any of it at Sunnyside (Fisher and others, 1960, p. 11).

BLACKHAWK FORMATION

As the Mancos sea retreated, a vast deltaic complex prograded eastward across much of central Utah (Howard, 1966, p. 31). In the Book Cliffs region, one such delta (Maberry, 1971) deposited a suite of sediments that is now called the Blackhawk Formation (Spieker and Reeside, 1925, p. 443). This formation comprises several depositional sequences of similar genesis which were laid down in an offlap relationship. Each sequence represents a progression from marine environments of deposition on the west to continental environments on the east. Each sequence also ended with a relatively minor transgression of the sea, followed by the next regressive sequence.

The Blackhawk forms the main scarp of the Book Cliffs in the Sunnyside district. It is composed of thick cliff-forming sandstone beds that are resistant to erosion, and weakly resistant slope-forming mudstone beds between the sandstones.

The Blackhawk Formation contains several extensive coal deposits, which are the basis for much of the economy of central Utah. Because of the economic importance of the coals, stratigraphers have subdivided the Blackhawk into members, each member containing one particular coal bed somewhere in the Wasatch Plateau or Book Cliffs Coal Fields. Various workers did not always use the same criteria for distinguishing members, however; historically, these criteria depended upon the goals of the individual investigators and upon the locations of their investigations. Spieker and Reeside (1925, p. 442) named the Star Point Sandstone, a unit that can be separated from the overlying Blackhawk on the basis of lithology and topographic expression. The Star Point occurs only in the Wasatch Plateau. Clark (1928, p. 11) distinguished two members of the Blackhawk (in ascending order): the Aberdeen Sandstone Member and the coal-bearing member; Young (1955) used topographic expression and inferred genesis in separating the Blackhawk into six members, including Clark's Aberdeen Member. Maberry (1971) redefined two of Young's members on the basis of lithology and unit mappability, and pointed out some of the stratigraphic problems inherent in naming rock strata of the Book Cliffs.

Only the Aberdeen Member, Kenilworth Member, upper mudstone member, lower mudstone member, and Sunnyside Member are present in the Sunnyside district (Maberry, 1971, p. 24). Members of the Blackhawk stratigraphically below the Aberdeen crop out farther west and tongue out into the Mancos Shale before reaching Sunnyside. Members stratigraphically above the Sunnyside occur to the south and east of the area of this report.

Maberry (1971) described both the Kenilworth and Sunnyside Members as being composed of marine sandstone. He described an upper mudstone member, above the Sunnyside, and a lower mudstone member, separating the Sunnyside and Kenilworth.

ABERDEEN MEMBER

The Aberdeen Member was named by Clark (1928, p. 18) for an outcrop in the western Book Cliffs, at the Aberdeen Mine near Kenilworth. In the Sunnyside district the member is only a thin zone of weakly resistant, shaly, fine-grained sandstone and siltstone that crops out discontinuously. It is underlain and overlain by the Mancos. Its base is some 200 ft (60 m) stratigraphically below the Kenilworth Member. South of Horse Canyon, rocks mapped as Aberdeen(?) form a low cuesta at the foot of the Book Cliffs. The eastern part of the Aberdeen contains the zoophycos-facies trace fossils and is interpreted as the offshore and prodelta slope facies of the deltaic beach-complex sandstone body that makes up the type Aberdeen. The Aberdeen Member in the Sunnyside district is barren of coal.

KENILWORTH MEMBER

Named by Young (1955, p. 183) for the type locality near its outcrop at Kenilworth, Utah, the Kenilworth Member at Sunnyside comprises three distinct sandstone tongues, each overlain by a shale sequence (fig. 13). Each sandstone tongue begins and ends farther east and south than the tongue it overlies. The entire Kenilworth was deposited in a three-cycle rhythmic succession of marine-to-continental-to-marine sedimentation. In the southern part of the district near the Price River, only the two upper tongues persist.

We placed the base of the Kenilworth at the lowest persistent sandstone bed in the Blackhawk Formation. The base thus defined rises stratigraphically to the south and east but remains physically consistent. This lithologic break is expressed physiographically as a sheer cliff composed of a series of sandstone ledges and is distinctly mappable. The member ranges in thickness from 110 to 220 ft (35 to 65 m).

The sandstone tongues of the Kenilworth were deposited as prograding beach and barrier complexes (Maberry, 1971). The vertical gradation from mudstone at the base to well-sorted sandstone at the top indicates progressive shoaling of the sea floor as the sea withdrew eastward. As the shoreline migrated seaward, coarser grains were deposited in the Sunnyside area as finer sediments were carried out to sea.

Mudstone units between sandstones of the Kenilworth and Sunnyside and above the Sunnyside commonly contain coal lenses and carbonaceous horizons. Most of these mudstones indicate positions of coal beds farther west and east which are paleoecologic indicators of low-lying swamps landward from the beach complex. The coal-bearing part of each mudstone unit is overlain by marine mudstone deposited when the sea made limited transgressions. In ideal cyclothemic stratigraphy, the coal-bearing units should be included

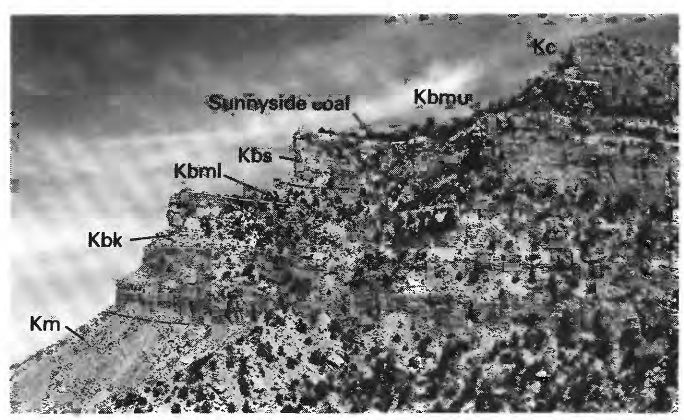


FIGURE 13.—Cyclic sedimentation units in Kenilworth and Sunnyside Members of the Blackhawk Formation at the mouth of Fan Canyon, 3 miles (5 km) east of Sunnyside (pl. 1). Km, Mancos Shale. Blackhawk Formation: Kbk, Kenilworth Member; Kbml, lower mudstone member; Kbs, Sunnyside Member; Kbmu, upper mudstone member; Kc, Castlegate Sandstone. This outcrop is the principal reference section of the Kenilworth Member (Maberry, 1971). Scale indicated by 1,000-ft (305-m) thickness from base of Kenilworth Member to top of Castlegate Sandstone.

with the sandstones at the top of a cycle, the marine part as the base of the next succeeding cycle. However, for convenience in mapping, the contacts at the bases of the sandstones were used.

LOWER MUDSTONE MEMBER

Above the Kenilworth Member is a 150–200-ft (45–60-m)-thick, slope-forming sequence of coal-bearing, generally dark-gray, clayey mudstones, shales, and sandy siltstones designated the lower mudstone member of the Blackhawk (Maberry, 1971, p. 26). The thin discontinuous and lenticular Rock Canyon coal bed lies on top of the tongue of the Kenilworth Member, but the coal tongues out southward into a very thin carbonaceous zone near Woodside.

Trace fossils and inorganic sedimentary structures of continental affinity are common throughout the lower half of the lower mudstone member, but the upper part contains biogenic and inorganic structures indicative of marine deposition. The lower continental mudstone was deposited landward of the beach complex. When the sea encroached upon the land the continental sediments were covered by sea-floor muds.

SUNNYSIDE MEMBER

Young (1955, p. 185) gave the name Sunnyside Member to a sequence composed of a massive basal sandstone tongue and the overlying coal-bearing rocks "which are replaced eastward by barrier-bar sandstones." This sequence is difficult to recognize at every point along the Book Cliffs; therefore, Maberry (1971, p. 27) redefined the Sunnyside Member, applying the name to the continuous cliff-forming sandstone unit about 200 ft (60 m) above the Kenilworth Member. The Sunnyside contains a 100–190-ft (30–58-m)-thick sequence of interbedded sandstone and siltstone at the base, grading upward through fine-grained sandstone to thick-bedded, medium-grained sandstone at the top (fig. 14). The upper boundary of the member is at the top of the uppermost sandstone bed in the sequence.

The Sunnyside sandstones were deposited as beaches and barriers as the Cretaceous sea withdrew from the area toward the east. The lower part of the member contains trace fossils and sedimentary structures that indicate a quiet offshore depositional environment. Upward in the section crossbedding is common, and the trace fossils are those of organisms that lived in shallow offshore marine environments. In the upper part of the member, only trace fossils of organisms that lived in a beach and near-shore littoral environment were found, and crossbedding and ripple marks indicate deposition in shallow water having high kinetic energy (Maberry, 1971, p. 27–30).

FIGURE 14.—Characteristic topographic forms and sedimentation units in the Sunnyside Member of the Blackhawk Formation, east side of Slaughter Canyon near the canyon mouth, sec. 32, T. 14 S., R. 14 E. Blackhawk Formation: Kbk, Kenilworth Member; Kbml, lower mudstone member; Kbs, Sunnyside Member; Kbmu, upper mudstone member; Kc, Castlegate Sandstone.

UPPER MUDSTONE MEMBER

The Sunnyside Member is overlain by 100–200 ft (30–60 m) of mudstone and discontinuous sandstone beds of the upper mudstone member. The thick and economically important Sunnyside coal is at the base of the member, directly above the thick sandstone of the Sunnyside Member (Maberry, 1971, p. 30). Above the coal are mudstone, siltstone, and sandstone beds that were deposited in back swamps and coastal plains westward of the beach area.

A thick sandstone, the lateral equivalent of the upper mudstone member (Maberry, 1971, p. 31), overlies the Sunnyside coal in the southern part of the district (fig. 15). This overlying sandstone, which begins near Horse Canyon and persists southward into the Beckwith Plateau where the Sunnyside coal bed pinches out, was designated the Grassy Member of the Blackhawk by Young (1955, p. 186). Fluviatile channel sandstones, the landward lateral equivalent of the Grassy, also crop out in Water Canyon and in Fan Canyon (sec. 8, T. 15 S., R. 14 E.), about 6 miles (10 km) north of the limits of the Grassy (fig. 16).

Large channel sandstones in the upper mudstone member are the lateral equivalent of estuarine and beach deposits farther east. These channel deposits are more common in the upper part of the upper mudstone member, and many merge or branch to form larger or smaller structures. The largest of these channel sandstones in the Sunnyside district is 150 ft (45 m) wide and 24 ft (7 m) thick at its thalweg. Internal crossbedding and ripple marks in the channel sandstones indi-

FIGURE 15.—Surface plant of the Book Cliffs Mine, abandoned in 1967, showing relation of the Sunnyside coal bed (at the level of the upper building) to the underlying sandstone beds of the Sunnyside Member (Kbs). Strata from the top of the Sunnyside Member to the top of the photograph are in the upper mudstone member of the Blackhawk Formation. The sandstone bed (ss), which overlies the coal, was designated the Grassy Member by Young (1955). Photograph by Vard H. Johnson.

cate that the principal flow direction was east-southeast.

Thin discontinuous lenses and pods of impure coal are common throughout the mudstone interval. These deposits are the remains of local short-lived swamps and bogs (back-swamp deposits) landward from the shore. Such coals are neither thick enough to be of commercial interest nor extensive enough to be useful for correlation.

The upper contact of the Blackhawk Formation is an unconformity, but is the product of a local diastem rather than a regional unconformity. Stream channels of the Castlegate Sandstone were cut into the soft muds and friable sands after deposition of the Blackhawk. These channels were filled in by coarse sands of the Castlegate Sandstone. Slump structures resulting from failure of channel banks locally are common in the base of the Castlegate, and thin deposits of carbonized plant debris are common along the contact between the mudstone and Castlegate Sandstone.

CASTLEGATE SANDSTONE

The name Castlegate Sandstone Member was applied by Spieker and Reeside (1925, p. 445) to the lowest cliff-forming sandstone member of the Price River Formation. At the former town of Castle Gate, Utah (fig. 1), the sandstone in Price River Canyon is eroded to buttresses and towers, reminiscent of castles and forts. Fisher, Erdmann, and Reeside (1960, p. 14) elevated the Castlegate to formation status on the basis of its areal extent and unique lithology.

At Castle Gate, Utah, the formation is about 550 ft (170 m) thick and is conglomeratic. The conglomerate grades laterally eastward into finer grained deposits. In the Sunnyside district the lower 150 ft (45 m) of Castlegate Sandstone is generally medium and coarse grained, comprising quartz, feldspar, chert, and rock fragments in a calcareous clay matrix. Above this is a fine- to medium-grained, moderately well-sorted quartzose sandstone unit about 50 ft (15 m) thick. In the northwestern part of the Sunnyside district, the upper part is fine-grained, well-sorted quartzose sandstone.

Most of the Castlegate in the Sunnyside district was deposited by a stream-channel network debouching onto the coastal plain area behind the Blackhawk beaches. The most common sedimentary structure in Castlegate channel deposits is large-scale crossbedding formed by dunes, antidunes, and point bars. Large-scale foreset crossbedding dips at right angles to channel flow. Three-dimensional field measurements of crossbedding indicate that overall flow direction was east-southeast, although individual channel flow varied as much as 90° from the major direction. Discontinuous beds of thinly interlaminated sandstone and siltstone occur locally at the base of the Castlegate. These beds are here interpreted to be deposits of sluggish tributary streams.

The Castlegate forms a prominent cliff above the Blackhawk Formation throughout the Book Cliffs (figs. 13, 14, 16). Units above the Castlegate form a series of retreating ledges and slopes parallel to the trend of the cliffs behind the Castlegate.

Deposition of the Castlegate Sandstone ended as the western highland was eroded. After the period of forceful, turbulent Castlegate sedimentation and the time of erosion of the Castlegate surface, deposition was slow and quiet as muds and silts accumulated on the alluvial plain during the final recession of the sea.

PRICE RIVER FORMATION

Spieker and Reeside (1925, p. 445) named the Price River Formation for outcrops in Price River Canyon, near Helper, Utah. Fisher, Erdmann, and Reeside (1960, p. 14) restricted the Price River Formation by removing the Castlegate Sandstone, and we mapped the Price River in two members (pls. 1, 2). The lower member is unnamed and consists of interbedded mudstones, claystones, siltstones, and fine-grained sandstones; the upper member is the Bluecastle Sandstone Member.

The Price River sequence west of the Wasatch Plateau is a thick conglomerate which has a deeply eroded upper surface. Progressing eastward, the Price River thins and grades into rocks composed largely of clay-size materials in western Colorado. The formation is as much as 600 ft (180 m) thick in Price River

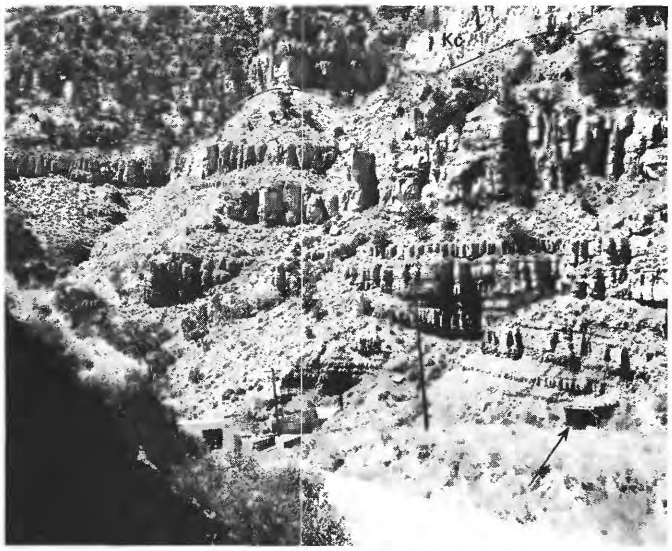


FIGURE 16.—Fluvial channel sandstone beds in the upper mudstone member of the Blackhawk Formation, Water Canyon, sec. 9, T. 16 S., R. 14 E. Upper limit of the Sunnyside coal bed is at the level of the old mine portal (arrow). Fluvial sandstone facies, the products of shifting stream-channel networks on the coastal plain, pinch out laterally into continental shale and mudstone facies. Kc, Castlegate Sandstone.

Canyon, about 35 miles (55 km) west of the Sunnyside district (Spieker, 1946, p. 120), but it thins eastward across the Sunnyside district and intertongues in eastern Utah with marine Mancos Shale units.

We found part of a fossil gastropod in the unnamed member of the Price River Formation on the east side of Whitmore Canyon, a quarter of a mile (400 m) south of the mouth of Pasture Canyon. This fossil was identified by D. W. Taylor of the U.S. Geological Survey (written commun., 1966) as the operculum of the freshwater snail *Reesidella nana* (White). Taylor stated:

> White (1886, p. 32) described this species (as "*Viviparus nanus*") from "Wasatch strata, near Wales, Utah, and in equivalent strata at several localities in the Wasatch Mountains." Later collectors have not found the species in either the Flagstaff Formation or Colton Formation, so it may have come from either the North Horn or the Price River Formation. The present occurrence is the first confirmation of the species in the Price River Formation.

LOWER UNNAMED MEMBER

The lower unnamed member of the Price River Formation consists of about 150–300 ft (45–90 m) of argillaceous fine-grained sandstone deposited on a coastal plain. Dominant colors are gray and brown. Crossbedding is common locally in siltstones and fine-grained fluviatile sandstones. Thin discontinuous impure coal beds occur at many horizons in the unnamed member. These coals indicate accumulation of organic and inorganic debris in restricted, short-lived upland swamps and bogs. Pods and lenses of sandstone occur at intervals throughout the member, indicative of channel cutting and infilling by slow-flowing streams. Fossils are uncommon in the member, but channel sandstones locally contain freshwater pelecypods, and we recovered incomplete remains of an unidentified large invertebrate from the member in Horse Canyon.

The unnamed member generally is soft and easily eroded because most individual strata are poorly cemented. The sediments contain large amounts of organic material and clay. The unnamed member in the Sunnyside district commonly forms low slopes behind the Castlegate cliffs. In the southern part of the district, where faulting and differential erosion have locally removed the overlying Bluecastle Sandstone Member, the drainage of Little Park Wash (pl. 1) formed along the strike of the unnamed member (fig. 17).

BLUECASTLE SANDSTONE MEMBER

The Bluecastle originally was designated as a bed of the Neslen coal-bearing member of the Price River Formation, a transitional marine unit in the Book Cliffs east of the Green River (Fisher, 1936, p. 18). V. H. Johnson of the Geological Survey recognized the Bluecastle as the upper 300 ft (90 m) of the Price River Formation in the Woodside Quadrangle (Fisher, Erdmann and Reeside, 1960, p. 17), and it was subsequently (Fisher and others, 1960, p. 11, 14) raised in stratigraphic rank to the upper member of the Price River Formation, west of the Green River and as an upper member of the Neslen Formation east of the Green

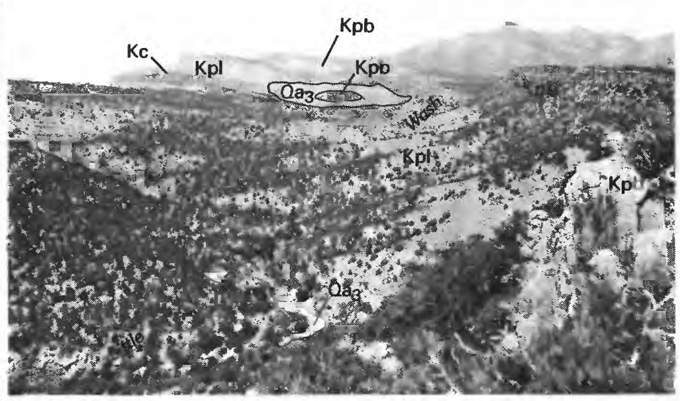


FIGURE 17.—Northward view of the upper reach of Little Park Wash, showing the alluvium-filled strike valley (Qa3); the upper part of the cliff, and dip slopes of the Castlegate Sandstone (Kc); lower unnamed member of the Price River Formation (Kpl), into which Little Park Wash is incised (steep canyon walls in lower left part of picture); and cliff and part of the dip slopes of the Bluecastle Sandstone Member of the Price River Formation (Kpb). High cliffs and slopes in the background are the Roan Cliffs, composed of the North Horn, Flagstaff, and Colton Formations. Skyline in left half of picture is top of Book Cliffs.

River. In mapping the Sunnyside district we found that the Bluecastle is a prominent mappable unit throughout the western Book Cliffs (pl. 1) and that the member becomes thinner and more fine grained eastward and intertongues with the upper part of the Neslen Formation. The Neslen Formation and the Price River Formation, composed of the lower unnamed member and the Bluecastle Sandstone Member, thus are considered to be time-equivalent facies of the same depositional episode.

The Bluecastle Sandstone Member consists of fine- to medium-grained quartz sandstone, cemented to varying degrees by silica, ferruginous clay, and carbonate. It is thickest and most coarse grained in the northwestern part of the Book Cliffs. Local casehardening by ferruginous silica cement is common throughout the unit, and desert varnish is common on weathered cliff faces.

The Bluecastle is 10–300 ft (3–90 m) thick in the Sunnyside district, and forms an abrupt vertical cliff between the lower unnamed member and the overlying North Horn Formation, particularly north of Sunnyside (pls. 1, 2), where it attains maximum thickness. Stripped dip-slope surfaces are common on top of the Bluecastle and result from downdip erosion of the softer North Horn. The Bluecastle is made up of multistory and multilateral crossbedded, interbedded channel sandstone bodies, interspersed with thick, flat-bedded sandstone beds. We believe that the channel sandstones were formed by lateral and vertical migration of mobile stream channels at the lower end of an alluvial plain derived from the western highland. Spieker (1946, p. 132) correlated the Price River Formation with "the postorogenic gravels of the western districts"; the channel sandstones and flat-bedded sandstones probably formed in response to the changing hydrologic regimen in the western highland. Sedimentary structures in channel bodies, such as ripple marks, dunes, flute casts, and prod marks, indicate formation in the lower flow regime of a stream system flowing generally east-southeast. Graded bedding locally is present in the flat-bedded sandstones, and internal structures of these beds include scour-and-fill crossbedding, chaotic and convolute lamination, and foreset crossbedding.

The upper surface of the Bluecastle has been postulated to be an unconformity (Young, 1955, p. 180), but the only evidence we have found to support this postulation is local concentrations of silicified wood on the upper surface and local lateral thickness variations in the unit. In most places the top of the Bluecastle appears to be conformable with the North Horn Formation.

CRETACEOUS AND TERTIARY SYSTEMS, UNDIVIDED

NORTH HORN AND FLAGSTAFF FORMATIONS

The North Horn Formation was named by Schoff (1937, p. 379) for exposures on North Horn Mountain in the Wasatch Plateau. Spieker (1946, p. 133) measured 1,650 ft (500 m) of North Horn at the type locality, and recognized that the unit consists of alternating beds of lacustrine origin and of overbank floodplain and fluviatile channel origin. The North Horn is of Late Cretaceous and Paleocene age. Cretaceous dinosaur remains were found in the lower part of the unit, and Paleocene mammal remains occur in the upper part, but there is no known clearcut boundary between rocks of the two ages (Cobban and Reeside, 1952, p. 1028). Whether a sharp boundary is of great importance is problematical, however. Spieker (1946, p. 142–149) concluded that any time boundary within the North Horn probably should be regarded as "an arbitrary device, founded *** on phenomena of natural significance, but hardly expressive of any comprehensive principle."

In the Sunnyside district the North Horn interfingers with and is transitional into the overlying Flagstaff Limestone (fig. 18). In this area the North Horn consists of interbedded claystones, mudstones, limestones, siltstones, and sandstones. The claystones and mudstones generally are brownish gray to blue gray and are highly plastic. Most contain much carbonaceous detritus and contain from 5 to 15 percent silt-

FIGURE 18.—Southward view of transition between and intertonguing of North Horn (TKn) and Flagstaff (Tf) Formations in sec. 9 (unsurveyed), T. 17 S., R. 15 E. Ledges in the middle of the hill are beds of Flagstaff Limestone; most of the slope is mudstone of North Horn Formation; the ledge at the crest of the hill is Flagstaff Limestone.

and sand-size quartz. Limestones generally are blue gray to reddish brown and commonly contain abundant freshwater pelecypod and gastropod fossils. Most siltstones and sandstones are brownish, lenticular, and contain much carbonaceous detritus and scattered fossils. Locally, the North Horn near Sunnyside contains fossil algae.

The Flagstaff was named Flagstaff Limestone Member of the Wasatch Formation by Spieker and Reeside (1925, p. 450). Spieker (1946, p. 135) later elevated the Flagstaff to formation rank. The type locality is on Flagstaff Peak in the Wasatch Plateau, where the unit is nearly 1,500 ft (460 m) thick. The formation is expressed both as ledges of varying thickness and as dip slopes throughout the Sunnyside district. Flagstaff sediments were deposited during middle and late Paleocene and early Eocene time in a freshwater lake. The lake was formed by intermittent basin downwarping in central Utah (Weiss, 1969, p. 1116) between phases of flood-plain deposition of North Horn and Colton sediments.

The Flagstaff is thick enough and lithologically distinct so that it may be traced northward continuously from Flagstaff Peak and around the Book Cliffs to a position between the town of Columbia and Horse Canyon. Here the formation thins and intertongues with the North Horn and Colton Formations. The Flagstaff is the most distinctive lithologic unit in the northern part of the district (pl. 2). It can be differentiated with difficulty in detailed stratigraphic sections in the central part of the district, and only individual interfingering beds of Flagstaff lithology are discernible in the southern part of the district (fig. 19). Flagstaff beds are distinguished by the wealth of contained fossils (La Rocque, 1960), and individual strata in the southern part of the Sunnyside district may be differentiated on this basis.

North Horn sediments were deposited on a base-level plain upon which environments alternated between lacustrine and alluvial plain. When North Horn deposition began, lacustrine conditions dominated near Sunnyside, and sediments were deposited in deltaic, near-shore, and offshore environments in the lake in response to changing climatic conditions. Weiss (1969, p. 1115) showed that the Flagstaff Lake persisted in Utah over a long period of time. He also showed that the upper surface of the Flagstaff is conformable with the Colton Formation (early and middle Eocene) or with the Green River Formation (early and middle Eocene).

The following fossils that we found at Sunnyside were identified by D. W. Taylor (written commun., 1966). He believes that these fossils indicate early Eocene (Gray Bull) age. The upper part of the Flagstaff in the Wasatch Plateau is equivalent to the upper part of the North Horn Formation and lower part of the Colton Formation in the Sunnyside district.

FIGURE 19.—Characteristic uniform bedding in Flagstaff Limestone in sec. 12, T. 16 S., R. 15 E. Scale indicated by motor scooter, 3.5 ft (1.1 m) high.

- Freshwater species
  - Class Pelecypoda
    - *Plesielliptio* sp.
  - Class Gastropoda
    - *Valvata bicincta* Whiteaves
    - *Hydrobia utahensis* White
    - *Bellamya* n. sp.
    - "*Campeloma*" *limneaformis* (Meek and Hayden)
    - *Physa* cf. *P. bridgerensis* Meek
    - *Cleopatra tenuicarinata* (Meek and Hayden)
    - *Hydrobia* sp.
    - *Pleurolimnaea tenuicosta* (Meek and Hayden)
    - *Bulinus (Pyrogophysa)* sp.
    - *Valvata* sp.
- Continental (land) species
  - Class Gastropoda
    - *Discus*? sp.
    - *Helminthoglyptidae*?

TERTIARY SYSTEM

EOCENE SERIES

COLTON FORMATION

The Colton Formation is a series of variegated sandstones and mudstones, ranging in thickness from 900 ft (275 m) to about 3,000 ft (900 m) in the Sunnyside district. The unit was named by Walton (1944, p. 120) for outcrops at Colton, Utah, about 40 miles (65 km) northwest of Sunnyside. Colton strata thicken to the southeast, reaching 3,400 ft (1,050 m) in thickness in the cliffs north of the town of Green River, Utah, but thin north of Sunnyside and grade laterally into the

Green River Formation. In the Sunnyside district, the Colton forms the Roan Cliffs, standing in north-trending steep slopes and sheer cliffs that face westward. Near Woodside, the Colton Formation changes strike to swing eastward toward the Green River. The change of strike occurs some distance before the Blackhawk and Price River Formations change strike, and the departure of the Roan Cliffs from the Book Cliffs is a conspicuous physiographic feature. In the northern part of the district, we divided the Colton, for mapping purposes, into a lower and an upper unit (pl. 2). The lower unit is mostly mudstone containing some sandstone channel deposits; the upper unit contains dominantly fluviatile sandstone deposits and is more resistant to erosion than the lower unit. The lower unit forms slopes and occasional ledges; the upper unit forms cliffs and bluffs having minor small slopes between. The upper unit of the Colton, called Wasatch Formation by Holmes, Page, and Averitt (1948), contains beds of bituminous sandstone ("tar sands") north of Sunnyside.

Interbedded fluviatile, overbank, flood-plain, and lacustrine beds make up the Colton (fig. 20). Bedding is expressed as channel-fill structures and in tabular and lenticular bodies of small individual areal extent. In the Sunnyside district, the Colton was deposited during a local interlacustrine period between the most extensive coverage of Lake Uinta, of which the middle and late Paleocene and Eocene Flagstaff Lake (C. B. Hunt, 1956, p. 76) is here considered a part, and the Eocene Green River Lake (C. B. Hunt, 1956, p. 78). Colton sediments are here thought to be a fluvial and overbank flood-plain facies of a depositional episode that elsewhere produced lacustrine deposits of the Flagstaff and Green River Formations.

In the Sunnyside district, most of the Colton is red, but strong hues of red, reddish brown, yellow, green, and gray alternate throughout the formation. The Roan Cliffs were named for the red-brown coloration given them by the Colton Formation.

The Colton originally was correlated with the lower part of the Wasatch Formation; historically, however, there is some disagreement among geologists concerning the "Wasatch problem" (Spieker, 1946, p. 137–139). In recent times the trend has been toward the use of Wasatch much in the same manner as Mesaverde, that is, to let the name indicate a typical assemblage of lithologies. Used in this way, the Colton Formation certainly may be called early Wasatch age.

GREEN RIVER FORMATION

In the Sunnyside district, the Green River Formation consists of a 0–125-ft (0–38-m)-thick sequence of freshwater limestone and marlstone, siltstone, sandstone, and shale. It occurs as the highest bedrock unit in the stratigraphic section and caps topographically high ridges and knobs. It is present only in the northeastern part of the district but was outside the area mapped during field investigations. The Green River is transitional with the underlying Colton Formation.

QUATERNARY SYSTEM

Surficial materials of Quaternary age are distributed widely throughout the Sunnyside district. These materials range from high-level deposits of stream alluvium of probable early Pleistocene age along the Book Cliffs and along the slopes above Whitmore Canyon to Holocene alluvium along modern stream courses and to man-induced talus formed since 1959 (fig. 41). The

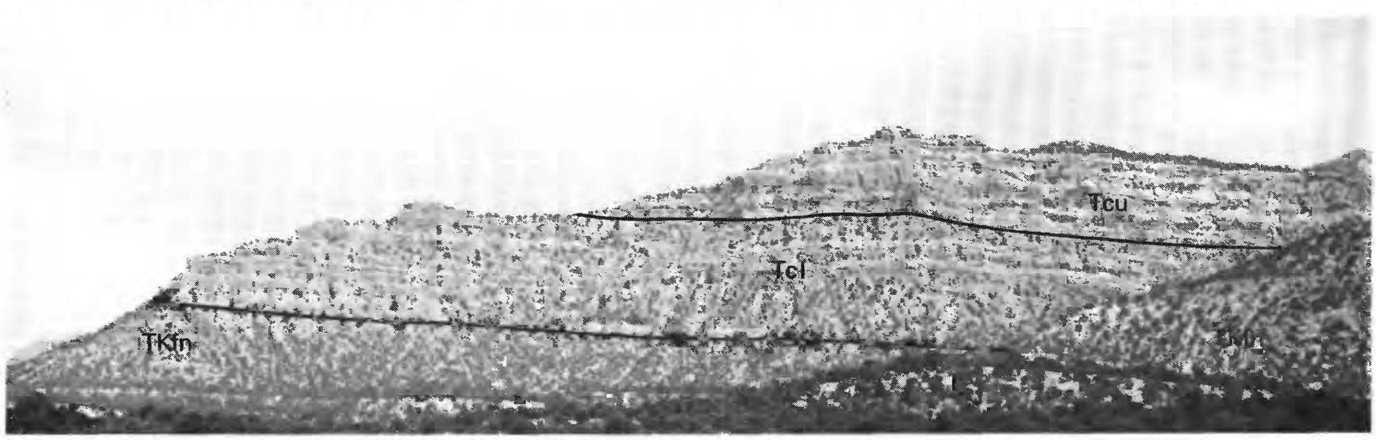


FIGURE 20.—Northward panoramic view showing topographic forms produced by lenticular and intertongued sandstones in the Colton Formation south of Horse Canyon in sec. 24, T. 16 S., R. 14 E. The Colton Formation overlies the TKfn, North Horn and Flagstaff Formations undivided; Tcl, lower unit, Colton Formation; Tcu, upper unit, Colton Formation.

Quaternary materials were of considerable interest to our investigations, because their depositional history provides clues to the diastrophic and erosional histories of the region, which bear importantly on the stress history of the coal and on the distribution of strain energy stored in the coal. Some sedimentary units of Quaternary age are correlated tentatively with similar units recognized by Richmond (1962) in the La Sal Mountains, Utah, about 130 miles (210 km) southeast of Sunnyside. These correlations are tenuous at best, because they are based largely on inferences drawn from the topographic positions of the units and from their relationships to the regional geomorphic development. Other units, on even less definitive evidence, are correlated with units elsewhere in the Colorado Plateau, as summarized by C. B. Hunt (1956, p. 27, 38).

PLEISTOCENE SERIES

SEDIMENTS OF EARLY PLEISTOCENE AGE

Stream-worn gravels and boulders indicative of former stream terraces are widely scattered on interfluvial divides along the face of the Book Cliffs and along valley slopes above Whitmore Canyon (Qa1 on pl. 2). These terrace remnants are found at several levels, but some that tentatively can be correlated indicate a gradual depositional gradient to the south. Cobbles and boulders in all remnants that we examined were derived from the Bluecastle Sandstone Member of the Price River Formation, sandstones of the North Horn Formation, the Flagstaff Limestone, and sandstones of the Colton Formation. Still higher and older remnants along the top and flanks of Patmos Mountain (pl. 1) overlie the Green River Formation and slope about 2° south; all fragments in these remnants were derived from the Green River Formation. In general, the rock types in each remnant are similar to the rocks near the stratigraphic level at which the remnant occurs; this similarity suggests that the former streams by which the rocks were deposited flowed southward in a series of strike valleys, as do the streams presently flowing in Range Creek, Little Park Wash, and in parts of Whitmore and Horse Canyons (pl. 1). Range Creek and Little Park Wash probably are survivors of the drainage pattern in which the gravels were deposited. Streams flowing westward down the face of the ancestral Book Cliffs, as the cliffs retreated to their present position, probably captured some of the older and higher streams (Osterwald and others, 1971, p. 13). The age of these remnants is unknown, but they clearly are older than the Book Cliffs. The old streams probably existed during early Pleistocene time, but they possibly could have been of Pliocene age.

Several feet of stream alluvium covers the top of West Ridge (pl. 1; Qt on pl. 2). Much of this alluvium is dark brown and deeply weathered and consists of silt, clay, and some sand. A few lenses of flat to oblate, rounded sandstone gravels and cobbles, as well as a few sandstone boulders, are interbedded with the fine-grained material. The alluvium fills low places in a gently rolling topography on top of the ridge. Small hills underlain by sandstones of the Colton Formation project upward through the alluvium in some places. Siltstones of the Colton beneath the alluvium are deeply weathered whereas sandstones are not, although they are less tightly cemented than the siltstones. In some places the alluvium is slightly plastic but is nonswelling. On the south part of West Ridge the alluvium fills a broad but shallow valley that may be an ancient stream course (pl. 2).

SEDIMENTS OF PRE-WISCONSIN(?) AGE

BOULDER DEPOSITS

In the Sunnyside district two separate areas of scattered, deeply weathered boulders (Qm on pl. 2) are the only units of Quaternary age that may be of glacial origin. These two areas, each several hundred feet long and a few hundred feet wide, are near the crest of West Ridge at altitudes of 8,640 to 8,800 ft (2,633–2,682 m). They are about 800 ft (245 m) above the floor of an ancient valley in which Whitmore Canyon is entrenched (p. 41; pl. 2), or about 1,750 ft (530 m) above the present floor of Whitmore Canyon. The boulders are rounded to subangular and range in size from 1 or 2 m to the dimensions of small houses. No matrix surrounds the boulders, presumably because it has long since been eroded. Bedding planes in the boulders trend at widely diverging attitudes, and only in a few is bedding parallel to the strike and dip of the underlying Colton Formation. The boulders were deposited on stream alluvium of probable early Pleistocene or Pliocene age. Although the boulders are similar lithologically to sandstones of the Colton Formation at lower elevations in West Ridge, no logical source for such boulders is present on West Ridge; therefore, they probably were transported to their present position by ice from one or more modified cirquelike depressions in the west side of Bruin Point at an elevation of about 10,000 ft (3,050 m) 4 miles (6.5 km) to the northeast, or from Mount Bartles (fig. 1) at a slightly lower elevation 7 miles (11 km) to the north. Whatever the source, the glacier could not have flowed on any presently existing topography because all the possible sources are separated from West Ridge by large canyons.

The exact age and correlation of the boulder masses cannot be determined directly. Because of their topographic distribution and general characteristics, the boulder masses may be correlative with some of the pre-Wisconsin glacial deposits in other parts of the Colorado Plateau, as summarized by C. B. Hunt (1956, p. 35–36). The boulder masses, which clearly antedate Whitmore Canyon, also may be correlative with Richmond's (1962, p. 25–35) lower member of the Harpole Mesa Formation in the La Sal Mountains, Utah, which occupies a similar topographic and physiographic position. Richmond correlated the Harpole Mesa Formation with the Nebraskan, Kansan, and Illinoian Glaciations of the midcontinent region.

ALLUVIUM OF BULL FLAT

A large area of alluvium (Qa2) underlies Bull Flat, a large and gently sloping bench 1,000 ft (300 m) below the top of West Ridge and 800 ft (245 m) above the floor of Whitmore Canyon (fig. 31, pl. 2). Smaller berms along the inner gorge of Whitmore Canyon but below the elevation of Bull Flat also are covered with alluvial materials. At the point where the unimproved road to West Ridge crosses the eastern edge of Bull Flat (pl. 2), the alluvium consists of about 1 ft (0.3 m) of dark-brown soil, rich in organic material, which is covered by as much as 20 ft (6 m) of reddish-brown silty alluvium containing some sand and many rounded cobbles, gravels, and boulders mostly derived from sandstones of the Colton Formation. Some of the boulders are as much as 15 ft (4.5 m) in diameter. The central part of Bull Flat is a broad shallow depression that apparently is an old southward-trending stream course partly reexcavated, and so the modern drainage is northward and into Whitmore Canyon (pl. 2). Some of the landforms along this depression apparently are meander scars (Harold Brodsky, U.S. Geological Survey, oral commun., 1959). Some of the alluvial deposits may be of the same age as those along the face of the Book Cliffs (pl. 2), but they are clearly younger than the alluvium at the top of West Ridge. The alluvium seemingly is overlapped at its west edge by light-reddish-brown slope mantle and colluvium of probable early Wisconsin(?) age which contains flat subangular plates of sandstone as large as small boulders. (See "Upland slope mantle.") The alluvium of Bull Flat probably is of pre-Wisconsin age.

PEDIMENT GRAVELS

Three series of pediment gravels formed at the base of the Book Cliffs between pre-Wisconsin(?), and Holocene(?) time in the Sunnyside district. Gravels, which contain pebble- to boulder-size fragments in a clay- to sand-size matrix and become coarser near the cliffs, cap the various pediment surfaces. The three series represent different ages and generally can be distinguished by their topographic position, degree of erosion, cementation, lithologic characteristics, and degree of weathering of included fragments. These three series of gravels in the district may be equivalent to the three or more units mapped by Fisher (1936, p. 6, pl. 9) at the base of the Book Cliffs in eastern Utah and western Colorado.

Oldest pediment gravel.—Remnants of the oldest pediment gravel (Qpo on pl. 1) are distributed along the base of the Book Cliffs throughout the district at elevations between 6,000 and 7,000 ft (1,830 and 2,135 m). These gently sloping, nearly planar remnants, which cap pediments cut in Mancos Shale, are large and abundant in the northern part of the district, where they are one of the most striking features of the landscape. They stand as isolated buttes and mesas as much as 300 ft (91 m) above surrounding lowlands, or as extensive high-level sloping plains as much as 6 miles (10 km) long and 3 miles (5 km) wide. Upper surfaces of the remnants appear to have a uniform dip away from the Book Cliffs, but the dip actually decreases gradually away from the mountains and therefore longitudinal sections of the surfaces approximate logarithmic curves. The dip, however, is not always directly away from the present face of the Book Cliffs; some remnants near the canyon of Bear Creek, about 5 miles (8 km) northwest of Dragerton, dip nearly south at a place where the front of the Book Cliffs trends northwest. The upper surface of a large remnant 4.5 miles (7 km) southwest of Dragerton (pl. 1) dips gently eastward toward the Book Cliffs, although a nearby surface from which the remnant was separated by erosion dips westward. These divergent surfaces are not related to mouths of major canyons, where streams debouched laterally at different times, indicating primary divergence of surfaces, as is commonly found in southern Utah (Fred Peterson, written commun., 1973).

The oldest pediment gravel (pl. 1) consists of subrounded to subangular rock fragments set in a matrix of pale-reddish-brown sand and silt. The material is crudely bedded (fig. 21), firmly cemented with calcium carbonate, and is more resistant to erosion than the

FIGURE 21.—Crudely bedded boulders, cobbles, sand, and silt in oldest pediment gravel. View northeastward one-quarter mile (0.4 km) south of Dragerton along Utah Highway 130.

Mancos Shale which it overlies. The pebbles, cobbles, and boulders consist of pieces of Flagstaff Limestone, sandstones of the Castlegate Sandstone, Colton Formation, and the Green River Formation, and scarce fragments of reddish hardened shale of the Blackhawk Formation which were derived from burning of coal beds in the Book Cliffs. Many boulders are stained white with caliche, particularly in the upper part of the unit. The sand and silt probably were derived mostly from various units of the Blackhawk and Price River Formations. The unit was deposited on an undulating surface of Mancos Shale and is as much as 40 ft (12 m) thick in some stream channels. North of Sunnyside, some pediment gravels extending eastward into canyons in the Book Cliffs are coextensive with early alluvial fills in the canyon bottoms (fig. 41).

The exact age and correlation of the oldest pediment gravel unit are unknown. The unit underlies alluvial sand and silt that may be of late Wisconsin age. Richmond (1962, p. 10) described similar units in the La Sal Mountains (fig. 1) which he thought were of early and middle Pleistocene age. High-level pediments and the fanglomerates on them in the Henry Mountains and along the foot of the Book Cliffs were stated by C. B. Hunt (1956, p. 38) to "appear to be of pre-Wisconsin age." Soils on some of the pediments near the Book Cliffs also were thought by C. B. Hunt (1956, p. 72) to be of pre-Wisconsin age. Flint and Denny (1958, p. 156) thought that the two earliest gravels of a similar series of pediments around the Aquarius Plateau, about 100 miles (160 km) southwest of Sunnyside, were of pre-Sangamon age. We found no direct evidence for the age of the oldest pediment gravel, but its position in the geomorphic sequence of the region makes a pre-Wisconsin age most likely.

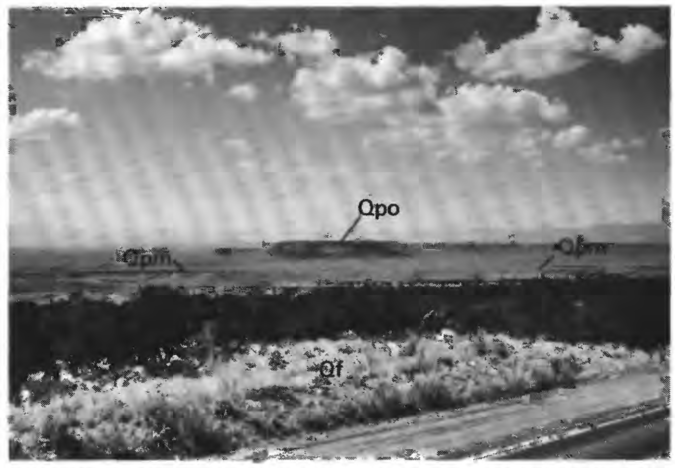


FIGURE 22.—Remnants of middle pediment gravel (Qpm) about 400 ft (120 m) below remnants of oldest pediment gravel (Qpo). Foreground is alluvial-fan material of Late Wisconsin(?) age (Qf). Northwest view from Utah Highway 124, about 3 miles (5 km) by road north of Geneva Mine.

Middle pediment gravel.—Remnants of the middle pediment gravel (Qpm on pl. 1) in the Sunnyside district stand at levels of 4,700–6,200 ft (1,433–1,890 m), about 400 ft (120 m) below nearby remnants of the oldest pediment gravel (fig. 22). Remnants of the middle pediment gravel are smaller and more widely distributed than remnants of the oldest pediment gravel but do not form as prominent features of the landscape as do remnants of the oldest unit. Crudely bedded materials within the unit consist of rounded to subangular pebbles, cobbles, and boulders of most of the resistant stratigraphic units above the Mancos Shale in the Book Cliffs, in a sandy and silty matrix. Fragments of rocks of the Mesaverde Group are, however, more abundant here than in the oldest pediment gravel. The middle pediment gravel is tan, is cemented with calcium carbonate, and characteristically contains a foot or two (less than 1 m) of white caliche overlain by a thin soil at the top of the unit (fig. 23). This unit is less than 30 ft (9 m) thick and was deposited on a slightly irregular channeled surface cut in Mancos Shale.

We found no direct evidence of the age and correlation of the middle pediment gravel, except that remnants projecting through alluvial-fan sand and silt near the mouth of Horse Canyon suggest that it may be older than late Wisconsin in age. The middle gravel may be of early or middle Pleistocene age. Flint and

FIGURE 23.—Middle pediment gravel showing thin caliche layer (white) overlain by thin soil. View northeastward along Utah Highway 124, about 2.5 miles (4 km) north of Geneva Mine. Whitmore Canyon is notch in cliffs (arrow) in left middle distance.

Denny (1958, p. 156) thought that similar pediment gravels in a series near the Aquarius Plateau were of pre-Sangamon age. The middle pediment gravel is offset by faults of little separation in the southern part of the district (pl. 1).

Youngest pediment gravel.—Remnants of the third or youngest pediment gravel (Qpy on pl. 1) are most abundant in the southern part of the district, where they stand about 50 ft (15 m) below adjacent remnants of the middle pediment gravel, at elevations between 4,800 and 5,300 ft (1,463 and 1,615 m). Youngest gravel remnants cap rounded but generally flat-topped hills and are made up mostly of weathered sandstone boulders, pebbles, and cobbles partly surrounded by uncemented sand and silt. Most of the clasts were derived from the Blackhawk and Price River Formations, but some fragments of Flagstaff Limestone and sandstones of the Colton and Green River Formations are present.

No evidence for the age of the youngest pediment gravel was found. Remnants of the unit in the lowlands south of The Cove (pl. 1) may be younger than late Wisconsin age, because The Cove was formed by erosion of a large remnant of the oldest pediment gravel and of alluvial-fan sand of late Wisconsin(?) age deposited upon it. The Cove, however, may have been partly excavated before the alluvial-fan sand was deposited at the mouth of Horse Canyon, because erosion dissected the oldest pediment surface at Whitmore Canyon before deposition of other similar alluvial fans.

SEDIMENTS OF EARLY WISCONSIN(?) AGE

Two types of sediments of early Wisconsin(?) age are present in the Sunnyside district. Both of these units cover the lower slopes of canyon walls and therefore are probably younger than the last phase of canyon cutting. The older of these deposits is present only as scattered remnants of cemented conglomerate on canyon walls; the younger consists of upland slope mantle and associated colluvium and landslide debris and is widely distributed throughout the district at elevations of 7,000 ft (2,135 m) and above.

CEMENTED CONGLOMERATE

Small remnants of tightly cemented conglomerate (Qcg on pl. 2), scattered throughout the northern part of the district, contain fragments of nearly all stratigraphic units above the Mancos Shale. These fragments are subangular to well rounded, are pebble to boulder size, and are cemented firmly in a silty and sandy matrix (fig. 24). Most of the cement is calcite, but one remnant on the north wall of Whitmore Canyon near its mouth is cemented with silica and contains a few thin veinlets of silica. Some remnants contain so much calcite that they resemble tufa. Most remnants are only a few hundred feet (less than 150 m) above the present valley floors and probably were formed since the most active phase of canyon cutting.

Somewhat similar deposits containing interlayered spring deposits are found along canyon walls in south-

FIGURE 24.—Cemented conglomerate of early Wisconsin(?) age near the mouth of Whitmore Canyon, several hundred feet (about 155 m) above the present valley floor. Randomly oriented sandstone blocks of Blackhawk Formation are cemented by calcareous material that resembles tufa. Scale indicated by notebook in upper left of photograph.

central Utah (C. B. Hunt, 1956, p. 38). These deposits probably are of early Wisconsin age; they formed after the major phases of canyon cutting when ground-water levels were high during a time of maximum rainfall (C. B. Hunt, 1956, p. 38). The cemented conglomerate remnants in the Sunnyside district probably are of similar age and origin because of their topographic position and because they bear no possible relationship to presently active springs.

UPLAND SLOPE MANTLE

One of the most widespread Quaternary units in the district is a thick cover of colluvial material composed of dark-gray to light-reddish-brown clay, silt, and sand containing large amounts of black organic material (Qs in fig. 31, pl. 2) that forms a widespread mantle of colluvium on slopes above 7,200 ft (2,195 m) in elevation, particularly in upland areas on north-facing slopes. This unit also contains variable amounts of subangular to angular rock fragments as large as several feet (less than 2 m) in diameter, derived locally from underlying bedrock. Some of the sand facies are crudely layered, having small flat rock fragments parallel to the layering. Much of the clay is somewhat plastic, and organic-rich parts, particularly those formed from shale or mudstone, are compressible. Some of the clays are highly expansive when wetted. The mantle forms convex slopes through which only a few prominent bedrock units project. Smaller areas of similar mantle are scattered along the face of the Book Cliffs, particularly on slopes facing north or northwest. Some masses extend downward into the lower gorge of Whitmore Canyon and its tributaries (pl. 2; fig. 25) and hence

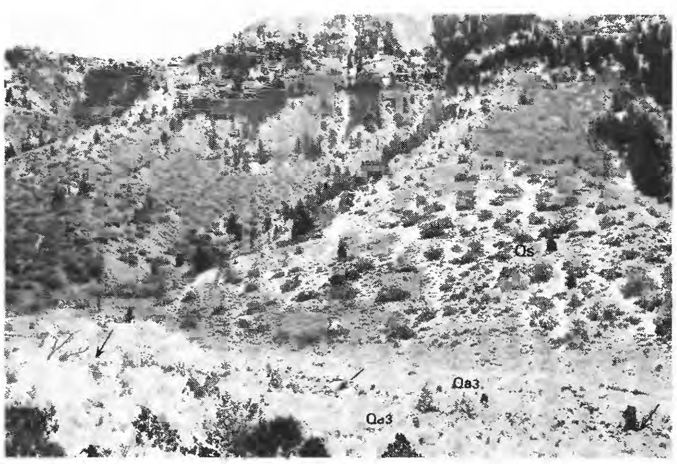


FIGURE 25.—Convex deposits of upland slope mantle (Qs) of early Wisconsin(?) age extending into the lower part of Bear Canyon, about 3.4 miles (5.5 km) northeast of Sunnyside. Mantle is overlapped by alluvium of late Wisconsin(?) age (Qa3) in valley floor. Modern drainage (arrows) is entrenched into alluvium about 8 ft (2.4 m).

were formed since the last major episode of canyon cutting. Locally, some of the mantle masses were disturbed by landsliding in Pleistocene time. In places, large areas of the lower east-facing slopes of Whitmore and other large canyons are covered by landslide debris that closely resembles slope mantle; locally, the debris merges imperceptibly into mantle. These landslides apparently moved at about the same time as the mantle was being formed, and they are mapped with the mantle as one unit. Some of the slides are active currently, and most masses of mantle are easily made unstable by excavation for roads and other structures (fig. 26).

The exact age of the slope mantle cannot be determined. No exact stratigraphic correlation can be made, but, because of its topographic distribution and the external form and internal characteristics of individual mantled slopes, the unit resembles the solifluction mantle facies of the Placer Creek Formation of early Wisconsin age described by Richmond (1962, p. 48, 87) in the La Sal Mountains. Because of these similarities, the slope mantle in the Sunnyside district also may have formed from solifluction debris of early Wisconsin(?) age.

The upland slope mantle and colluvium apparently are older than the alluvial fill in valley floors, because wherever streams cut into mantle slopes, dark-gray clay and silt are exposed in cut banks below the level of reddish-brown alluvium.

SEDIMENTS OF LATE WISCONSIN(?) AGE

GRAVEL ALONG CANYON WALLS

Small remnants of the oldest alluvial gravel (Qg on pls. 1, 2) are found 100 ft (30 m) or more above modern stream courses along the lower slopes of large canyons and tributaries, particularly along Whitmore Canyon (figs. 27, 28) and Horse Canyon (pl. 1) and also along Neversweat Wash in the San Rafael Swell (pl. 2). Some of these remnants retain terracelike flat upper surfaces that were dissected before most of the alluvial valley fill was deposited. Modern stream courses and tributary gulches also are incised into the gravel remnants, and deposits of younger talus overlap some of them. A gravel-capped terrace of late Wisconsin(?) age near the portal of Sunnyside No. 1 Mine (pl. 2) was deeply eroded.

Materials within the remnants consist of about 80 percent subrounded to rounded pebbles, cobbles, and small boulders as much as 2 ft (0.6 m) in diameter in a 20-percent matrix of silt, sand, and clay. All of the fragments appear to be derived from sedimentary units of Cretaceous and Tertiary age that crop out in the present slopes and ridges upstream from the remnants.

FIGURE 26.—Landslide debris, probably derived from upland slope mantle of early Wisconsin(?) age, on east-facing slope of Whitmore Canyon at the dam for the Sunnyside domestic water-supply reservoir (pl. 1). Colton Formation at top right of photograph dips about 4° toward observer; dam extends across the canyon, away from the viewer, in lower center foreground of the photograph. Excavation for dam abutment and roadway has reactivated landslide. Dark areas in slide are water seeps. Automobile shows scale.

We know of no direct evidence of the age of the alluvial gravels along Whitmore and Horse Canyons, and Neversweat Wash. They clearly are younger than the last phase of canyon cutting but are older than extensive alluvial valley sand and silt, because some, particularly near the mouth of Whitmore Canyon (figs. 27, 28), are partly overlapped by alluvium of probable late Wisconsin age. The thickness, elevation above stream courses, and general composition of the alluvial gravel remnants are similar to those of Richmond's alluvial gravel facies of the Placer Creek Formation (Richmond, 1962, p. 46–47), which is of early Wisconsin age (Richmond, 1962, p. 87), although the gravels in the Sunnyside district are slightly thicker and higher above the stream courses than those in the La Sal Mountains.

SAND AND SILT

Most of the larger valleys in the Sunnyside district are floored by alluvial sand and silt (Qa3 on pl. 2) or by the lower part of the alluvium (Qa on pl. 1) that is as much as 50 ft (15 m) thick in Little Park Wash (pl. 1) and at least 20 ft (6 m) thick in Whitmore Canyon (pl. 2). Some of the alluvial fills probably are much more than 50 ft thick, but their bases are concealed. The upper part of the alluvial sand and silt is light brown and contains dark organic-rich layers and layers rich in limonite (fig. 29). Locally, lenses of crudely bedded gravel and cobbles occur in the sand and silt (fig. 30); many of these lenses in Whitmore Canyon are about 5 ft (1.5 m) below the flat upper surface of the alluvium, but we saw no evidence of an unconformity or of an erosion surface at the level of these gravels.

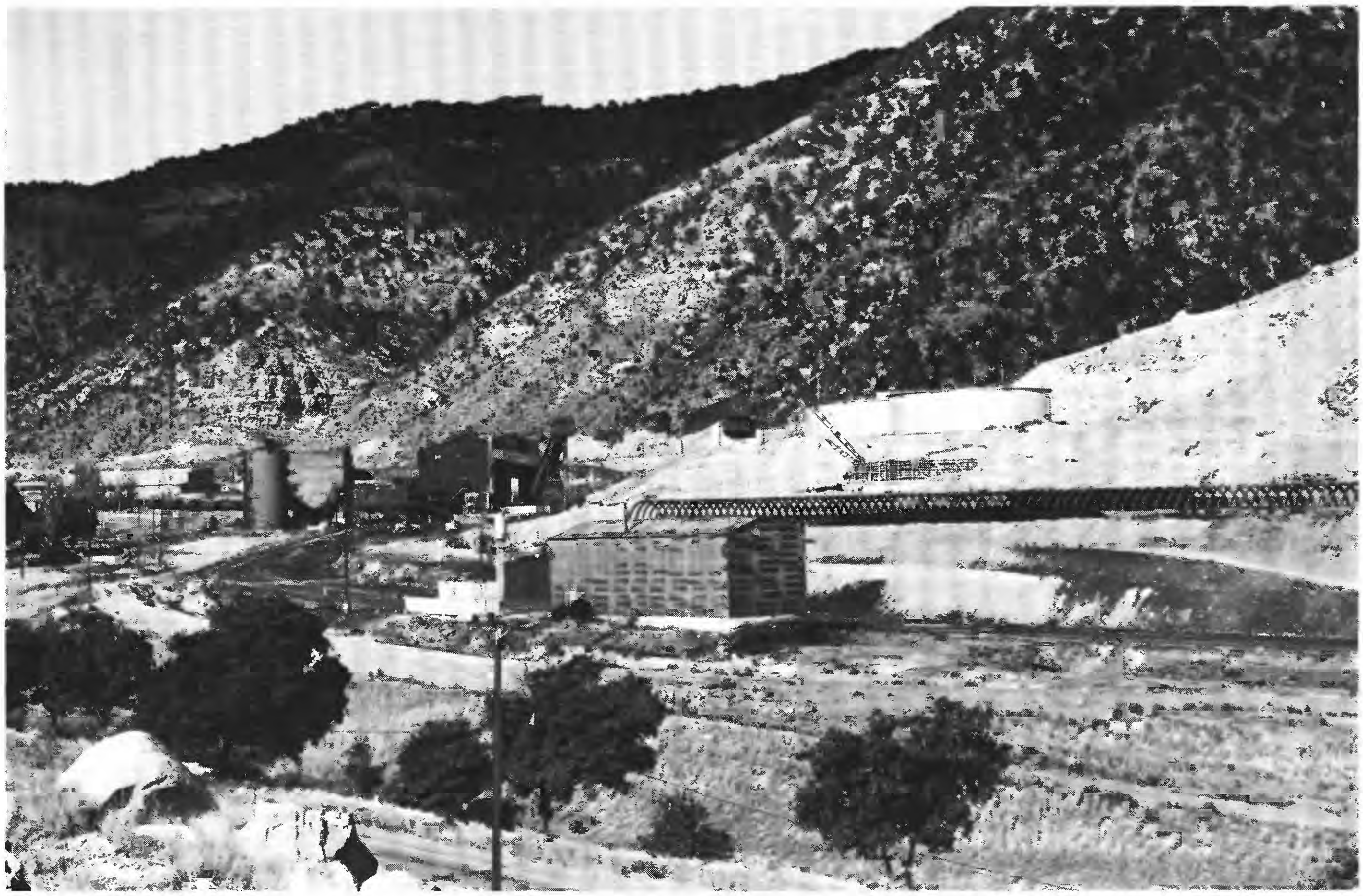


FIGURE 27.—Large mass of alluvial gravel of late Wisconsin(?) age (beneath water tanks) along south side of Whitmore Canyon. Gravel overlaps Kenilworth and Sunnyside Members of Blackhawk Formation, and is overlapped by younger alluvium of late Wisconsin(?) age along the canyon floor. Structures in left center of picture are the machine shop (left), backfill plant, and tipple (right) for the Sunnyside coal mines. Cliffs behind structures are the Castlegate Sandstone. Grassy Trail Creek is incised several feet (less than 2 m) into the younger alluvium to left of and in front of railroad buildings in center of picture. Boulders in left lower corner are remnant of alluvium of late Wisconsin(?) age. Long structure having many arches is railroad tunnel under construction (1968) for use in continuous loading of coal trains. Tunnel, which was built partly on artificial fill and partly on alluvial gravel, was unstable for a long time after its construction because the fill was only loosely compacted. View is northeastward across Whitmore Canyon near its mouth.

The sand and silt clearly is younger than the cutting of the inner gorge of Whitmore Canyon and seemingly overlaps the lower parts of some solifluction mantle masses in the upper reaches of Whitmore Canyon and its branches (fig. 31). Many tributary valleys have deposited small alluvial fans upon the surface of the sand and silt (figs. 29, 31) since its deposition. Small talus cones along canyon walls also overlap the alluvial sand and silt. Modern streams flowing in the alluviated valleys are entrenched as much as 15 ft (4.5 m), and most of them meander extensively. Examples of such entrenched streams are Grassy Trail Creek in Whitmore Canyon (fig. 32), Range Creek (fig. 33), and Little Park Wash (fig. 17). Locally, modern streams also have formed small flood plains and terraces below the surface of the sand and silt. All available evidence indicates that the sand and silt was deposited by streams having greater flow than the modern streams.

We know nothing directly of the age of the alluvial sand and silt in the Sunnyside district; no fossils or other materials were found from which an age determination could be made. Most of the critical relationships at canyon mouths are strongly disturbed by surface operations of coal mines, by residential developments, and by farming. Sand and silt from alluvial valley fills apparently accumulated on the upstream parts of extensive pediment surfaces after erosion had cut into the surfaces as much as 50 ft (15 m). Alluvium was deposited in a stream channel cut into the oldest pediment surface along Grassy Trail Creek in the town

FIGURE 28.—Small remnants of gravel (Qg) of late Wisconsin(?) age overlap Mancos Shale and are overlain by talus and alluvial-fan debris (Qnt) of Holocene age. Westward view of the north side of Whitmore Canyon, near its mouth. Grassy Trail Creek flows in small gully in lower left foreground.

FIGURE 30.—Lens of subangular to subrounded pebbles and cobbles and a few boulders in alluvium of late Wisconsin(?) age in Bear Canyon. Gravel is crudely bedded and cross-stratified. Cross-strata dip to right which is upstream. Bank is about 8 ft (2.5 m) high.

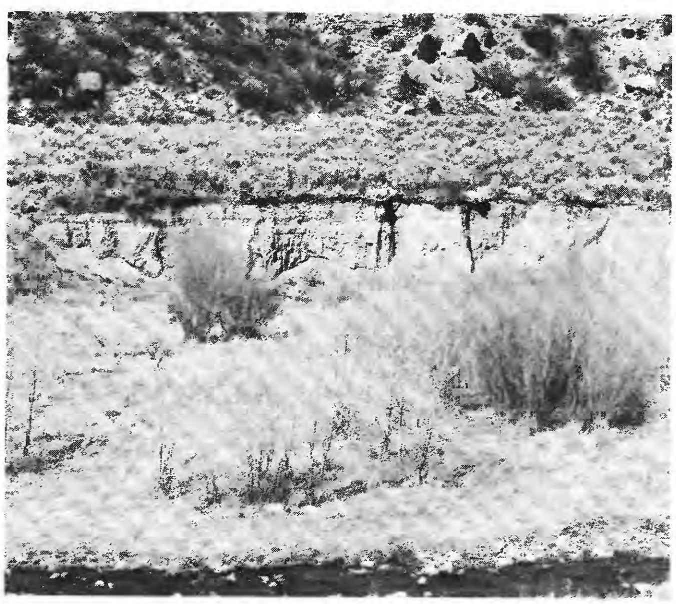


FIGURE 29.—Upper part of alluvium of late Wisconsin(?) age, exposed in bank of Grassy Trail Creek, showing stratification of silty and clayey alluvium, with soil in the top 2 ft (0.6 m). Flat area beside stream is veneer of Holocene alluvium. Westward view in Whitmore Canyon, about 2 miles (3 km) above the Sunnyside No. 1 Mine.

of Dragerton (fig. 34). The older parts of the alluvial sand and silt, however, may have been disturbed during the cutting of some of the youngest pediments.

The alluvial sand and silt in the Sunnyside district is probably of late Wisconsin(?) age. Its composition, texture, distribution, and relationships to topography closely resemble similar facies of the Beaver Basin Formation of Pleistocene and Holocene age in the La Sal Mountains as described by Richmond (1962, p. 60–61, 87). The smooth upper surfaces, uniform composition, and topographic setting of the alluvial sand and silt also are similar to those of the alluvium of late Wisconsin age in the Colorado Plateau as summarized by C. B. Hunt (1956, p. 38–39).

ALLUVIAL-FAN DEPOSITS

Large older alluvial fan deposits dominantly composed of sand and silt, but having small local lenses of gravel, extend outward from the mouths of Horse Canyon and Whitmore Canyon (Qfo on pl. 1). Pebbles, cobbles, and small boulders are more abundant within 0.5 mile (0.8 km) of the canyon mouths and in the central part of the fans than elsewhere. Smaller, less distinct fans containing relatively more gravel and less sand than the large fans extend outward from a canyon near the town of Columbia, Utah, and from Water Canyon. The fan near Columbia (pl. 1) originates in a valley about 150 ft (45 m) below the large erosional remnants of the oldest pediment surface in the district. Areas underlain by alluvial-fan sand are more permeable and hence bear a much more lush flora, consisting of tall grass, pinon-pine, and many types of wild

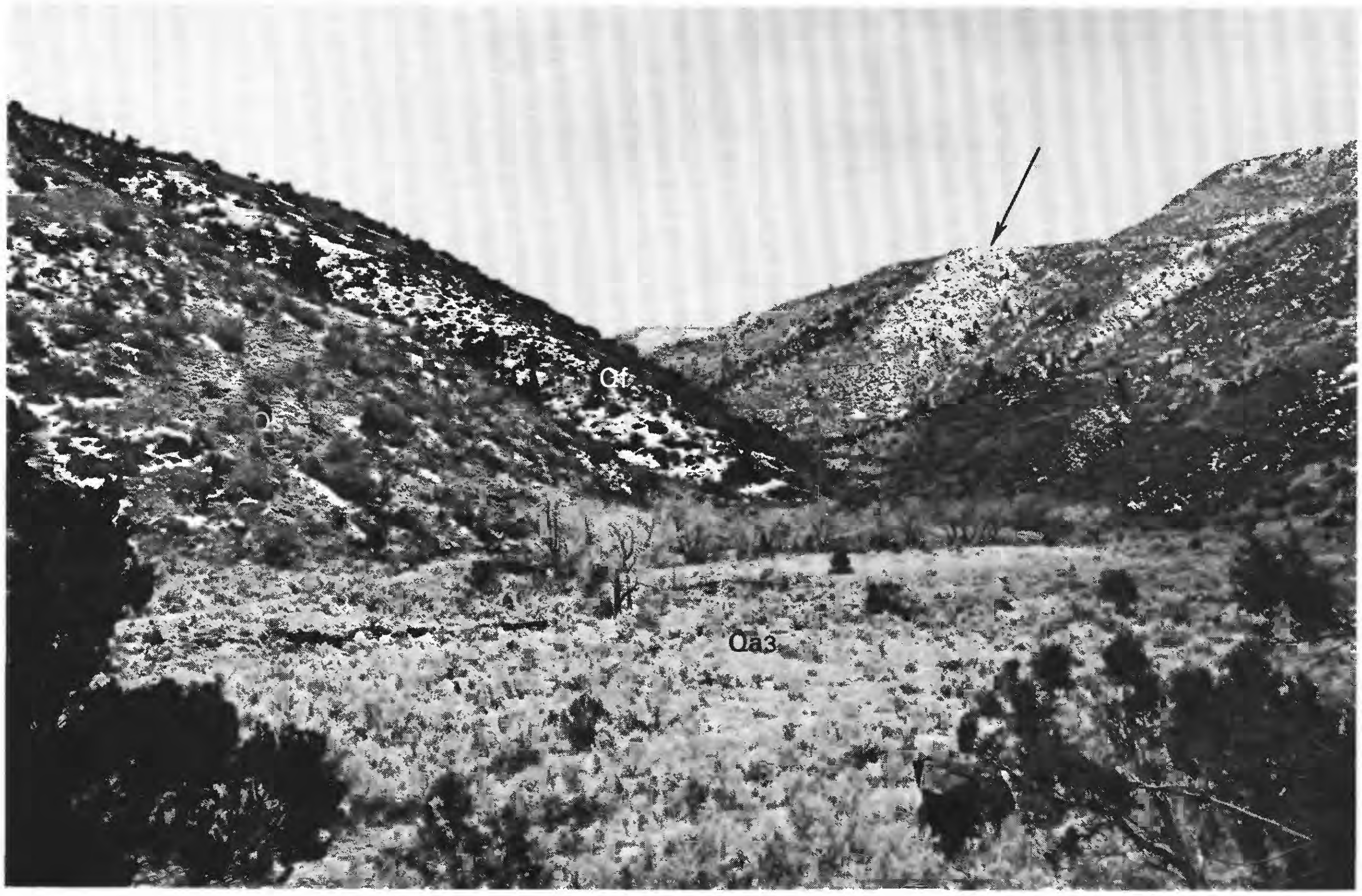


FIGURE 31.—Alluvium, Qa3, overlapping upland slope mantle (convex slope, Qs, left center of photograph). View southwest in Bear Canyon, a branch of Whitmore Canyon. Photograph also shows an alluvial fan (Qf) deposited on the alluvium from a tributary watercourse to Bear Canyon. Bull Flat (arrow) is covered with pre-Wisconsin alluvium. Top of West Ridge (skyline, right side of photograph) is another alluviated surface, older than Bull Flat.

flowers, than do nearby areas underlain by Mancos Shale or by alluvium derived from the Mancos and therefore are valuable grazing areas for livestock. They also are much more easily traversed by vehicles when wet than are adjacent areas underlain by Mancos Shale, which become almost impassable when wet.

The alluvial fan extending outward from the mouth of Horse Canyon is the largest in the district; remnants overlap upturned sedimentary rocks of the San Rafael Swell near Grassy Trail Creek, 8 miles (13 km) southwest of the canyon mouth. The fan is as much as 6 miles (10 km) wide. Its surface slopes to the west about 200 ft (60 m) per mile, but is markedly convex, as shown by topographic contours (fig. 35). Small intermittent water courses as much as 10 ft (3 m) deep flow down the fan; the creek flowing in Horse Canyon is perennial, but the flow disappears within the alluvial sands. The fan clearly is younger than the oldest and middle pediment gravels. One large remnant of the oldest pediment gravel stands about 250 ft (75 m) above the fan surface near the mouth of Horse Canyon. Mancos Shale crops out beneath the gravel and boulders capping the pediment and above the fan surface (pl. 1). Smaller remnants of the middle pediment gravel extend through the alluvial-fan sand in the northern part of the fan, apparently along old drainage divides. Streams have deeply eroded the southern edge of the fan and the Mancos Shale beneath it, forming a very prominent steep scarp known as The Cove (fig. 36), which is as much as 400 ft (120 m) high. The fan's western edge is being cut into isolated remnants by Grassy Trail Creek and its tributaries. The western or downslope end of the fan filled an older broad valley into which the present valley of Grassy Trail Creek was cut. The older alluvial-fan deposits at the mouths of Whitmore and Horse Canyons, therefore, are older than the valley of Grassy Trail Creek and its alluvial fill of late Wisconsin(?) age.

FIGURE 32.—Northward view of the inner gorge of Whitmore Canyon, from a point just north of the Sunnyside No. 1 Mine portal. Nearly flat valley surface is floored by alluvial sand and silt of late Wisconsin(?) age that is entrenched about 8 ft (2.5 m) by Grassy Trail Creek. East (right) side of canyon has large, buttresslike headland between Pole and Bear Canyons. Broad, flat bottom of older U-shaped valley is outlined by upper surface of headlands in upper right, and by edge of Bull Flat, in upper left corner of photograph. Kc, Castlegate Sandstone; Kpb, Bluecastle Sandstone Member of Price River Formation; TKnf, North Horn and Flagstaff Formation; Tc, Colton Formation.

FIGURE 33.—Entrenched channel of Range Creek, 0.5 mile (0.8 km) upstream from mouth of Sheep Canyon. Bank in left middle ground is stratified alluvium of late Wisconsin(?) age. Bank at extreme right rear is west margin of entrenched channel. Flat area beside stream is modern alluvium.

The younger alluvial-fan deposits extending westward from the mouth of Whitmore Canyon were deposited in a shallow stream valley cut into a large remnant of one of the oldest pediment gravels in the district (fig. 37) and extend about 4.5 miles (7 km) west-

FIGURE 34.—View west along Grassy Trail Creek in Dragerton, Utah. Smooth surface of alluvial sand and silt of late Wisconsin(?) age is farmed; houses are on adjacent pre-Wisconsin(?) pediment remnants.

ward down the slope of the pediment from the canyon mouth. The fan is about 3 miles (5 km) wide; the northern margin is indistinct and merges with various segments of the oldest pediment gravel. This fan contains much more coarse material, at least in its upstream part, than does the one in Horse Canyon. The western end of the fan is a featheredge that merges nearly imperceptibly with the oldest pediment gravel. The southern margin of the fan is being eroded rapidly by Holocene streams (Icelander Creek and its tributary drainages) along a steep scarp about 500 ft (150 m) high cut into underlying Mancos Shale (fig. 38). The scarp, however, is not entirely of Holocene age, because the smaller compound alluvial fan at the mouths of Water Canyon and another canyon near the town of Columbia, which presumably is of about the same or slightly older geologic age as the one in Whitmore Canyon, overlaps the lower slopes of Mancos Shale at the base of the scarp (pl. 1). The upstream section of the fan west of Whitmore Canyon, near the base of the Book Cliffs, and part of the northern margin are covered partly by coalescing younger alluvial fans formed near the mouths of small canyons cut by streams flowing down the face of the cliffs.

The upper surface of the alluvial fan at the mouth of Whitmore Canyon is considerably more altered by erosion than is the surface of the fan at the mouth of Horse Canyon, probably because Grassy Trail Creek and its tributaries have a much larger perennial flow than does the creek in Horse Canyon, which has only a trickle of water in dry seasons. Grassy Trail Creek has cut a narrow gulch about 5–10 ft (1.5–3 m) deep into the fan at the mouth of Whitmore Canyon near the town of Sunnyside, but about 1.5 miles (2.4 km) west, at Dragerton, this creek has cut a valley about 1,000 ft

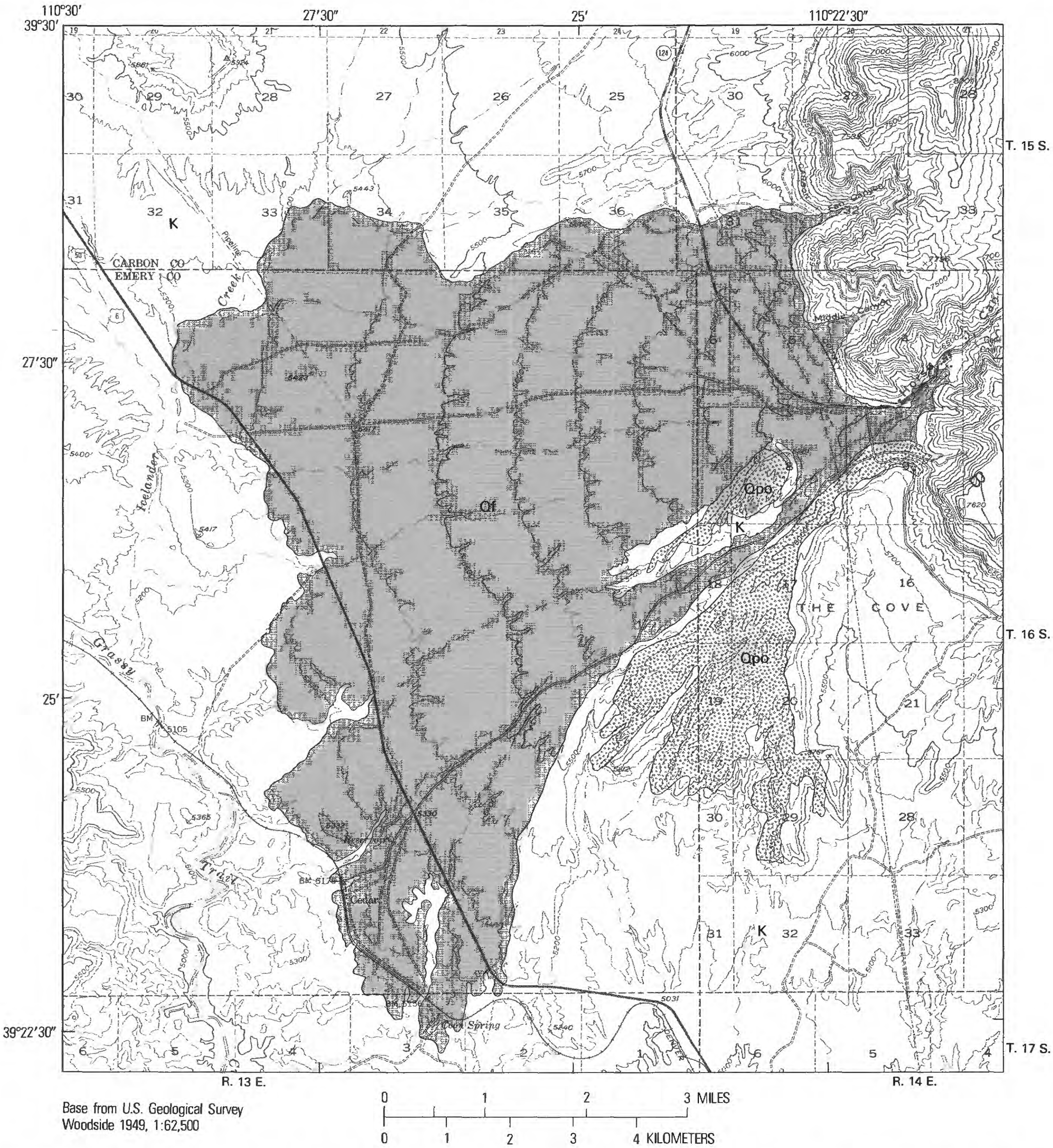


FIGURE 35.—Topographic map of part of the alluvial fan (Qf) of Late Wisconsin(?) age in Horse Canyon. Base modified from U.S. Geological Survey Woodside Quadrangle, 1:62,500, 1948. Remnants of the oldest pediment gravel (Qpo) of pre-Wisconsin(?) age cap hills above the fan surface, and is underlain by remnants of Cretaceous (K).

(300 m) wide and 20 ft (6 m) deep into the fan. Smaller intermittent streams north and east of Dragerton are cutting steep-sided gulches as much as 15 ft (less than 5 m) deep into the fan.

FIGURE 36.—Westward view of The Cove (fig. 35, pl. 1) from a point above the Book Cliffs Mine. The Cove is an erosional depression having a steep scarp carved in Mancos Shale at the north edge. Pre-Wisconsin pediment gravel (Qpo) forms the rim above the Mancos Shale (Km) around most of The Cove. Alluvial-fan sand, silt, and gravel of late Wisconsin(?) age (Qfo) surround a remnant of pediment material and extend to the eastern edge of The Cove.

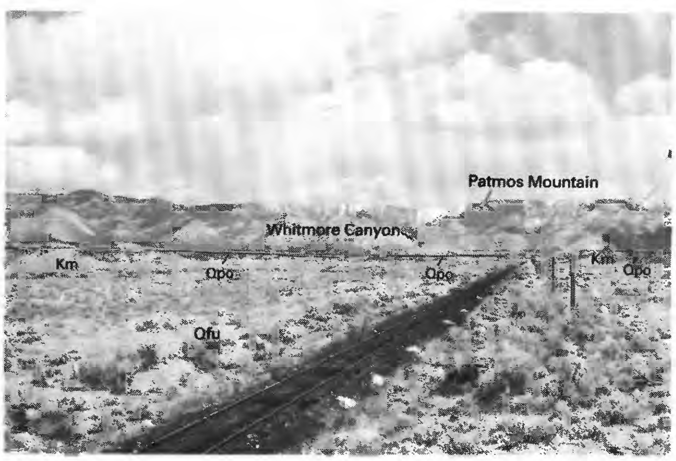


FIGURE 37.—Shallow, broad valley in oldest pediment gravel of pre-Wisconsin(?) age (Qpo) filled with alluvial-fan material of late Wisconsin(?) age (Qfu). Mancos Shale (Km) crops out below pediment gravel. View east along Denver and Rio Grande Western Railroad, about 4 miles (7 km) west of Dragerton. Patmos Mountain on right skyline, Whitmore Canyon mouth in right center.

FIGURE 38.—Steep scarp eroded in Mancos Shale (Km) near the mouth of Whitmore Canyon by Icelander Creek and its tributaries. Oldest pediment gravel of pre-Wisconsin(?) age (Qpo) forms skyline. Alluvial-fan debris of late Wisconsin(?) age (Qf) from Water Canyon and other canyons covers slopes in foreground. Icelander Creek issues from Whitmore Springs (informal name) below the pediment gravel in the right center of the photograph. View northward across Utah Highway 123 and Carbon County Railway track.

North of Dragerton, alluvium at the mouths of several canyons forms a compound fan that merges with the one at the mouth of Whitmore Canyon to the south. The compound fan was deposited on part of an early pediment surface and may be contemporaneous with the fan at the mouth of Whitmore Canyon.

Age and correlation of the alluvial-fan deposits are poorly known. Distribution and extent of the alluvial-fan debris in the Sunnyside district, however, closely resemble Richmond's descriptions (1962, p. 46–47) of alluvial-fan gravel in the La Sal Mountains that he assigned to the Placer Creek Formation of early Wisconsin age. Because of its position with relation to other Quaternary units, however, we think that the younger alluvial-fan deposit is of late Wisconsin age. The alluvial-fan materials presumably are at least slightly older than alluvial sands and silts along canyon floors, as described below; if they were younger than the sands and silts, much of the material along the canyon floors would have been removed by the increased flow of water necessary to deposit the alluvial-fan debris. The alluvial sand and silt may have been deposited during the decline of streamflow following deposition of alluvial-fan sand, silt, and gravel; if so, materials in the fans may be correlative with alluvial-fan gravel facies of the Beaver Basin Formation (Pleistocene and Holocene) in the La Sal Mountains (as described by Richmond, 1962, p. 47). The fans once supported a thriving prehistoric human culture, as described earlier in this report.

TERRACE GRAVEL

Flat-topped dissected remnants of stream-terrace gravel and of gravel-capped benches line the valley of the Price River and its tributaries in the southern part of the district (Qt on pl. 1) for many miles. Pebbles, cobbles, and boulders in these terraces are subrounded to rounded, and most were not locally derived. The terrace gravels are as much as 20 ft (6 m) thick and are at elevations about 150 ft (45 m) above the present stream level. The age of these terrace gravels is not known, but presumably they are correlative with similar gravels, along the Green River that were described by Hansen (1965, p. 174). Associated with terrace gravels west of the Price River, about 1.5 miles (2.5 km) upstream from Silvagni Ranch (pl. 1) are some well-defined meander scars, also about 150 ft (50 m) above the stream.

ALLUVIUM OF LATE(?) WISCONSIN AGE

Modern stream courses are bordered by considerable amounts of alluvium, which comprises mostly locally derived silt and clay, lesser amounts of sand, and little gravel (Qa on pls. 1, 2). Upper surfaces of this alluvium generally are smooth. Silty clay, derived mostly from Mancos Shale, forms broad flats in the southern part of the district (pl. 1). Such flats are particularly abundant near the Price River where they are as much as 1 mile (1.5 km) wide (fig. 39), but they contain much greater amounts of sand, derived mostly from sandstones of Cretaceous and Tertiary age many miles upstream. Subrounded to rounded pebbles, cobbles, and boulders make up poorly defined, discontinuous beds in the alluvium along the Price River and also are abundant in other drainages within a few miles of the Book Cliffs. The alluvium is deeply gullied by modern watercourses—impassable steep-walled trenches make travel across some alluvial flats extremely difficult. As much as 15 ft (4.5 m) is exposed in gullies, but the base is not exposed and the maximum thickness could not be determined.

The alluvium generally resembles Wisconsin alluvium in the Colorado Plateau, as summarized by C. B. Hunt (1956, p. 39). Although we found no direct evidence of the age of the alluvium in the Sunnyside district, it may be of late(?) Wisconsin age.

Most of the alluvial flats near Price River support little vegetation. Attempts were made in the past, apparently by early settlers, to farm some of the flats along Price River and Marsh Flat Wash near Woodside (fig. 40, pl. 1). The settlements and adjacent fields were abandoned long ago, probably because of barren soils and lowered water tables in the alluvium as a result of gullying.

HOLOCENE SERIES

TALUS AND ALLUVIAL-FAN DEPOSITS

Small natural talus cones and alluvial fan deposits (Qnt on pls. 1, 2) accumulated at the mouths of small drainages tributary to major canyons (pl. 1) and also along the front of the Book Cliffs. Material in these cones and deposits is locally derived and ranges from clay and silt to large boulders. Coarser pieces range from subrounded to angular, and most are only slightly weathered. Lower parts of many cones and deposits consist mostly of boulders. Many overlap alluvial sand and silt in canyon floors (fig. 41). Accumulations of gravel and boulders along the bases of

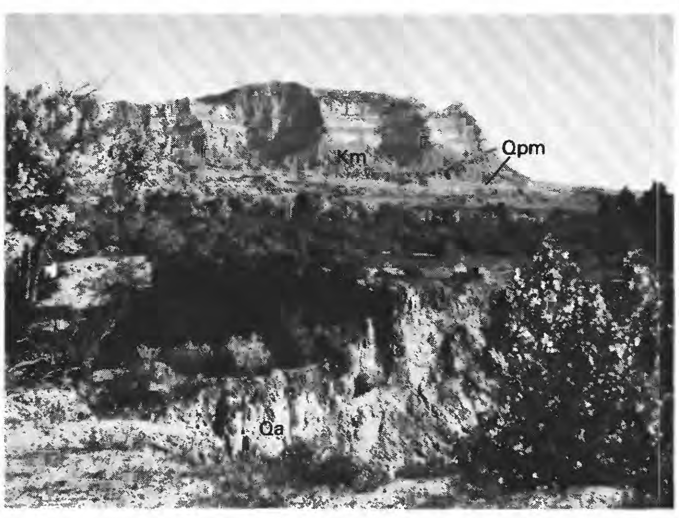


FIGURE 39.—Thick silty and clayey alluvium (Qa) of late(?) Wisconsin age, derived mostly from Mancos Shale along Price River. Cliffs on skyline are Blackhawk Formation; slopes of Mancos Shale (Km) are below cliffs and above oldest pediment gravel (Qpm) of pre-Wisconsin(?) age. View southeast across Price River, about 2 miles (3 km) east of Woodside.

FIGURE 40.—Ruins of an early settler's home near Marsh Flat Wash, about 4 miles (6.5 km) northwest of Woodside. Living space was made by roofing over a rectangular excavation in silty and clayey alluvium of late(?) Wisconsin age derived from Mancos Shale. View northeast, toward Book Cliffs.

FIGURE 41.—Holocene(?) talus (Qnt) overlapping alluvium of late(?) Wisconsin age of valley floor. Ledge (Kpb) at side of road in left center of picture is Bluecastle Sandstone Member of Price River Formation. Prominent cliff (Tcu) on skyline is upper part of Colton Formation. Northward view of east side of Whitmore Canyon, near mouth of Pole Canyon.

steep slopes below pediment-surface remnants in Clark Valley are derived entirely from material weathered from gravel and boulder pediment caps (pl. 1). These accumulations probably are equivalent in age to the talus and alluvial fans along the cliff front and in the canyons. Material is still being added to most of the deposits as debris rolls down or is washed from above during storms. The deposits are of Holocene(?) age and may be equivalent to similar facies of the Gold Basin Formation in the La Sal Mountains (Richmond, 1962, p. 78–80).

ALLUVIUM OF HOLOCENE(?) AGE

Deposits of young alluvium (Qa on pls. 1, 2) in the Sunnyside district are abundant along modern stream courses in the Clark Valley, particularly north and west of Woodside (fig. 1). The alluvium, consisting of pebbles, cobbles, and boulders mixed with silt, sand, and clay, is strewn along flats bordering the streams but is entrenched as much as 10 ft (3 m) by modern watercourses. The upper surfaces of these deposits are rough and undulating and have as much as 5 ft (1.5 m) of relief. The exact age of the alluvium is unknown, but it is younger than the time at which the modern drainage system was established and is Holocene(?). Some of the alluvial deposits appear to be rudimentary pediment gravels forming during the present erosional cycle.

MAN-INDUCED TALUS

Mining activities are causing accumulations of talus at several places along the Book Cliffs in the northern part of the district. These accumulations (Qmt on pl. 2) consist of angular boulders, many of huge size, derived from sandstones of the Blackhawk and Castlegate. Most of the debris falls from cliffs on the sides of large headlands, above areas where coal is actively mined, probably as a result of subsidence into the mined-out voids and of the shaking due to numerous earth tremors (Barnes and others, 1969; Osterwald, 1961). An example of such talus accumulation can be easily seen along a cliff face 2.5 miles (4 km) north of Dragerton (fig. 42). We traversed the slopes below this cliff several times in 1958 and 1959 during geologic mapping (Osterwald, 1962a), at which time little or no debris had fallen. Mining began beneath the headland in 1959, and within 2 years the cliff became unsafe for travel due to unpredictable debris falls. Other large talus accumulations are found along the Book Cliffs between Columbia, Utah, and the Geneva Mine, and south of the Geneva Mine near Lila Canyon.

MINE DUMPS

Mine dumps consist of refuse from mining operations, such as clinker and coke breeze from old mining and coking operations mixed with later debris consisting of bony coal, coaly shale, rock, and heavy minerals, as well as pieces of mine timber, fragments of metal, and miscellaneous trash. This refuse, which makes up as much as 30 percent of the current total output of the Sunnyside mines, is removed from the mined coal in the washer. These mine dumps have been used for as long as 70 years; the dumps in Water Canyon and Fan Canyon (fig. 43*A*, *B*) now are abandoned and inactive, but the one near Sunnyside at the head of Icelander Creek is enlarged daily, and also served as the town garbage dump for many years (fig. 43*A*).

FIGURE 42.—Large area of man-induced talus (Qmt) from cliffs of Castlegate Sandstone (Kc) and ledges of sandstones of the Blackhawk Formation (Kb) 2.3 miles (3.7 km) north of Dragerton, Utah. Photograph taken in October 1968.

FIGURE 43.—Mine waste dumps near Sunnyside. *A*, Present dump of Sunnyside mines showing steep face of dump filling valley above Carbon County Railway near the head of Icelander Creek. *B*, Abandoned dump (arrow) of Sunnyside No. 2 and No. 3 Mines along the north side of Water Canyon.

The Water Canyon and Fan Canyon dumps were constructed by dumping mining debris along one side of the canyons and smoothing the upper surface with heavy equipment (fig. 43*B*). Both dumps are limited in their lateral extent by the narrow canyon walls, and as a result are long narrow masses having extremely steep sides.

The Sunnyside dump is constructed by dumping mining debris into a gully between two pediment remnants until the dump reaches the level of the pediments. The dump is then built laterally and vertically along the pediment surface and over the front of the pediment. This dump is not physically limited in lateral extent, and so forms a high, long, lobate structure having extremely steep sides. The upper surface is planed regularly by heavy equipment to allow for the addition of more debris. Three trucks of approximately 10-ton (9,000-kg) capacity constantly haul debris from the washer to the dump while the mines are in operation.

The Sunnyside and Water Canyon dumps were afire in 1971. These fires probably started by spontaneous combustion of volatile and flammable material in the dumps. Of the two, the Sunnyside dump had the more active fires. Smoke and occasional flames emanated from the dump during the day, and many areas of flaming debris were seen at night. The almost daily influx of new combustible material added to the potential fire area and enabled the flames to continue. Fire is not so apparent at the abandoned Water Canyon dump; the oxidation of combustibles beneath the surface causes some smoke, but we have never seen flames at this dump. Several near-surface hot areas exist, however, and these are marked at the surface by warm, viscous, tarlike substances, by soft, puffy ground, and locally by small blister and spatter cones formed by partial melting of dump material. Such burning waste dumps elsewhere in the United States are known to be very hazardous, because they are prone to local but violent explosions when wet, and because the surface crust is thin, allowing persons to fall into the burning material (McNay, 1971, p. 12–13).

The dumps contribute smoke, suspended solids, and odor to the atmosphere, and minerals to the streams and ground water. A fork of Icelander Creek runs along the west side of the Sunnyside dump, and the drainages of Fan and Water Canyons run along the south and southeast sides of those dumps. The garbage on the Sunnyside dump harbors rats and other rodents less than a mile (1.6 km) from town, and may contribute trash and pollutants to Icelander Creek. Although we made no measurements, we feel that the very steep sides of all dumps pose a landslide threat. The Carbon County Railway track is below the west end of the Sunnyside dump (pl. 2). We believe, however, that the dumps are no great hazard to life and property because all are situated far from main roads and are topographically or geographically far below or away from towns. Because of the sparse vegetation near the dumps, we believe that no fire hazard exists from the dump fires. They are potential hazards to occasional visitors and to animals because they are burning beneath a thin but solid-appearing crust. The dumps in Water Canyon and Fan Canyon also may be hazardous because of potential slumping onto mine-access roads (fig. 43*B*). Only the Sunnyside dump is readily visible; it may be seen from State Highway 123, south of Sunnyside, and from much of the town. The dumps contribute to environmental pollution through smoke and its attendant suspended solids, and through mineral pollution of Icelander Creek and the surface and underground drainages of Fan and Water Canyons.

QUATERNARY HISTORY

The Sunnyside district has a complicated Quaternary history of interrelated events consisting of erosion and deposition, structural deformation, drainage changes, and probable climatic variations. Geomorphic development of the district and its surrounding regions was strongly influenced by a master drainage system along the Green River. Times of erosion and deposition were controlled by climatic changes (variations in precipitation and glaciation), as well as by tectonic events. Tectonic events, by changing relative heights not only within the district but elsewhere within the surrounding regions, also may have influenced strongly the climate of the district. The sequence of Quaternary events summarized below enabled us to decipher the stress history of the coals in our study of coal-mine bumps. Particularly, the sequence has yielded information on timing and rate of unloading of stress due to removal of overburden and on the timing and nature of diastrophic stresses. The influence of the Quaternary history on stress changes in the coal beds is discussed elsewhere.

The sequence of events leading to the present landforms of the region surrounding the Sunnyside district actually began when the present drainage system of the Green River was established across the Tavaputs Plateau, presumably by late Pliocene time (Hansen, 1969, p. 63–65; C. B. Hunt, 1956, p. 84–85). Although C. B. Hunt (1956, p. 84) suggested that upper Tertiary rocks were deposited in the Clark Valley, we found none, and if they were deposited they were completely removed later by accelerated erosion resulting from uplift of the Colorado Plateau (C. B. Hunt, 1956, p. 85). Some poorly sorted beds of cemented conglomerates in Neversweat Wash (pl. 1) which underlie alluvial-fan material may be of late Tertiary age, but we think that the beds probably are of Pleistocene age, perhaps equivalent to the cemented conglomerates (early Wisconsin(?)) near Sunnyside.

Isolated remnants of alluvial gravels containing bedded pebbles, cobbles, and boulders, most of which are rounded to well rounded, are found on several surfaces on high, narrow divides between tributaries to Whitmore Canyon, as well as on the summit of West Ridge, on Patmos Mountain, and on Bull Flat. Three major levels of these surfaces are well defined along Whitmore Canyon, one slightly above the base of the Green River Formation, one in the Colton Formation which includes the surface of West Ridge, and one at about the level of the Flagstaff Limestone which includes the alluviated surface of Bull Flat (fig. 44).

FIGURE 44.—Southwestward view from Patmos Mountain, above Bear Canyon southeast of Bruin Point, showing remnants of alluviated erosion surfaces in Whitmore Canyon at top of West Ridge (1), on Bull Flat and on corresponding surfaces above east side of inner gorge (2), and at bottom of inner gorge (3). South end of West Ridge is in the right middle distance, San Rafael Swell in the background.

Other small alluviated remnants are found between these three, as well as below the Flagstaff Limestone surface. Nearly all of the clasts in these gravels are composed of sandstone from the Colton Formation. These clasts and the distribution of the surfaces imply that a strong stream flowing generally southward in a strike valley began cutting downward from the level of Bruin Point and Patmos Mountain at least as soon as early Pleistocene time, judging from the position of glacial deposits of possible early Pleistocene age. It may, however, have begun in late Pliocene time, when the Green River began flowing southward (C. B. Hunt, 1956, p. 82). Downcutting probably was interrupted several times, perhaps during times of continental glaciation.

There is little evidence concerning the early Pleistocene history of the district except for the high-level alluvial materials. Deposits containing exotic boulders, high on West Ridge at an altitude of more than 8,500 ft (2,590 m) (pl. 2), possibly may indicate pre-Wisconsin glaciation, perhaps during Nebraskan time. The source of the hypothetical glacier is not known.

Many pediments also formed along the base of the Book Cliffs in pre-Wisconsin time. (See the section on "Pediment gravels.") According to C. B. Hunt (1956, p. 38), the gravels capping these pediments may have been derived from glacial or periglacial deposits; if so, the pediments probably formed during or shortly after a major phase of pre-Wisconsin glaciation in an arid climate. They are much younger than the glacial debris on West Ridge, however, because much erosion occurred after the glaciations and before the pediments were formed. The earliest pediments were dissected, probably when streamflow increased during a phase of glacial recession, but late pediments also may be of pre-Wisconsin age, suggesting a return to arid conditions because of a readvance of ice in the surrounding mountains. The later pediments were in turn dissected by increased streamflow, and the soils that developed on top of the pediments indicate a moist climate (C. B. Hunt, 1956, p. 72). Fragments of clinker in the oldest pediment gravel indicate that coal outcrops in the cliffs were burned before or during cutting of the pediment. These clinkers may indicate that the Book Cliffs region was forested before the pediments formed, because similar burnings of coal-bed outcrops at Grand Mesa, Colo., probably were started by forest fires (Lee, 1912, p. 216–217). Most prehistoric forest fires in a similar environment at Mesa Verde, Colo., were determined to have resulted from lightning (Erdman and others, 1969, p. 17–19). This origin of the clinkers at Sunnyside seems more applicable than spontaneous combustion, because experiments in abandoned coke ovens by Kaiser Steel Corp. were unsuccessful in finding any means of generating spontaneous combustion (J. T. Taylor, oral commun., 1959).

Extensive erosion in the mountains behind the Book Cliffs followed the pre-Wisconsin glaciation, before and during the times that pediment surfaces below the cliffs were being cut and dissected. The erosional events are well illustrated in Whitmore Canyon, which separates West Ridge from the main part of the Roan Cliffs (fig. 1, pl. 1). Furthermore, the front of the Book Cliffs north of Sunnyside has not retreated appreciably since the pre-Wisconsin pediments were cut, because deposits of Wisconsin age along the front were laid directly upon the pediments (pl. 2).

Whitmore Canyon apparently was formed in two or more stages. At high levels along the canyon walls, particularly near West Ridge, the canyon has a broad, flattened, U-shaped cross section that later was deeply eroded in the bottom to a V-shaped cross section. Walls of the V-shaped canyon were extensively eroded by tributary streams, so that only remnants of the walls remain. We found many remnants of former stream terraces on top of narrow buttresses along the walls of the main canyon. The largest remnant along which a few old meander scars are visible is on Bull Flat, which probably was part of the bottom of the old U-shaped valley. Other remnants, recognizable from their grassy surfaces and their position on narrow east-trending ridges, can be identified southward from Bull Flat beyond the present mouth of Whitmore Canyon. If this broad U-shaped valley was the course of an ancient stream, it has since been tilted, because valley remnants within 2 miles (3 km) south of Sunnyside are higher than remnants to the north and south. The stream may have joined the original drainage of Horse Canyon and flowed southward into Little Park Wash (pl. 1).

The stream flowing in ancestral Whitmore Canyon apparently was captured near the town of Sunnyside by a more active stream flowing down the face of the Book Cliffs. Capture is suggested by Grassy Trail Creek, which flows southward through most of its course in Whitmore Canyon but turns abruptly westward at the Sunnyside coal mines and emerges from the Book Cliffs (fig. 45, pls. 1, 2). Similar capture of southward drainage by a stream flowing down the face of the Book Cliffs took place at Horse Canyon and on a tributary to Little Park Wash, about 3.5 miles (5.5 km) southeast of Horse Canyon. Further capture of Little Park Wash is imminent (Osterwald and others, 1971, p. 13), 4 miles (6.5 km) southeast of Horse Canyon (pl. 1).

Since capture of the original Whitmore Canyon drainage, a narrow V-shaped gorge about 800 ft (250 m) deep was eroded into the bottom of the original

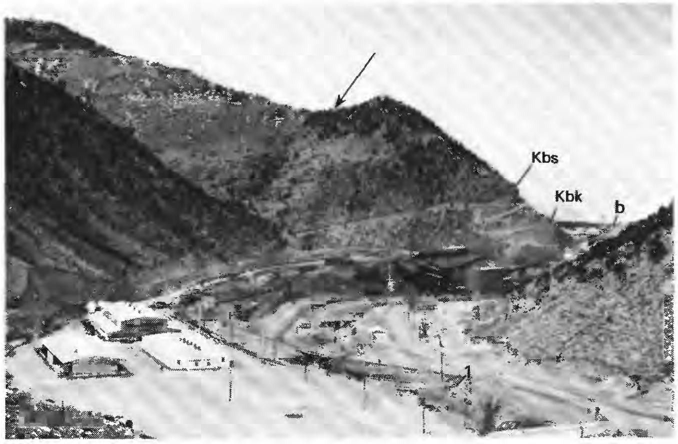


FIGURE 45.—View southwest toward the mouth of Whitmore Canyon showing the abrupt bend in Grassy Trail Creek near the Sunnyside No. 1 Mine before the creek emerges from the canyon. Small saddle (arrow) on ridge above coal tipple probably is a former channel of Grassy Trail Creek. Excavations on slope in right center of photograph for unit-train loading facility caused Kenilworth Member of Blackhawk Formation to become unstable. 1, Portal of Sunnyside No. 1 Mine; 3, portal of Sunnyside No. 3 Mine; and b, stacking belt for unit-train loader installed in 1968. Number Two Canyon in left center of photograph. Kbk, Kenilworth Member; and Kbs, Sunnyside Member of Blackhawk Formation.

broad valley. The time of capture of the Whitmore Canyon drainage cannot be determined accurately, but deposits of early Wisconsin age are found on the walls of the gorge near the mouth of the canyon, and the gorge antedates an alluvial fill that probably is of late Wisconsin(?) age, so the capture and gorge sculpture are probably of pre-Wisconsin age.

We found no evidence of glaciation younger than the West Ridge boulder areas (pre-Wisconsin(?)) in the Sunnyside district. Pre-Wisconsin glacial features are not known in the Wasatch Plateau, 25 miles (40 km) west of Sunnyside, although younger glacial features are abundant (Spieker and Billings, 1940). This lack of evidence for pre-Wisconsin glaciation may indicate that the plateau was uplifted as much as 2,000 ft (610 m) during Pleistocene time (Spieker and Billings, 1940, p. 1194–1196; C. B. Hunt, 1956, p. 61). Glaciation equivalent in intensity to that in the Wasatch Plateau might have occurred in the Roan Cliffs during Wisconsin and later times if the Wasatch Plateau had remained at its pre-Wisconsin altitude during the Pleistocene (Spieker and Billings, 1940), but during and after Wisconsin time most of the precipitation from eastward- and northeastward-moving storms probably was trapped by the Wasatch, as it is now.

Cemented Pleistocene conglomerates along the lower canyon walls may be remnants of outwash from glaciation of highlands during early Wisconsin(?) time. A moist climate during that time is indicated by abundant calcium carbonate cement, which probably resulted from a high ground-water level. Abundant upland periglacial mantle, probably formed by solifluction during a glaciation of early Wisconsin(?) age, also indicates deep weathering and abundant moisture. Alluvial gravel and boulder terraces in the lower parts of the canyons (fig. 28) may be of late Wisconsin(?) age and perhaps were derived from outwash during subsequent times of high streamflow. Deposition of alluvial-fan debris at canyon mouths, followed closely by alluvial sand and silt in canyon floors during late Wisconsin(?) time, probably indicates another time of high streamflow, which may have resulted either from melting snow and ice on the high mountains or from increased precipitation.

The region surrounding the Sunnyside district was the site of considerable tectonic activity during Pleistocene time. Some of the oldest pediment surfaces formed in pre-Wisconsin time were warped before the beginning of the Wisconsin, because remnants of the youngest pre-Wisconsin pediment gravels are not noticeably warped. At two places in the southern part of the district, however, remnants of the middle series of pediments are offset a few feet (less than 2 m) along steeply dipping faults (Osterwald and Maberry, 1974). The ancestral course of Whitmore Canyon is at a higher elevation just south of Sunnyside than it is farther north or south, presumably as a result of local warping. Thirty miles (50 km) west of the Sunnyside district, Pleistocene deformation was much stronger; in the Wasatch Plateau, early Pleistocene drainages were offset by faults, and glacial cirques of Wisconsin age were faulted (Spieker and Billings, 1940, p. 1192).

Evidence of late Pleistocene faulting in surrounding regions was mentioned by Hansen (1969, p. 117), who found faults offsetting glacial-outwash gravels of Bull Lake age (early Wisconsin) along the south margin of the Uinta Mountains, about 75 miles (120 km) north of Sunnyside. Alluvial silt of Wisconsin age along the west side of Marsh Flat Wash seemingly was cut by a west-northwest-trending fault. The smooth upper surface of the alluvium is not visibly offset, but a prominent 1-ft (0.3-m)-wide zone of efflorescent salts, which marks the trace of the fault in nearby Mancos Shale, continues several hundred yards into the alluvium and can be seen easily on aerial photographs. Any surface offset which may have been present probably was destroyed by sheetwash during modern storms. Seismic evidence indicates that some faults in east-central Utah may still be active (Osterwald and others, 1971).

Holocene sediments in the Sunnyside district indicate a time of increased aridity, times of rapid alluviation due to increased runoff, and times of rapid erosion.

Rudimentary pediments along the courses of modern streams indicate a cold and arid period, probably during a temporary return to glacial conditions in surrounding highlands. Glacial features of probable Holocene age were found nearby in the La Sal Mountains (Richmond, 1962, p. 75–84) and in the Wasatch Plateau (Spieker and Billings, 1940, p. 1188). Talus and alluvial-fan debris along cliffs and canyons probably resulted from a climate that was originally cold, then warmed and became more moist as ice and snow melted. Alluvium along stream courses also indicates a time of abundant water following Holocene glaciation in nearby regions. Alluvium of late Holocene age along modern stream courses in the district (pl. 1) may represent either the prepottery Holocene alluvium (about 2,000–4,000 yrs B.P.) or the historic alluvium (about 1500 A.D. to 1600 A.D.) of C. B. Hunt (1956, p. 38–39), or it may be a combination of both. Abundant campsites of early man along the course of Grassy Trail Creek indicate that some of the alluvium is equivalent to Hunt's prepottery Holocene alluvium. We found no evidence in the Sunnyside district of a cycle of arroyo-cutting (gullying) about 1200 A.D., as mentioned by C. B. Hunt (1956, p. 39) for the Colorado Plateau, but modern gullies as deep as 15 ft (less than 5 m) have been cut in Holocene alluvium. These gullies may be the result of an erosional cycle that began in 1880–95 (C. B. Hunt, 1956, p. 39), because the Denver and Rio Grande Western Railway had considerable trouble from flooding and washouts along Grassy Trail Creek during the 1880's (Denver and Rio Grande Western Railroad, written commun., 1965). The cycle of arroyo-cutting probably resulted from a drying climate, combined with frequently intense flash-flooding in and along the mountains.

STRUCTURAL GEOLOGY

The geologic structure of the Sunnyside district is simple. Except for small areas in fault zones, the beds dip less than 20°, generally to the east and northeast toward the Uinta Basin. These gentle eastward and northeastward dips indicate that the district is on a flank of the San Rafael Swell, a major north- to northeast-trending, flat-topped anticlinal uplift in central Utah (Kelley, 1955; fig. 1). The gently dipping beds extend northeastward for many miles beyond the district toward the axial part of the basin. The beds generally dip 6°–18° east and northeast near the Book Cliffs; they commonly dip no more than 4° one mile (1.6 km) northeast and east of the cliffs (Osterwald and Dunrud, 1966, p. 99). Rocks in the district are cut by at least three sets of steeply dipping joints, one trending north to north-northwest about parallel to the strike of beds, one trending west-northwest, and one trending northeast to east-northeast, about parallel to the dip of beds. The most consistently oriented faults in the district are about parallel to the important joint directions, although the east-northeast-trending faults vary in strike and locally trend nearly east. A few east-trending faults cut the beds in the Geneva Mine area (Dunrud and Barnes, 1972), and some in the southwestern part of the district (pl. 1; Osterwald and Maberry, 1974) trend north-northwest to north-northeast. Stratigraphic separation on all the faults at the surface within the mining area is less than 200 ft (60 m); separation on most is only a few feet. As much as 4,000 ft (less than 1200 m) of stratigraphic separation on a fault cutting subsurface rocks of Paleozoic age is known from seismic refraction studies (Tibbetts and others, 1966, p. D136) and horizontal separation of the Ferron Sandstone Member of the Mancos Shale at the surface is about three-quarters of a mile (1.2 km) along an east-northeast-trending fault, near Cedar.

FOLDS

Most folds in the Sunnyside district are broad and gentle and related spatially and genetically to the San Rafael Swell. The Woodside anticline and an adjacent syncline plunge north-northeastward into the southern part of the district (pl. 1) from the northeastern part of the swell. A few broad but very gentle anticlinal noses and synclines plunge northeastward beneath the Book Cliffs, east of the town of Sunnyside (Clark, 1928, pl. 22). A few other small open anticlines, having only a few feet of structural relief, trend eastward across the eastern boundary of the San Rafael Swell in the southwestern part of the district; examples are in the area west of the confluence of Grassy Trail Creek and Price River (pl. 1).

Other local folding in the Sunnyside district may have resulted either from elastic rebound of Mancos Shale during erosional unloading as the Book Cliffs were eroded eastward and northeastward toward their present position or from monoclinal folding parallel to the present cliffs. Several lines of evidence indicate that the present attitudes of beds along the cliffs are related partly to the present topography. Dip of the coal bed in the Sunnyside No. 1 Mine steepens gradually toward the cliffs from the lowest parts of the mine (pl. 2), which suggests an upward bending of the beds near the front of the cliffs. Geologic mapping at the surface (Osterwald, 1962a) indicates that dips along the cliffs are as much as 19°, but underground in the Sunnyside No. 1 Mine and along Whitmore Canyon, about 2 miles (3 km) east of the cliffs in the northern part of the district, dips are as little as 4°.

Strikes of sandstones in the Sunnyside Member of the Blackhawk Formation along the north side of the right fork of A Canyon (pl. 2) change from north-northwest on the east to almost west-northwest on the west, parallel to the topographic surface at the mouth of the canyon (Osterwald, 1962a). The sandstones at the head of the canyon dip 9° to the east, but on the west, at the mouth of the canyon, they dip as much as 19°. Although attitudes of the sandstones on the north slope of the ridge in the left fork of A Canyon cannot be determined accurately because of thick surficial cover (pl. 2), we think that strikes may trend more nearly north along the central part of the ridge and that dips are greater on the west end of the ridge than they are to the east. The patterns produced by these variations in attitudes along the flanks and ends of some ridges in the Book Cliffs suggest that broad, gently plunging synclines underlie some of the ridges and that some of the large canyons transverse to the cliffs may be along the crests of gentle anticlinal noses.

The steepening of dip near the front of the Book Cliffs may be due to upward elastic rebound of the Mancos because of erosional unloading, monoclinal folding having anticlinal and synclinal bends trending northwest, or a combination of these two processes. Upward rebound of the Mancos is suggested by attitudes of beds around large promontories where the beds dip beneath the promontories from the sides as well as at the front (pl. 2). A cross section drawn through the main slope of the Sunnyside No. 1 Mine indicates a flattening of dip a short distance southwestward from the cliff front; this change in dip suggests that the present cliff front is near the anticlinal bend of a monocline (pl. 2). The parallel, though variable, trends of northwestward joints and faults and their near-parallel alinement with the Book Cliffs and with the strike of beds in the Sunnyside No. 1 Mine also suggest monoclinal folding. Rotated joints along the Book Cliffs, however, and conjugate shear joints indicate late movement and vertically directed components of compressive stress after initial folding and erosion of the cliffs to their present position, probably because of rebound.

The steepening of dip of beds near the Book Cliffs does not resemble closely the steepening of dip that would result entirely from bending of beds on a monocline, because:

1. The "synclinal bend" is not at the front of the Book Cliffs, as observed in many monoclines of the Colorado Plateau, but is about 2,000 ft (600 m) east of the cliffs.
2. Dips in the Mancos Shale and Kenilworth Member of the Blackhawk Formation are less westward from the face of the Book Cliffs (zone of steep dips) than they are east of the steep dip zone (pl. 2).
3. Beds that strike nearly parallel to the trends of major ridges in the Book Cliffs and that dip inward beneath the ridges are more compatible with an origin of local uplift (elastic rebound) than they are with an origin related to monoclinal folding.

Uplift along the cliffs may have proceeded as widespread pediments were cut in Mancos Shale at the base of the cliffs in pre-Wisconsin time. (See the section on "Pediment gravels.") Some pediments, particularly those in the northern part of the district, steepen rapidly toward the cliffs (fig. 46), and at the base of the cliffs attain slope angles as steep as 40 percent. This steepening of the original slope may have resulted in part from upward rebound of the Mancos when the retreat of the cliffs was slowed during a climatic change, and in part from the decreased sediment load carried by streams (Lobeck, 1939, p. 557). Such slopes seem much too steep to have been formed entirely by either decreased sediment load or accelerated erosion and deposition near the cliffs, as is common on pediment surfaces elsewhere.

Elastic rebound of the Mancos Shale as the actual cause of the pre-Wisconsin uplift along the cliffs seems likely, however, because of the known physical behavior of the Mancos and similar rocks. Dips near the outcrop of coal beds in the Grand Mesa, Colo., coal field steepen similarly; these increases are attributed by Lee (1912, p. 65) to "relief of pressure as the superincumbent rocks were eroded away." A few feet of elastic rebound, equivalent to an expansion of about 10 percent, in the very similar Pierre Shale at Oahe Dam,

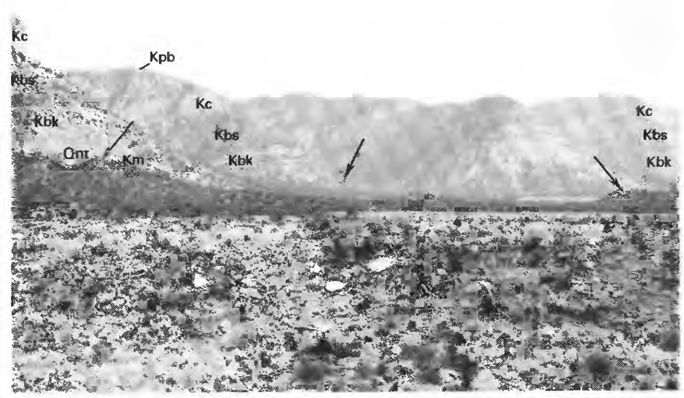


FIGURE 46.—View southeast near mouth of A Canyon, north of Dragerton, Utah. Steeply sloping remnants of pre-Wisconsin pediment (arrows) near the Book Cliffs, separated from cliffs by late Pleistocene erosion and by some talus of late Pleistocene age (Qnt). Bank in foreground is wall of gulch about 20 ft (6 m) deep that resulted from late Pleistocene erosion of pediment surface. Km, Mancos Shale; Kbk, Kenilworth Member, Blackhawk Formation; Kbs, Sunnyside Member, Blackhawk Formation; Kc, Castlegate Sandstone; Kpb, Bluecastle Sandstone Member of Price River Formation.

S. Dak., occurred during excavation of about 150 ft (46 m) of overburden (Underwood, 1957; Underwood and others, 1964). Similarly, a cut slope in tuffaceous rocks about 125 ft (40 m) high, in the State of Washington, failed massively as a result of rebound amounting to 0.5 ft (0.15 m) horizontally and 1.5 ft (0.5 m) vertically (K. R. Meadaris, oral commun., 1973). This rebound was equivalent to more than 10-percent expansion vertically. We observed cores of Mancos Shale tongues in the Blackhawk Formation, taken from a drill hole in Whitmore Canyon, that expanded longitudinally (upward) and broke into many small disks when withdrawn from core barrels. Expansion of less than 10 percent in the 3,000–4,000-ft thickness of the Mancos Shale in the Sunnyside district probably could account for the observed changes in bedding attitudes near the cliffs.

JOINTS

Joints at most localities in the district occur in three principal sets, although one or more of the sets locally may not be clearly discernible, and at some localities additional sets may appear. Nearly all joints in the district dip steeply, but slight variations in both dip and strike were noted at many places. Upper-hemisphere pole diagrams of joints show distinct girdle patterns, local statistical concentrations representing the major sets (fig. 47). These statistical concentrations vary slightly in the different parts of the district, probably as a result of different structural patterns. Many joints were rotated slightly since their formation, probably during Wisconsin time. Blocks of rock bounded by joints commonly fall from cliff faces and probably contributed significantly to retreat of the cliffs to their present position. On the crest of West Ridge (pl. 2), outward rotation of large sandstone joint blocks which are loose but have not yet fallen has produced gaping troughs, partially filled with soil, that are several feet wide and deep and several tens of feet long.

NORTHWEST- TO NORTH-NORTHWEST-TRENDING JOINTS

Joints of the northwest- to north-northwest-trending set are more variable in attitude than are joints of the west-northwest set, probably because the strike of beds, which the northwest to north-northwest joints nearly parallel in trend, changes from nearly north in the southern part of the district to northwest in the northern part. In addition, these joints apparently were rotated to different angles during local uplift of the Book Cliffs, because the joints trend almost at right angles to most of the prominent west-trending ridges forming the front of the cliffs (pl. 1). In some areas along the cliffs, as in the Geneva Mine area, differential rotation along faults (Dunrud and Barnes, 1972) apparently produced two or more joint attitudes that diverge in trend and dip steeply southwest (fig. 47*E*). Locally, joints of the northwest- to north-northwest-trending set occur in zones a few feet wide containing individual joints less than 1 ft (0.3 m) apart; the zones themselves are a few feet to 20 ft (6 m) apart.

Movement has occurred along many joints of this set, particularly near the northwest-trending Sunnyside fault zone, and many have as much as a few feet of stratigraphic separation. A few joint surfaces, particularly near Columbia, are coated with thin films of calcite and a few others are coated with gypsum.

NORTHEAST- TO NORTH-NORTHEAST-TRENDING JOINTS

A set of joints trending northeast to east-northeast, which nearly parallels the direction of dip of beds, varies considerably in spacing of fractures but is rather consistent in trend between the various parts of the district. The set generally forms a nearly orthogonal pair with the west-northwest set, striking nearly northeast in the northern part (fig. 47*A, B*) and in the extreme southern part of the district (fig. 47*H*). Near the Geneva Mine the strike of joints is about east-northeast (fig. 47*E, H*), probably because the strike of beds near the mine is nearly north, and suggesting that the joints formed in response to stress that produced the folding. South of the Geneva Mine, beds strike more north, and the northeast joints strike more east than at the Geneva Mine (pl. 1, fig. 47*E, F, H*). Apparent conjugate sets of generally northeast-trending joints along the Book Cliffs near the Sunnyside No. 1 Mine (fig. 47*A*) and near the Columbia Mine (fig. 47*C*) may have resulted from opposing dips of beds on opposite sides of northeast-trending ridges which probably were caused by vertical stress components resulting from upward elastic rebound of Mancos Shale as deep canyons were cut into the cliffs. Varying attitudes of northeast-trending joints near the Geneva Mine (fig. 47*E, F*) may have resulted from differential movement along fault blocks (Dunrud and Barnes, 1972) as a consequence of similar rebound.

Some conjugate sets of steeply dipping, northeast-trending, vertically curved shear joints locally cut sandstones of the Sunnyside Member along the cliffs, particularly between the towns of Sunnyside and Columbia (fig. 48). These shear joints, which probably formed in response to vertical stress components because their acute bisectors are nearly vertical (fig. 48), also may have resulted from upward elastic rebound of Mancos Shale during erosional unloading. Similar joint sets were not observed in any sandstone units above the Sunnyside Member.

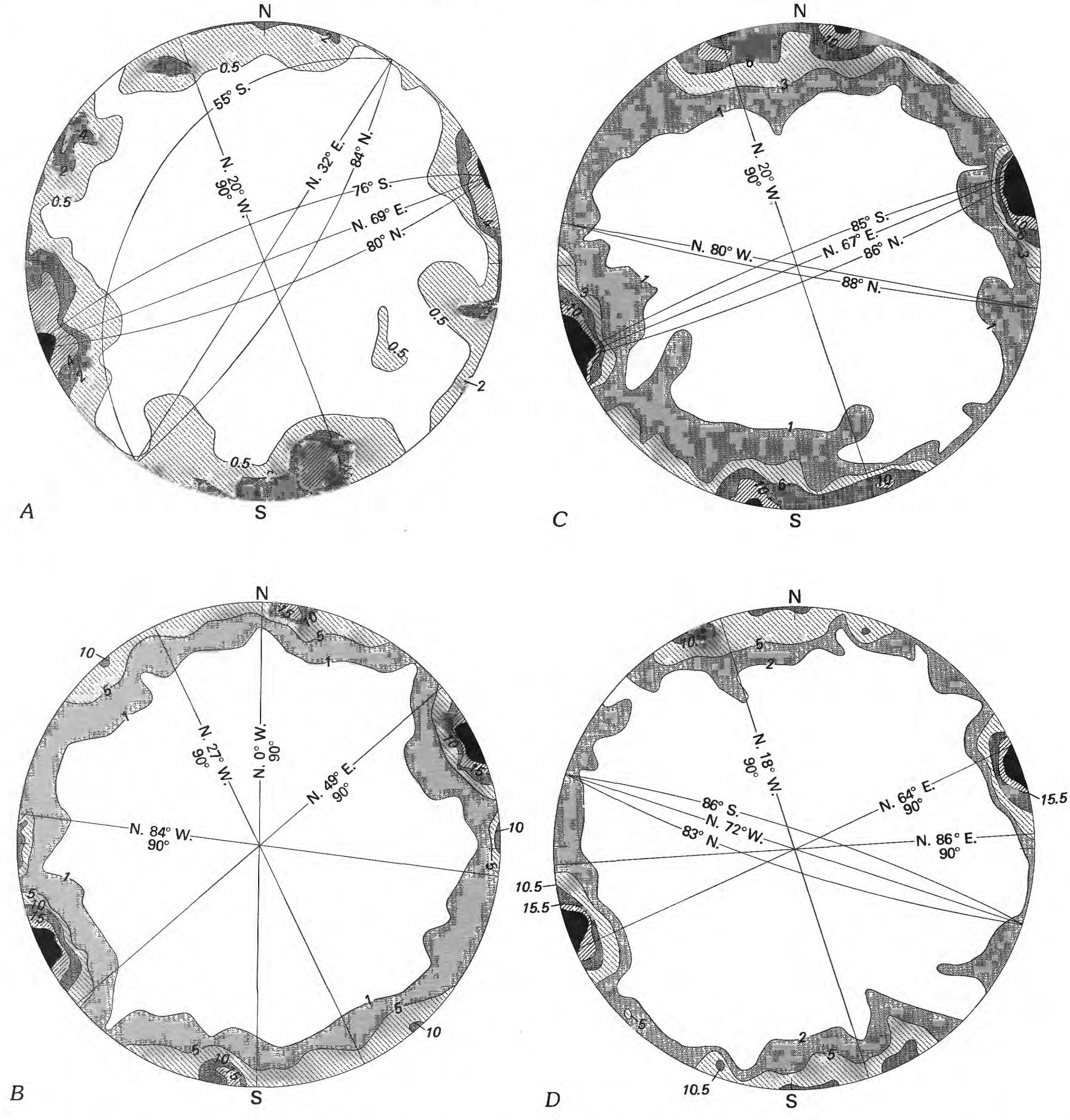
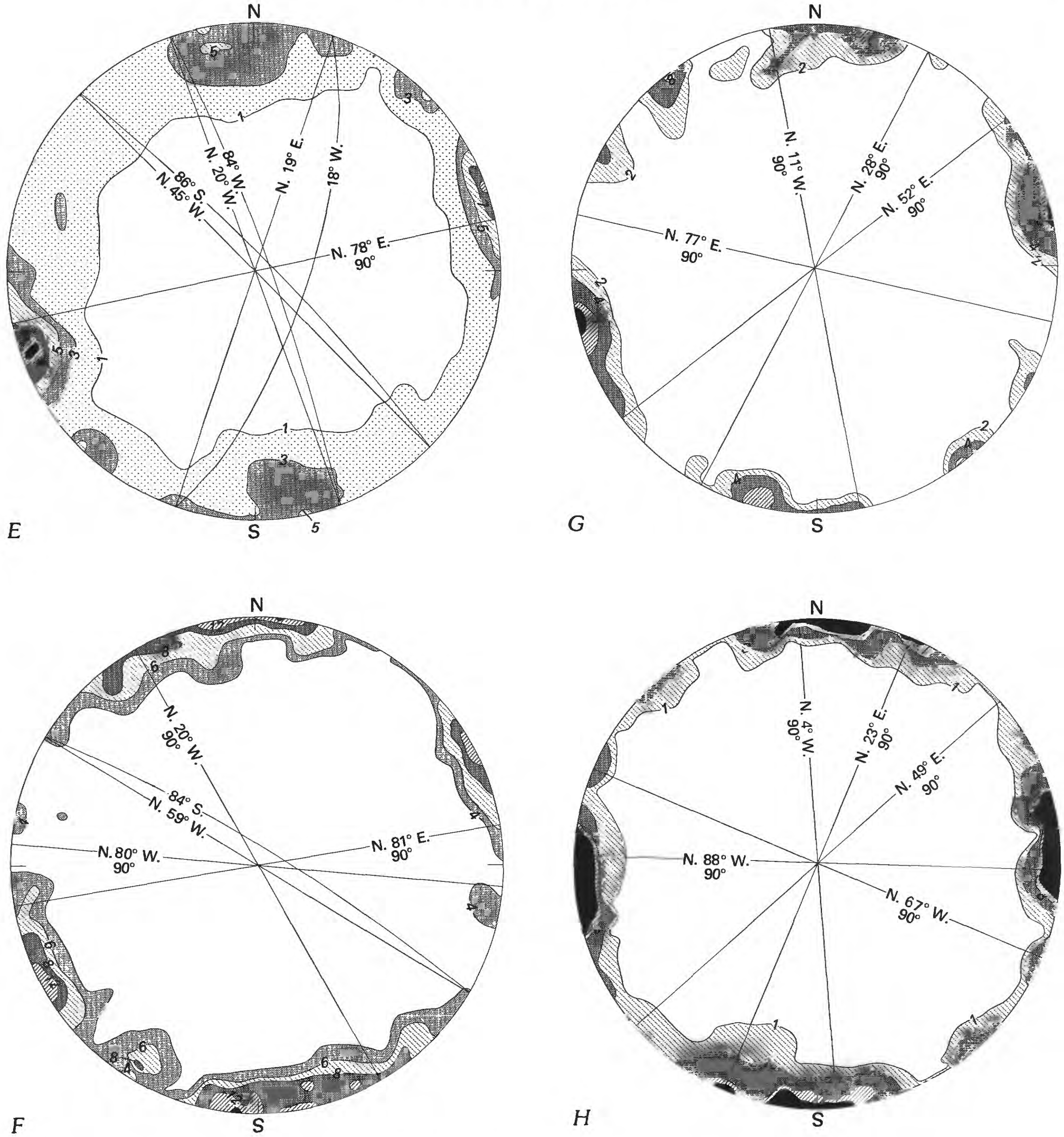


FIGURE 47.—Stereograms of joint poles in the Sunnyside coal mining district, plotted on upper hemisphere of equal-area net showing attitudes of major statistical joints. *A*, 78 joints along the Book Cliffs, Sunnyside No. 1 Mine area, maxima (black) at 7 percent, contours at 4, 2, and 0.5 percent. *B*, 319 joints behind Book Cliffs, Sunnyside No. 1 Mine area, maxima (black) at 19 percent, contours at 15, 10, 5, and 1 percent. *C*, 323 joints along Book Cliffs, Columbia area, maxima (black) at 40 percent, contours at 10, 6, 3, and 1 percent. *D*, 96 joints behind Book Cliffs, Columbia area, maxima (black) at 20 percent, contours at 15.5, 10.5, 5.0, and 2.0 percent. *E*, 437 joints

FAULTS

Most faults and fault zones in the Sunnyside district are obscure at the surface, in spite of excellent outcrops along the Book Cliffs and in steep canyon walls, because individual fractures are discontinuous and because the stratigraphic separation along individual faults commonly is less than the vertical variations in



along Book Cliffs, Geneva Mine area, maxima (black) at 9.5 percent, contours at 9, 7, 5, 3, and 1 percent. *F*, 118 joints behind Book Cliffs, Geneva Mine area, maxima (black) at 15 percent, contours at 12, 8, 6, and 4 percent. *G*, 50 joints east part of Woodside 15-minute quadrangle south of Geneva Mine, maxima (black) at 10 percent, contours at 8, 4, and 2 percent. *H*, 84 joints, northeast part San Rafael Swell, maxima (black) at 10 percent, contours at 8, 3, and 1 percent.

stratigraphic positions of rock contacts. Some faults, especially those in the northern part of the district, are indistinct because small amounts of movement are distributed along joints over zones a few tens of feet (less than 15 m) wide. Fault traces in hard sandstones behind the cliff front are best discerned on high-altitude (1:60,000-scale) aerial photographs. Fault traces in the Mancos Shale of the low-lying Clark Valley are best

FIGURE 48.—View southwestward of conjugate shear joints in sandstones of Sunnyside Member of Blackhawk Formation along south side of Fan Canyon, north of Columbia, Utah. Joints strike northeast; acute bisector of joint planes is nearly vertical. Sandstone ledge is about 25 ft (7.5 m) thick near center of the photograph. Sunnyside coal bed is exposed by bulldozer cut just above ledge.

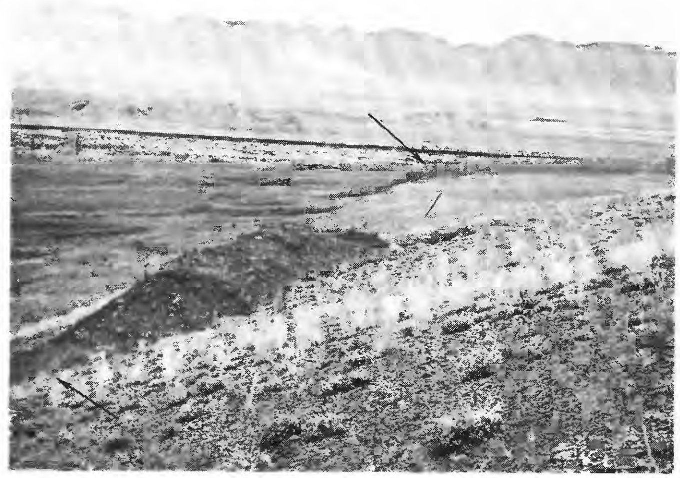


FIGURE 49.—Erosional scarp (arrows) along fault cutting Mancos Shale in the southern part of the Sunnyside district, about 1 mile (1.6 km) west of Grassy siding on Denver and Rio Grande Western Railroad. Stratigraphic separation is about 40 ft (12 m) up to the right in the photograph. Dark material in lower left center is spoil from small excavation. View southeast toward Book Cliffs.

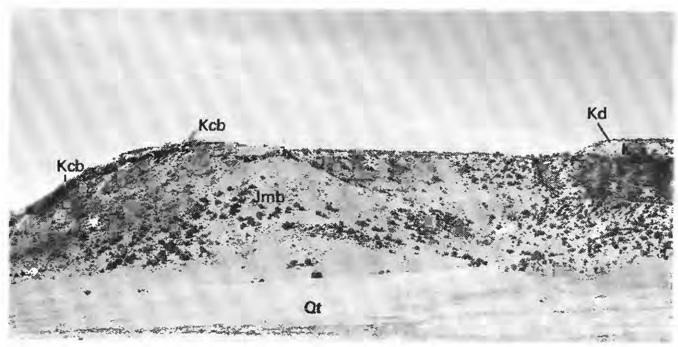


FIGURE 50.—Buckhorn Conglomerate Member (Kcb) of Cedar Mountain Formation draped over faults cutting Brushy Basin Member (Jmb) of Morrison Formation about 2 miles (3 km) northwest of Cedar. U, upthrown side; D, downthrown side. Flat in foreground is covered by upper Wisconsin(?) terrace gravel (Qt). Ridge on skyline is capped by Dakota Sandstone (Kd) underlain by shale member (Kcs) of Cedar Mountain Formation. View westward.

discerned as straight lines on 1:20,000-scale aerial photographs. Subsequent field examination in the low-lying areas commonly revealed erosional scarps as much as 40 ft (12 m) high resulting from retreat of soft, weathered shale from underlying thin, resistant beds (fig. 49). A few faults and fault zones are silicified, iron stained, or filled with calcite and gypsum, and thus can be easily traced, but most are unmineralized, uncemented, and indistinct.

Changes in strike and dip of faults are common within short distances along the faults. Most movement along faults in the district was vertical, but along east-northeast-trending faults in the northern part of the district, horizontal slickensides, gash fractures, and obliquely intersecting shear fractures in fault zones locally indicate horizontal components of movement. One east-trending fault north of Horse Canyon apparently moved horizontally (pl. 1). Faults in the northern part of the district are nearly vertical, but most faults in the Geneva Mine area (central part of the district) dip less steeply, and some dip 45° or less. Faults in the southern part of the district dip nearly vertically. Small gash fractures filled with silica, calcite, and iron oxides are common in clearly exposed fault zones along the flank of the San Rafael Swell (fig. 1, pl. 1) and indicate considerable components of horizontal movement. Beds of Jurassic and older age in the northeastern part of the San Rafael Swell are draped over major faults and fault zones (pl. 1, fig. 50), indicating large components of vertical fault movement. In general, stratigraphic separation on major faults in the district is large in Jurassic and Lower Cretaceous rocks, moderate in Upper Cretaceous rocks, and small in Tertiary rocks.

SUNNYSIDE FAULT ZONE

Most of the north-northwest-trending faults in the Sunnyside district are part of the Sunnyside fault zone, which extends from the Geneva Mine area to West Ridge (pl. 1). Near the Geneva Mine the zone is as much as 1.5 miles (2.5 km) wide (Osterwald and Dunrud, 1966, p. 99), but it is only 10 ft (3 m) wide in the Sunnyside No. 1 Mine (Osterwald, 1962b, p. 64). Individual faults within the zone dip steeply. Average stratigraphic separation of coal in the zone is about 30 ft (9 m) in the northern part of the district at the Sunnyside No. 1 Mine (Clark, 1928, p. 25), and about 40–60 ft (12–18 m) in the southern part of the district at the Geneva Mine. Most faults within the zone are nearly parallel to the trend of the zone, but some diverge at small angles and merge with other faults in the zone that are parallel with the zone boundaries. The map relationships of the faults within the zone suggest that the diverging faults may be gash fractures resulting from small components of horizontal movement in which the block northeast of the zone moved relatively northwestward. Thus, the total displacement across the zone may be much greater than the 30 ft (less than 10 m) of stratigraphic separation. At a few localities, for example in the north side of Number Two Canyon (pl. 1), strongly fractured zones in the Castlegate Sandstone show no stratigraphic separation and may have resulted from predominantly horizontal motion. Many faults in the zone are parallel to north-northwest-trending joints, and less than 1 ft (0.3 m) of stratigraphic separation can be measured on joint planes at many localities near the fault zone.

The zone varies widely in its internal characteristics. At some localities in the northern part of the district, for example in the southernmost bleeder slopes of the Sunnyside No. 1 Mine (Osterwald, 1962a), no single fault plane is present in the zone, and the separation is distributed along numerous minute fractures across a width of several feet. Elsewhere, as in the main slope of the Sunnyside No. 1 Mine (Osterwald, 1962a), the position of the zone is marked by gouge, breccia, and fractured rock (fig. 51). The fault zone is easy to trace at the surface in the northern part of the district only where it is locally silicified and iron stained. In the southern part of the district, where the zone is broad, it consists of widely spaced individual faults.

FIGURE 51.—Gouge, breccia, and fractured rock along Sunnyside Fault, in southeast rib of old right-side manway, Sunnyside No. 1 Mine, Utah. View is southeast along strike of fault. Stratigraphic separation is about 13 ft (4 m); downthrown block is on right side of picture. Photograph by J. C. Witt.

EAST-NORTHEAST- TO NORTHEAST-TRENDING AND EAST-TRENDING FAULTS

Faults that trend east-northeast and east are widely distributed throughout the district but are more numerous near the Geneva Mine. These faults trend about parallel to the dip of beds but vary considerably in strike and dip (Dunrud and Barnes, 1972). Most of these faults dip steeply in the northern part of the district but dip less steeply farther south, and at the Geneva Mine they dip 45° or less. East-northeast-trending faults offset faults of the Sunnyside fault zone and hence may be younger than the zone, both in the Sunnyside No. 1 Mine area (Osterwald, 1962a) and in the Columbia area (Osterwald and others, 1969), although we realize that offsets of fault sets may not indicate the relative ages of the sets (McKinstry, 1948, p. 354–360).

Stratigraphic separation on individual east-northeast-trending faults is as much as 150 ft (46 m) in the Book Cliffs, but on most faults it is much less. Separation on many of the faults is greatest near the cliffs but decreases eastward away from the cliffs, particularly about 1 mile (1.6 km) north of the town of Sunnyside (fig. 52). Separation also is less along these faults in the Colton Formation than it is in older rocks, indicating either that movement began during Cretaceous time and continued with decreasing energy into early Tertiary time, or that the fault separation diminished to the east. Horizontal separation of the Ferron Sandstone Member of the Mancos Shale along one such

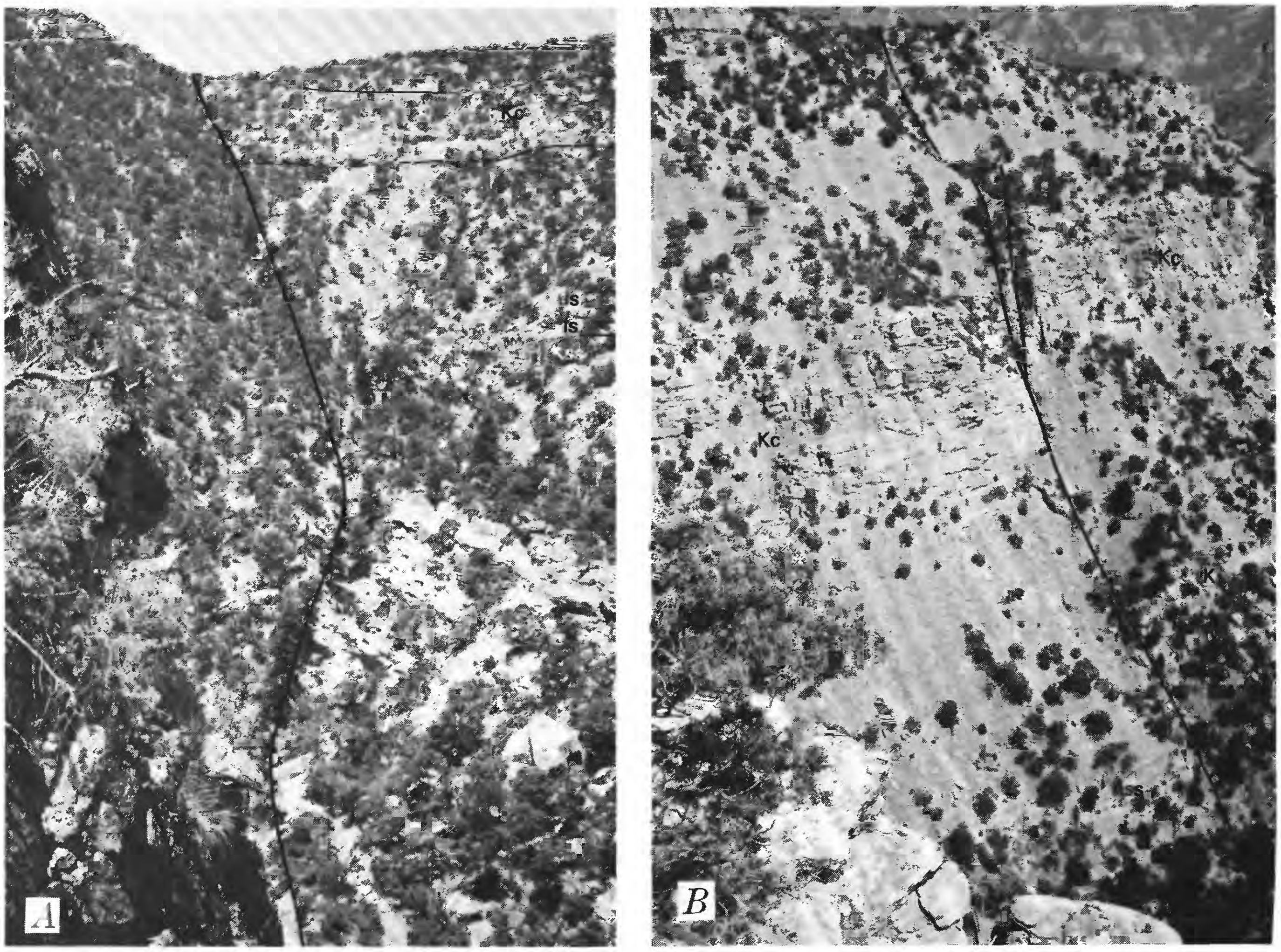


FIGURE 52.—East-northeast-trending fault cutting Castlegate Sandstone (Kc) in Slaughter Canyon, north of Sunnyside, Utah, illustrating decreasing stratigraphic separation east of Book Cliffs. *A*, Fault cutting Castlegate in west side of canyon about 1,500 ft (460 m) east of Book Cliffs; separation is greater than thickness of Castlegate. Kss, sandstone of Sunnyside Member of Blackhawk Formation; us, upper split, and ls, lower split, Sunnyside coal bed. *B*, Same fault cutting Castlegate in east side of canyon, about 4,500 ft (1,400 m) east of Book Cliffs; separation is less than thickness of Castlegate.

fault about 1 mile (1.6 km) north of the Cedar railroad siding, nearly 6 miles (10 km) west of the Book Cliffs, is approximately three-quarters of a mile (1 km).

Many small east-northeast- or northeast-trending faults follow joint planes and have only a few tenths of a foot (less than 15 cm) to a few feet (less than 2 m) of stratigraphic separation. Locally, as in the Colton Formation on the east side of Whitmore Canyon between Bear Canyon and Pole Canyon (pl. 2), several of these small faults along joint planes show as much as 4 ft (1.2 m) of separation across a zone 40 ft (12 m) wide. Rock along some of the small faults is brecciated, and individual sand grains are broken, although the stratigraphic separation on each fault may be as little as 0.5 in. (1.3 cm); locally, the brecciated rock is recemented with calcite (pl. 2). Other faults belonging to this set have thin veins of calcite and gypsum less than 0.5 in. (1.3 cm) wide, and one contains a few grains of a copper sulfide mineral.

Movement on most of the east-northeast- and northeast-trending faults apparently was dip slip. Locally, as in the now inaccessible part of Sunnyside No. 3 Mine beneath the mouth of Schoolhouse Canyon (pl. 1), horizontal slickensides in the coal indicate strike-slip movement, but slickensides along a calcite vein in the Bluecastle Sandstone Member of the Price River Formation at the surface in the same locality plunge 24° southeast, indicating components of dip slip. We believe that the first movement along the east-northeast faults was dip slip but that subsequent motion (after some faults were filled with calcite) may have been vertical, horizontal, or somewhere in between.

SUBSURFACE FAULT

A fault having about 2,600 ft (800 m) of stratigraphic separation in subsurface rocks of Paleozoic age trends northwestward beneath the south-central part of the district and was detected by seismic methods (Tibbetts and others, 1966, p. D136; pl. 1). Stratigraphic separation in overlying rocks decreases as the age of the rocks decreases, and the fault dies out upward in the Mancos Shale. We found no evidence of this fault at the surface or in mine workings, but the fault pattern of the district differs on opposite sides of the surface projection of its subsurface position. North-northwest-trending faults (Sunnyside fault zone) are much more abundant northeast of the subsurface fault, and east-northeast-trending faults are more uniformly spaced and vary less in strike and dip southwest of the subsurface fault than they do to the northeast. These differences suggest that slight movements along the subsurface fault may have caused stress readjustments in the Upper Cretaceous and Tertiary rocks, thus influencing the distribution and attitude of younger faults. The fault probably is the southwestern margin of an uplift that was raised in Paleozoic time (Heylmun, 1959, p. 172–173). Based on the log of a hole drilled for oil in SW¼SW¼ sec. 25, T. 16 S., R. 15 E. (several miles south of the section in pl. 1), the Mancos Shale is thicker northeast of the fault than it is in sections measured below the Book Cliffs.

WEST-NORTHWEST-TRENDING FAULT BELT

A belt of numerous west-northwest-trending faults crosses the district south of the Geneva Mine (pl. 1). Individual faults within this belt are only a few miles (less than 10 km) long, but in reconnaissance work the belt was traced from the confluence of Range Creek and the Green River 10.4 miles (16.1 km) east of the Woodside 15-minute Quadrangle for a distance of 32 miles (51 km) to near Desert Seep Wash, 12 miles (19 km) south-southeast of Price, Utah (fig. 1). Most faults in the belt dip steeply or vertically and strike nearly parallel to the trend of the belt; directions of stratigraphic separation on the steeply dipping faults indicate that most are normal faults.

Upper Cretaceous and Tertiary rocks within the fault belt are not tilted or brecciated, but beds of Jurassic age within the belt dip northward as much as 57° about 1.5 miles (2.5 km) south of Cedar (pl. 1, fig. 53). Stratigraphic separation seemingly is greater in rocks of Jurassic age than in those of Tertiary age, indicating that movement along faults in the belt began during or after the Jurassic rocks were deposited and continued intermittently into the Tertiary. Some pediment surfaces of pre-Wisconsin age also are offset a few feet (less than 2 m) by faults within the belt in the south-central part of the Woodside Quadrangle (pl. 1; Osterwald and Maberry, 1974), but alluvial-fan material of late Wisconsin(?) age 3 miles (5 km) southeast of Cedar overlaps faulted Ferron Sandstone Member of Mancos Shale without visible offset (fig. 54).

Structure sections drawn through the fault belt indicate that it is at the crest of a broad anticline which has collapsed (Osterwald and Maberry, 1974). The length, surface pattern of faulting, and trend of the belt sug-

FIGURE 53.—View west of steep southward dip of Brushy Basin Member of Morrison Formation in fault zone about 1.5 miles (2.5 km) south of Cedar. Skyline in distance is capped by thick conglomeratic sandstone lens in the upper part of the Brushy Basin, which dips gently northeastward.

FIGURE 54.—View north about 2 miles (3 km) northeast of Cedar of alluvial-fan debris (Qfl) of late Wisconsin(?) age from mouth of Horse Canyon overlapping faulted Ferron Sandstone Member (Kmf) and the overlying part of Mancos Shale (Km). Alluvial-fan debris shows no visible offset. U, upthrown side; D, downthrown side. Book Cliffs near Sunnyside, Utah, in background; abandoned embankment for U.S. Highway 6 in middle ground.

gest that it is similar to but less strongly developed than the well-known anticlines near Moab, Utah, and Naturita, Colo., about 90–150 miles (145–240 km) southeast of Sunnyside, that resulted from diapiric movement of salt beds at depth (Cater, 1955; Jones, 1959). Some of these anticlines extend northwestward to the vicinity of Green River, Utah (Jones, 1959, p. 1890; Cohee and others, 1961), about 40 miles (64 km) southeast of Sunnyside and only about 20 miles (32 km) from the confluence of Range Creek and Price River. The fault pattern in the collapsed anticline (pl. 1) closely resembles the fault patterns in the upper parts of salt anticlines as described by Baars (1966, p. 2107) and Stokes (1948) and as illustrated by Jones (1959, p. 1872). We infer, therefore, that the fault belt is the surface expression of a salt anticline at depth, probably near the northern margin of a basin of salt deposition during Pennsylvanian time.

Some faults in the belt may still be active, because some earth tremors recorded by us at Sunnyside, Utah, originated within the belt.

ECONOMIC GEOLOGY

Several commodities of actual or potential economic value are present within the Sunnyside district, but coal is the most abundant and of the most economic value. Gypsum, present in the Carmel Formation in the southwestern part of the district, is a potential source of plaster and wallboard if economic conditions in central Utah become favorable for its exploitation. Underground water, although rare, emerges as springs at various places within the district and is used locally for domestic and stock water. A cold-water geyser, charged by carbon dioxide probably derived from deeply buried Paleozoic carbonates, is near the Price River at Woodside. The geyser, which discharges periodically, is used only as a tourist attraction. It is the result of a well drilled many years ago by the Denver and Rio Grande Western Railroad for a source of boiler water.

Asphalt-impregnated sandstone, quarried from the Colton Formation northeast of Sunnyside (Holmes and others, 1948), formerly was used to pave streets and roads, but the quarry has long been idle. Petroleum and carbon dioxide are produced from the Grassy Trail Oil Field about 8 miles (13 km) west-southwest of Dragerton. The Jurassic and Lower Cretaceous rocks in the southwestern part of the district were extensively prospected for uranium, but little ore is known to have been produced.

Other commodities in the district are only of scientific interest as mineral occurrences but have no present economic value. Most of these occurrences consist of grains of metallic minerals scattered along some faults.

COAL

Coal at Sunnyside was discovered in 1898 by Jefferson Tidwell (Peterson and others, 1956, p. 206). Natural coke also was found in 1898 where the coal outcrop had been burned (Lewis and Varley, 1919, p. 67). The Sunnyside mines were opened in 1899 (Harrington, 1901) by Daniel Harrington and James Westfield, and 1,200 men soon were at work (Peterson and others, 1956, p. 206). Shortly afterward the mines were acquired by the Utah Fuel Co., a subsidiary of the Rio Grande Western Railway (Athearn, 1962, p. 194–195), largely to provide a source of locomotive fuel (Storrs, 1902, p. 455). Because the Sunnyside coal could be used to make metallurgical coke, it became too valuable to use only for locomotive fuel, and by 1919 the largest beehive coke-oven plant in the United States was at Sunnyside (fig. 55; Lewis and Varley, 1919, p. 68). Kaiser Steel Corp. bought the Sunnyside mines in 1950 as a source of coking coal for their steel plants in California.

The Columbia Mine (pl. 1) was opened by Utah Fuel Co. in 1924 and later was acquired by the Columbia-Geneva Steel Corp. as a source of coking coal for mills near Provo, Utah. Columbia-Geneva Steel Corp. later was acquired by United States Steel Corp., the present owner of the Columbia Mine. Small coal prospects in Horse Canyon known as the Carlson and Woodard Mines were opened during the 1930's on leased Federal lands. These prospects were acquired by the Defense Plant Corp. during World War II, and, through a contract with the Columbia-Geneva Steel Division of United States Steel Corp., were developed into the Horse Canyon coal mine (also known later as the Geneva Mine). Columbia-Geneva bought the property outright after World War II. The Book Cliffs Mine, also known as the Murray Mine and adjoining the Horse Canyon (Geneva) Mine, was developed during World War II and was operated by the Book Cliffs Coal Co. until 1966. Mining ceased in the Columbia Mine in 1967 because of many faults which caused dangerous mining conditions.

The three principal settlements in the district are Sunnyside, Columbia, and Dragerton. Sunnyside, the oldest settlement, originally was in the lower part of Whitmore Canyon near the present portal of the Sunnyside No. 1 Mine; it was a company town owned by Utah Fuel Co. During World War II, additional modern houses and business buildings were built in the town of Sunnyside near the mouth of Whitmore

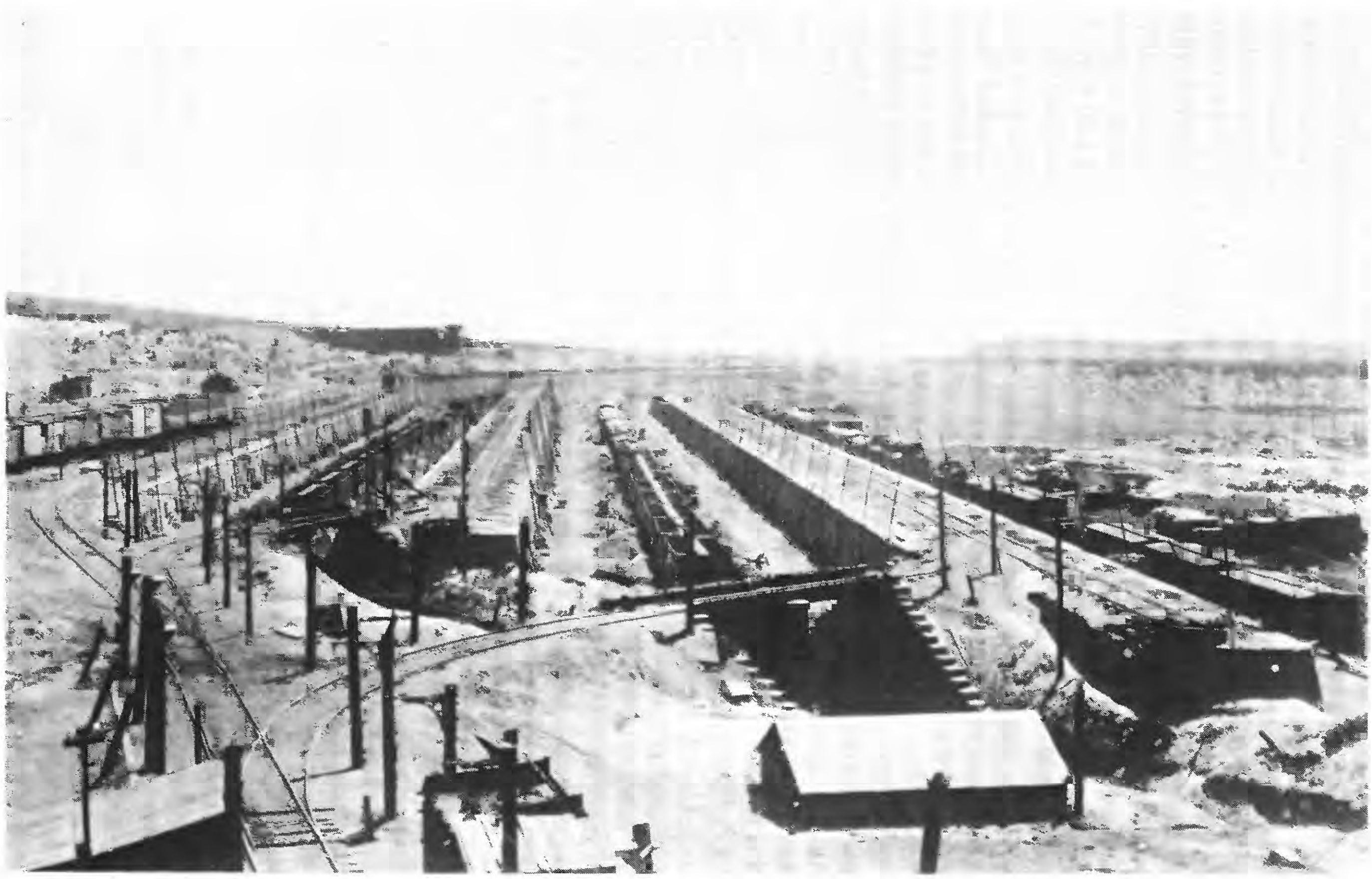


FIGURE 55.—Coke-oven plant at Sunnyside, Utah, probably before 1910. Each small opening along the brick wall at left center of photograph is an individual coke oven. Each oven along the brick walls was operated manually by one man (see fig. 58). Photograph courtesy Library, State Historical Society of Colorado.

Canyon by the Defense Plant Corp., in an area known locally as Sunnydale, and were leased to Utah Fuel Co. Following World War II, Sunnydale was sold to Utah Fuel Co., and subsequently, the entire Sunnyside property (mines, surface plant, and townsite), was sold to Kaiser Steel Corp. Some of the World War II buildings and a few cement-block houses built by Kaiser Steel remain in Sunnyside. Columbia was built about 1924 as a company-owned town by Utah Fuel Co. to provide housing for miners at the Columbia Mine; later it was sold to Columbia-Geneva Steel Corp. and subsequently was acquired by United States Steel Corp. During the 1950's, the buildings in Columbia were sold to individual residents; the town now is privately owned. Dragerton, the business center of the district, also was built during World War II by the Defense Plant Corp. to provide modern dwellings and business facilities for miners at the Horse Canyon (Geneva) Mine. Subsequently it was sold to United States Steel Corp. and was resold to individual owners and shopkeepers at the same time as Columbia was sold. In 1972, about 700 persons lived in Dragerton, 150 in Columbia, and 200 in Sunnyside. Columbia and Dragerton were incorporated as East Carbon City about 1974.

Most mining in the Sunnyside mines was done by room-and-pillar methods, at first by individual men using hand-mining methods and later by using various electrically driven cutting and loading machines. Early machine mining was done by undercutting the face and blasting down the coal. Much mining at Sunnyside, however, does not require blasting because the coal is stressed and fails continuously in a series of small bumps. Old miners report that, in some places, a pick thrown at the face at the beginning of a work shift caused an immediate bump so that the remainder of the shift could be devoted to loading broken coal. All room-and-pillar work in the district at present (1974) is done by using continuous-mining machines that feed automatically into rubber-tired self-propelled shuttle cars. These shuttle cars transport mined coal to underground loading points where it is dumped into mine cars hauled by electric motors. Longwall mining methods were first used in the Sunnyside mines during the early 1920's by a simple modification of mining procedures in which cutting machines and loading equipment were adapted to operation along a continuous face rather than to a series of gradually progressing rooms and pillars (James Westfield, oral commun., 1961). Modern longwall mining methods were introduced in the Sunnyside mines in 1963, using automatic equipment.

Mining plans in the Sunnyside mines are designed to permit complete collapse of the roof over mined-out areas (John Peperakis, oral commun., 1958). Entries are driven approximately along the strike of the coal bed, to the right and left of haulage slopes which are about parallel to the dip of the coal. The entries intersect bleeder slopes near the boundaries of each mine; the bleeder slopes provide continuous ventilation circuits and also serve as escapeways should the main slopes be blocked. Rooms are driven up the dip of the coal bed from each entry, leaving a 300-ft (90-m) or 275-ft (84-m) barrier pillar beside the bleeder slope. Only a few rooms are started at one time, and pillars separating rooms are reduced progressively in size until only a small remnant remains. These remnants are then either removed by mining or blasted to destroy their strength so that the roof will cave completely. Modern longwall faces are oriented about parallel to the dip of the coal bed. Roofs adjacent to longwall faces are supported by movable hydraulic props, and are allowed to collapse a few feet from the face as soon as the props are advanced. This progressively retreating method of mining allows nearly all of the mining work, except for actual working of the faces, to be done in solid, undisturbed coal, and is much safer and more economical than traveling through partially developed or worked-out blocks of coal.

Surface operations at the Sunnyside mines became more efficient as changes were made in underground

FIGURE 56.—View southeastward of Utah Fuel Co.'s surface plant at Sunnyside, in Whitmore Canyon, probably before 1908. Miners' houses are in foreground. Smoke is from coke ovens near mouth of Whitmore Canyon. Compare figures 45 and 57. Photograph courtesy of the State Historical Society of Colorado.

operations. A coal-fired electric plant provided power for underground and surface machinery soon after the mines were opened (Clark, 1922, p. 212), and large preparation plants and loading tipples were built (fig. 56). The miners' living quarters remained primitive, however (fig. 56). The preparation plant, washer, and tipple were enlarged and modernized by 1958, but railroad cars still were loaded individually and manually rolled into the load yard, much as they were 50 years earlier. Car loading was mechanized in 1968, when a unit-train loader that commonly fills 80 railroad cars of 125-ton (113,400-kg) capacity in about 1 hour was installed near the mouth of Whitmore Canyon (fig. 57).

Beehive coke ovens were first operated at Sunnyside in 1903 (Allen, 1925, p. 2). When the Sunnyside No. 2 Mine was acquired by Kaiser Steel Corp., additional coke ovens were built near the Columbia yards of the Carbon County Railway (pl. 1). Operation of the beehive coke ovens was an individual piecework procedure (fig. 58), requiring a large force of men. The beehive ovens were abandoned in 1958; since then all the coke has been produced in modern byproduct ovens at the Kaiser Steel plant in Fontana, Calif. Coal from the Columbia and Geneva Mines is hauled by rail to Wellington, Utah, where it is sized and washed. It is then reloaded and hauled by rail to Provo, Utah, where it is coked in byproduct ovens.

Coal mining is normally a hazardous occupation, and mining in Utah is no exception. Fatalities in Utah coal mines historically are numerous, and several major disasters, defined by the U.S. Bureau of Mines as having five or more fatalities, have occurred. For example, the fatality rate per million man-hours of employment in Utah coal mines during 1941 was the highest in the United States (Adams and Geyer, 1944a, p. 6). Two hundred men were killed at Scofield, Utah, in 1900, and 171 men were killed at Castle Gate in 1924 in mine-gas explosions (Adams and Geyer, 1944b, p. 120). Over the years, many other miners were killed by numerous small explosions and by falls of faces or ribs, including bumps, in various Utah mines. Twenty-three miners died in a gas explosion in the Sunnyside No. 1 Mine in 1948 (Harrington and others, 1950, p. 28). We believe that geologic features and processes underlie many of the physical phenomena involved in such mine failures and that a knowledge of failure characteristics of mine rocks and coal beds can yield useful information to better understand and eventually control the violent release of energy in such disasters.

FIGURE 58.—Coke-oven operation at Sunnyside, about 1950. Coal was delivered to individual ovens by the track-mounted hopper car above, the coal was coked, then it was removed into a wheelbarrow by the oven operator and dumped into railroad cars. Ovens were individually closed and opened by operators using bricks and mortar. Photograph courtesy of W. R. Muehlberger.

FIGURE 57.—Unit-train loader of the Sunnyside mines, in lower Whitmore Canyon. The train backs through the tunnel, then pulls forward continuously so that about 80 cars of 125-ton (113,400-kg) capacity are loaded in an hour. Coal is loaded through trap doors in the tunnel beneath the coal pile. Bulldozer pushes coal up to crater at top of pile while loading. Coal pile and part of the tunnel are supported by artificial fill. View southeastward across Whitmore Canyon from a point above and north of Sunnyside. Photograph taken in 1968. Compare figures 45 and 56. Sandstones of Kenilworth and Sunnyside Members of Blackhawk Formation in cliff above leading locomotive. Ledges of Castlegate Sandstone are on slope above the coal pile.

COAL-MINE BUMPS

Bumps, which have been a major hazard to coal mining in the district, are the same physical phenomena as rock bursts which occur in many noncoal mines. They also are known by many other names, such as crumps, bounces, mountain shots, and pounces, but all these terms fundamentally refer to the same process—the sudden, sometimes catastrophic release of stress stored in the rock or coal. All such failures are referred to as bumps in this report, although miners in the district most commonly use the term "bounce." Our usage of the term "bump" (Osterwald, 1970, p. 2083–2084) follows the definitions of Holland and

Thomas (1954, p. 3), but varies from the usage of Obert and Duval (1967, p. 582), who restricted "bump" to the noise or shock wave resulting from a rock or coal failure (burst).

Mine faces that bump continuously during mining are common in the district. Clark (1928, p. 80), a pioneer geologist in the Book Cliffs Coal Field, noted that in 1911 "The unweathered coal is brittle and hard to pick and has a metallic ring when struck with the hammer. While mining is going on the working faces are continually snapping and splintering." Such small bumps actually are beneficial to some degree, because they make mining easier and reduce the need for blasting; however, they are hazardous because unwary personnel may be killed or injured by even small bumps. Modern room-and-pillar mining in the district is done by various types of continuous-mining machines. While these machines are being operated, small to moderately large pieces of coal are ejected continuously from many faces, accompanied by explosion-like reports as loud as those from a large-caliber rifle and by perceptible tremors in the floor. During these ejections, slabs of roof rock may fall onto the machines, ribs may become active and crumble, and floors may heave. Such activity continues at an apparently decreasing rate when mining is temporarily discontinued.

Many coal miners believe that they can foretell the probability of large bumps by the actual mining conditions at the face. Presumably, such bumps are more apt to occur when the coal becomes "hard to cut." Whether or not such a correlation actually exists is difficult to determine. Bumps may occur without such premonitory sensations, and "hard cutting" coal is not always followed by a bump.

SUNNYSIDE COAL BED

The Sunnyside coal bed varies in thickness from a few inches in the west near Kenilworth, Utah, to as much as 24 ft (7 m) in a single bed in parts of the Sunnyside district. The coal commonly splits into two beds, with as much as 75 ft (23 m) of rock intervening. Both seams are exploited where multilevel mining is practical. The Sunnyside coal bed has been mined extensively in the northern and central parts of the district, but most coal in the southern part of the district has not been exploited, and only a few prospect pits have been opened south of the Book Cliffs Mine (pl. 1).

Clark (1928, p. 2) named the Sunnyside coal bed for the Sunnyside Mine, where the bed was first worked. He distinguished the "Lower Sunnyside" and "Upper Sunnyside" beds and traced the "Lower Sunnyside" from a point between the canyons of Soldier Creek and Coal Creek (T. 13 S., R. 11 E.) to Horse Canyon (T. 16 S., R. 14 E.) (fig. 1). During our field investigations, we found that the Sunnyside bed also extends southward continuously along the Book Cliffs beyond the Price River into T. 16 S., R. 15 E. In compiling the following discussion, we have drawn freely upon the works of Brodsky (1960) and V. H. Johnson (written commun., 1951), as well as upon our own work.

The Sunnyside coal interval consists of locally thick coal accumulations interrupted at places by variably thick rock partings (fig. 59). Field studies have shown that no single parting persists throughout the lateral extent of the coal interval, and that most partings are open to the east and south. Data from drill cores indicate that partings are variable and of only local extent. It is therefore probable that peat accumulation never was simultaneously interrupted by inorganic sedimentation throughout the district, and consequently the "Upper" and "Lower" Sunnyside beds are not separate but are splits of the same bed (Brodsky, 1960; Maberry, 1971, p. 30).

The lower coal split of the Sunnyside bed is about 3 ft (1 m) thick in outcrops in the canyon of Soldier Creek, about 16 miles (25.5 km) northwest of Sunnyside, and it thickens eastward to as much as 24 ft (7 m) in the Sunnyside No. 2 Mine. The upper split is not as extensive as the lower, but is discontinuously present from Dugout Canyon (T. 14 S., R. 12 E.) to a point southeast of Whitmore Canyon. The stratigraphic interval between the upper and lower splits is variable due to local fluvial conditions in the swampy area in which the coal-forming material was deposited (Brodsky, 1960, p. 26; Maberry, 1971). During deposition of coal-forming materials, anastomosing streams flowed seaward across an area of low-lying coastal swamps and lagoons.

FIGURE 59.—Sunnyside coal bed, cropping out in the Book Cliffs in sec. 26, T. 16 S., R. 14 E. Lower coal split is shaly and bony; 3-ft (1-m) sandstone parting at level from man's waist to near his ankle; upper coal split is pure. Thick channel-fill sandstone directly overlies the coal at this locality. Photograph by V. H. Johnson.

The streams cut channels and filled and abandoned them, cutting new channels at the same time, in the same manner as streams in present-day deltas. The channel-fill sand bodies became interconnected and formed multilateral and multistory channel-fill deposits. These sand bodies, with some overbank deposits of silt and organic debris, and surges of sediment deposition locally interrupted peat concentration in the swamps.

Trace fossils indicative of marine to brackish-water environments are found in sandstone bodies that we interpret to be channel-fill deposits of tidal inlets and delta distributaries overlying the coal bed. Microscopic examination of the coal shows that it consists of fragments and leaves of small plants and grasses. Pieces of large plants in the Sunnyside coal are rare. Invertebrate shell fossils which we found slightly above the Sunnyside coal bed are the brackish-water forms (*Crassostrea, Anomia micronema* Meek, *Brachidontes,* and "*Corbula*"), according to W. A. Cobban (written commun., 1968). The main Sunnyside coal bed overlies a thick marine-transitional sandstone. These lines of evidence suggest that coal accumulated in a backwater swamp and lagoonal area near the shore of the Late Cretaceous sea.

Both open and closed partings occur in the coal. In open partings the coal beds join in one direction only; in closed partings the coal surrounds the rock. Closed partings may be lenticular pods of clastic sediment or they may be channel-fill deposits; open partings were formed by lateral migration of stream courses and by deposition of overbank deposits in a wedge of sediment.

Local thickness variations in the coal are due mostly to differential compaction and to channel-fill sandstone bodies that cut the coal from above to various depths. These sandstone bodies occupy relict stream channels, abandoned as the coastal plain prograded seaward.

In Utah only the Sunnyside coal is known to contain the qualities necessary for the production of metallurgical coke, and it is the most important source of coking coal in the Western United States (Averitt, 1966, p. G23). The Sunnyside coal produces a poor-quality, weak, granular coke owing to the lack of fusion between particles (Gray and Schapiro, 1966, p. 55). Consequently, the Sunnyside coal is blended with coking coal from other areas to improve the quality. The Sunnyside consists largely of attrital coal, although it contains some vitrain. The lack of fusion of the coke is due mostly to the low degree of metamorphism of these vitrain particles. The coal contains 68–69 percent vitrain particles, and the degree of their metamorphism during coalification determines the ability of the coal to form coke (Gray and Schapiro, 1966, p. 55).

Names for the rank of coal, such as lignite, bituminous, and anthracite, are relatively familiar to most geologists. Names for types of coal are less familiar, although the type of coal is a significant criterion for determining the depositional environment of the coal. Some confusion exists as to the meaning of certain terms regarding type of coal, however, because terms are variously defined in different classifications. For clarity, the terminology of coal and its petrographic features are briefly reviewed below.

The U.S. Bureau of Mines divides megascopic types of coal into (a) banded, consisting of "bright," semisplint, and splint coal, and (b) nonbanded, consisting of cannel and boghead coal and peat (Schopf, 1960, p. 28). Microscopically, coal consists of anthraxylon, attritus, and fusain (Parks and O'Donnell, 1956). Anthraxylon is derived from the woody tissues of plants, including both wood and bark, and forms the brilliant strips and lenses in coal. It appears in thin section as orange to red or brown bands and commonly shows well-preserved cell structure. Attritus is a mixture of minute particles of vegetable debris and contains, among other materials, spores, pollen, seeds, cuticles, and resinous bodies. Attritus appears megascopically as dull gray bands and streaks. Fusain is soft and lusterless, resembling charcoal. It contains a high percentage of carbon with little hydrogen and oxygen. In thin section fusain is opaque, having distinct cell walls and fibrous structure.

The terms vitrain, clarain, and durain are used in Europe for major coal types. Vitrain and clarain are closely analogous to "bright" and semisplint coal, and durain is similar to splint coal (Francis, 1954, p. 261).

"Bright" coal, splint, and semisplint types are found in Sunnyside beds. According to Raistrick and Marshall (1939, p. 195):

> There is little doubt that whereas clarain resulted from the accumulation of vegetable débris derived from generations of plants which grew *in situ*, and so gave rise to the coal peat, the durain layers have been formed during periods when the peat was inundated by water. Then, instead of normal peat formation, there would be produced a mud of the finest plant and mineral debris resulting from the accumulation of washed-in plant fragments and sediment, together with material derived from the coal peat. When the waters retreated, normal peat accumulation was resumed. This view as to the origin of durain is supported by the high proportion of sedimentary mineral matter which is characteristic of that type of coal.

Figure 60 shows a comparison of some megascopic features of the Sunnyside coal, including brilliant bands of clarain and vitrain ("bright") material and dull fusain.

Splint coal (durain) in the Sunnyside mines is random and discontinuous in the coal measures, and what

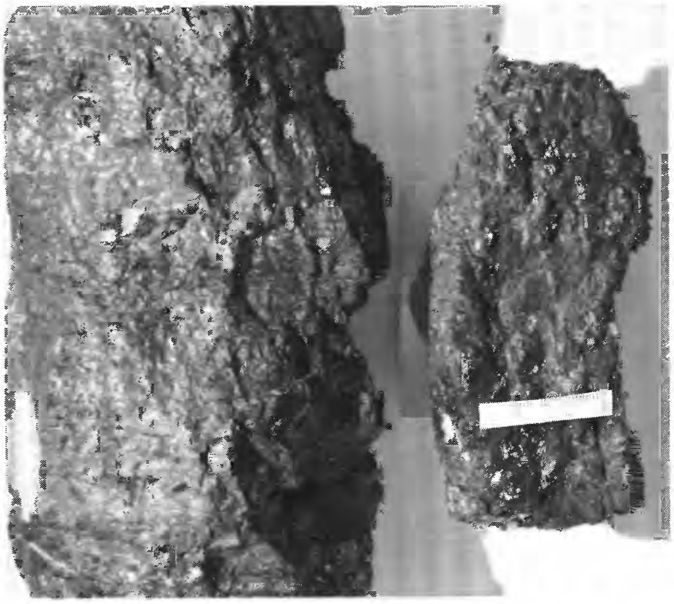


FIGURE 60.—Megascopic features of Sunnyside coal. Left piece is horizontally banded clarain and vitrain (brilliant bands) coal; it has a nearly vitreous luster. Right piece is "bright" coal on each end, with a band of fusain (dull) in the middle. Scale is in centimeters (1 in. equals 2.54 cm).

little there is probably formed as a result of fluviatile inundation, rather than by sea-level rise.

STRUCTURES IN THE COAL

Structures in the Sunnyside coal include banding and a particular type of cleavage known as "eye coal," as well as cleavage, joints, and fracture zones. Banding in coal is due to alternating layers of different texture or composition. In the Sunnyside coal, banding varies from microscopic size to layers several inches thick.

The origin of banding in coal is problematical. Some coal geologists believe that it has an environmental significance. White and Thiessen (1913, p. 29) attributed banding to changes in water level and to the influence exerted by bacterial solutions and oxygen content of the water on the rate of decomposition of plant debris. Davis (1946, p. 17) believed that banding was inherited from original differences in plant constituents. Lahiri (1951, p. 89–93) observed that banded structure is usually absent in low-rank coals such as cannel and lignite and concluded that banding is due to differentiation during compaction when constituents were separated on the basis of their chemical mobility and were segregated into bands. J. M. Shopf of the U.S. Geological Survey (oral commun., 1960), however, doubts that the cell structure could be preserved in the vitrain component if segregation during metamorphism had occurred. The variations in thickness and extent of individual bands in the coal in the Sunnyside mines point to the conclusion that banding in the Sunnyside coal is due to original differences in composition and in plant types that accumulated in the swamp during deposition.

Eye coal derives its name from numerous smooth and shining, crudely equidimensional to elongate spots on nearly parallel cleavage planes (fig. 61). The size of individual eyes in the Sunnyside coal ranges from 1 in. (2.5 cm) to more than 6 in. (15 cm) in diameter. The eyes have no third dimension.

The origin of eye-coal cleavage is not well understood. Stutzer (1940, p. 253) stated that it is the same as slaty fracture in rocks, which is produced in a direction normal to the direction of pressure. It is possible also that eye coal may originate with shrinkage during coalification. Eye-coal cleavages were mapped in the Sunnyside No. 1 Mine (Osterwald, 1961, p. C349) and at coal outcrops (Osterwald, 1962a).

Small structural features, including cleavages and vertical shatter zones, in the Sunnyside coal bed, similar to those described in underground workings of the Sunnyside No. 1 Mine (Osterwald, 1962b), were measured at the outcrop to determine the relationships between these features and the joint and fault patterns. Cleavages, which commonly were the best defined of these small structural features, were mapped at many coal outcrops (pl. 2; Osterwald, 1962a; Osterwald and others, 1969). We were also able to map nearly vertical

FIGURE 61.—Eye coal from the Sunnyside No. 1 Mine. Eye spots are smooth, and many are highly reflective. The eyes occur on cleavage planes in the coal. Scale is in centimeters (1 in. equals 2.54 cm).

shatter zones, which probably are important in the occurrence of bumps in underground coal mines (Osterwald and Brodsky, 1960) at a few localities. In general, where we could map cleavages at the outcrop, they were nearly parallel to northwest- and east-northeast-trending joints in nearby sandstone ledges, indicating that the cleavages were formed by the same stress system that caused jointing. The shatter zones also are nearly parallel to these same joint sets.

ANALYSIS OF THE COAL

Generally, the Sunnyside coal is high in volatiles and fixed carbon, low in sulfur and other impurities, and has a good heating value (tables 1, 2). Coke from the Sunnyside coal is high in fixed carbon, has low ash and very low sulfur contents, and has a relatively high heating value (table 3). Coke made from the Sunnyside coal yields about two-thirds its weight in furnace-size coke pieces, and these contain many lateral and transverse fractures (Averitt, 1966, p. G24). When the coal is blended with higher rank coals and coked at a fast rate of heating, the fusion of the coke is improved and the yield is metallurgical-grade coke (Gray and Schapiro, 1966, p. 71).

RESERVE ESTIMATES

Clark (1928, p. 100–103) estimated that the Sunnyside coal bed contained 1,811 million short tons (1.643×10^{12} kg) of coal in the Sunnyside Quadrangle. His estimate was based on the assumption that a coal bed extends laterally under overburden for approximately the same distance that it extends along the outcrop, that it will have an average thickness the same as at the outcrop, and that it thins at the same rate under overburden as it thins along the outcrop. V. H. Johnson (written commun., 1951) estimated reserves of the Sunnyside bed in the Woodside Quadrangle to be about 410 million short tons (3.7×10^{11} kg) in beds more than 14 in. (36 cm) thick under less than 3,000 ft (900 m) of overburden. Johnson's estimate was based on zones of relative confidence of thickness and extent of coal beds. Of his 410-million-ton (3.7×10^{11}-kg) figure, Johnson estimated 391 million tons (3.55×10^{11} kg) in the category of measured reserves (80-percent confidence), 15 million tons (1.4×10^{10} kg) in indicated reserves (about 50-percent confidence), and 5 million tons (4.5×10^{9} kg) of inferred reserves (about 25-percent confidence). Kaiser Steel Corp. in 1965–66 drilled exploratory holes in the Sunnyside Quadrangle on land that was completely unexplored for coal in Clark's time, and cores recovered by that drilling program show that Clark's concepts were approximately correct.

Although a comprehensive drilling program would be necessary to prove coal reserves in the southern part of the district, Johnson's estimate seems to be realistic because of the continuity and regular thickness variations of the coal bed. The main seam of the Sunnyside coal bed, for example, is about 15 ft (4.5 m) thick in the southernmost part of the Geneva Mine (sec. 24, T. 16 S., R. 14 E.) and is about 17 ft (5 m) thick directly updip at the outcrop, more than a mile (1.6 km) away.

TABLE 1.—*Ultimate and proximate analyses of nine samples of Sunnyside coal*
[Modified from Clark, 1928, p. 83–86]

	Condition of coal	
	Run-of-mine (percent)	Dry (percent)
Moisture	4.1–9.0	2.4–5.1
Volatiles	31.8–39.9	33.2–40.8
Fixed carbon	47.7–52.7	48.7–54.3
Ash	4.7–8.2	4.9–8.5
Sulfur	.46–1.73	.47–1.79
Hydrogen	5.0–5.7	4.7–5.6
Carbon	62.2–71.9	64.9–73.8
Nitrogen	1.25–1.6	1.3–1.6
Oxygen	11.8–22.9	10.8–20.1
BTU	10,860–13,030	11,330–13,420

TABLE 2.—*Proximate analyses (in percent) of ranges of five samples of Sunnyside coal from the Sunnyside No. 1 Mine, and average of two samples of Sunnyside coal from the Columbia Mine*
[R. F. Abernethy, U.S. Bureau of Mines, analyst (1958). Leaders (---), not applicable]

	Moisture	Volatile matter	Fixed carbon	Ash
Sunnyside No. 1 Mine				
As received	1.8–2.2	36.4–40.1	55.7–58.4	2.1–4.9
Moisture free	---	37.4–40.9	56.8–59.7	2.3–5.0
Moisture and ash free	---	38.4–41.8	58.2–61.6	---
Columbia Mine				
As received	2.25	40.5	59.2	7.6
Moisture free	---	41.7	50.6	7.7
Moisture and ash free	---	45.3	54.7	---

TABLE 3.—*Averages of 20 proximate analyses of coke samples made from Sunnyside coal, Sunnyside and Columbia Mines*
[From Reynolds and others, 1946, p. 45]

	Number of samples	Data
True specific gravity	6	1.90
BTU	20	12,946
Volatiles	20	[1]1.84
Fixed carbon	20	[1]88.33
Ash	20	[1]9.83
Sulfur	20	[1].82

[1]In percent.

GYPSUM

A nearly horizontal bed of apparently pure gypsum crops out over large areas in the southwestern part of the district and in adjacent areas to the south and east. The gypsum, which is at least 10 ft (3 m) thick, is near the base of the upper part of the Carmel Formation. The gypsum bed is irregular, having large pinches and swells, probably as a result of differential hydration of anhydrite. The gypsum, cropping out in an area of gently rolling topography dissected by numerous small gulleys, weathers to a distinctive reticulate pattern in the soil as a result of minor differential leaching. Local ponding of surface-water runoff in small basins produces locally derived gypsum-rich silty and clayey soils (gypsite), which weather to similarly patterned surfaces.

Several small prospect pits were opened in the gypsum in SE¼, T. 18 S., R. 13 E. (unsurveyed), about 2 miles (3 km) south of the southwest corner of plate 1. Although a few tons apparently were removed, probably for testing, no gypsum was commercially produced. The deposit is about 15 miles (24 km) from the nearest railroad by a rough unimproved road.

Gypsum also occurs at the top of the Summerville Formation and locally is as much as 50 ft (15 m) thick (V. H. Johnson, written commun., 1951). Our field investigations showed that this gypsum is more silty than that in the Carmel, and it crops out mostly along steep canyon walls. Other thin beds, lenses, and veins of impure gypsum are common throughout the Summerville (fig. 7). No prospect pits or other exploration works for gypsum in the Summerville are known in the district.

WATER

Potable water, from surface and underground sources, is a scarce and valuable commodity in the Sunnyside district. The only permanent streams in the district containing water suitable for human consumption are Range Creek and Grassy Trail Creek. Domestic and boiler water for the town of Sunnyside and for electric power in the mines formerly was obtained from Range Creek by an elaborate pumping and pipeline system that raised the water about 1,400 ft (430 m) to the crest of Patmos Mountain, then dropped it about 2,600 ft (800 m) to Sunnyside (Clark, 1922, p. 212). This system was replaced in 1952 by a dam and reservoir in the upper part of Whitmore Canyon on Grassy Trail Creek, although the Range Creek pumps and diversion ponds were left in place and ruins of the pipe over the mountain remain as a standby system. Water from Price River is unfit for human consumption but is used as stock water and for irrigation water at Silvagni Ranch. During 1977 some water pumped from the Sunnyside No. 3 Mine was used to supplement domestic supplies. The only other sources of potable water in the district are small springs near the base of sandstones in the Colton and Green River Formations and in limestone beds in the North Horn and Flagstaff Formations. Several large springs issue from the bases of alluvial fans near Horse Canyon and Whitmore Canyon. A few wells in surficial material contain potable water, mostly near Grassy Trail Creek.

The alluvial-fan sand, silt, and gravel at the mouth of Whitmore Canyon is one of the most valuable sources of water in the region. Springs issue from the base of the alluvial fan or from the base of the pediment gravel beneath it at several places along the southern and western margins of the fan. Whitmore Spring (informally named), the source of Icelander Creek, half a mile (0.8 km) south of Dragerton, formerly was used as a source of industrial water. Other springs along the perimeter of the fan, such as Big Spring (informally named), about 4.3 miles (7 km) southwest of Dragerton (pl. 1), as well as shallow wells within the fan, are important sources of domestic, irrigation, and livestock water for various ranches. Water from Big Spring formerly was piped about 10 miles (16 km) to Cedar for use in railroad-locomotive boilers. The springs probably are supplied by flow within the fan, which is recharged from Grassy Trail Creek and from underground flow within the alluvial sand and silt of Whitmore Canyon.

Coon Spring, at the southwestern edge of the alluvial fan at the mouth of Horse Canyon, about 1 mile (1.6 km) southeast of Cedar (pl. 1), is a valuable source of stock water. A few other small springs derived from underground flow within the Horse Canyon fan are also usable as sources of stock water. Water from all other springs within the lowland area west of the Book Cliffs contains large amounts of gypsum and alkali salts (V. H. Johnson, written commun., 1951).

Water pollution is a serious problem in much of the Sunnyside district. Streams and springs in the Colton and Green River Formations generally are pure, except where locally polluted by livestock, and also are free from high concentrations of dissolved salts. Streams crossing the Mesaverde Group and older rocks, however, rapidly acquire high concentrations of sulfates and alkali salts. Industrial operations also contribute large amounts of pollutants to Grassy Trail Creek, Icelander Creek, and to the intermittent stream in Horse Canyon. Although much wash water from the coal preparation plant at Sunnyside is recycled, as is much mine water pumped from the Sunnyside No. 3 Mine, large amounts go to the Sunnyside Mine dump (pl. 1), where additional organic and chemical pollutants are acquired that eventually flow into Icelander Creek.

Other water from the Sunnyside mines that contains much dissolved iron, as well as salts, is used for irrigation in the town of Sunnyside.

Ground water in the alluvial fan at the mouth of Whitmore Canyon, which is a valuable source of domestic, livestock, and irrigation water, probably is prone to industrial, commercial, and domestic pollution. Most of the town of Sunnyside, as well as Dragerton and various outlying business establishments, is on the fan. Surface water bearing waste from these localities percolates easily into the alluvial fan and into the alluvium along Grassy Trail Creek which is entrenched into it. The Sunnyside sewage-treatment plant also is on the fan; effluent from the plant is used to irrigate a golf course on the fan. Water percolating downward into the basal part of the fan from these varied operations probably mingles with the natural underground flow and eventually could contaminate springs along the fan margin.

PETROLEUM-SERIES COMPOUNDS

Deposits and occurrences of solid, liquid, and gaseous compounds belonging to the petroleum series are widely distributed in the Sunnyside district. None of these deposits and occurrences are of commercial value at the present time, but asphalt-impregnated sandstone was quarried from the northeastern part of the district for many years, and small quantities of oil are produced from the Grassy Trail field in the eastern part of T. 15 S., R. 13 E., about 8 miles (13 km) west-southwest of Dragerton (fig. 1). The variety and wide distribution of such compounds in the district have stimulated much exploration and several attempts at commercial extraction in the district.

ASPHALT-IMPREGNATED SANDSTONE

Several layers and lenses of asphalt-impregnated (or bituminous) sandstone in the upper part of the Colton Formation and in the lower part of the Green River Formation are known to crop out on steep west-facing cliffs (pl. 1). Asphaltic sandstones crop out near the crest of Patmos Mountain from the head of Pasture Canyon to the head of the left fork of Whitmore Canyon, a horizontal distance of about 12 miles (19 km) and in a vertical stratigraphic interval of about 1,000 ft (300 m); they probably extend much farther south and west (Holmes and others, 1948, fig. 2). The thickest deposits and the largest number of asphaltic layers, however, are on the south and west faces of Bruin Point (Holmes and others, 1948, figs. 1, 2), about 6 miles (10 km) northeast of Sunnyside.

Bituminous material partly fills pore spaces in the asphaltic sandstone and amounts to as much as 13 percent by weight of the rock. Sandstone containing considerable amounts of asphaltic material is black when freshly broken but weathers to a characteristic medium gray. This weathering, however, extends only a fraction of an inch into the rock (Holmes and others, 1948). Richly impregnated sandstones, when exposed to hot summer sun, exude asphalt which can be ignited with a match and burns with a smoky orange flame. Asphaltic sandstone is resistant to erosion; it forms steep cliffs and commonly contributes boulders of richly impregnated sandstone to the alluvium along Grassy Trail Creek in Whitmore Canyon. We found a few of these boulders in pre-Wisconsin pediment gravels several miles from the mouth of Whitmore Canyon.

The asphaltic sandstones near Bruin Point were quarried intermittently from 1892 to about 1950. Total production was estimated to be about 335,000 tons (3.04×10^8 kg) until 1948, nearly all of which was used for paving material (Holmes and others, 1948). All shipments contained more than 9 percent asphalt. The deposits were estimated to contain 1,600,000 cubic yards (yd^3) or 1.2×10^6 cubic meters (m^3), of which 900,000 yd^3 (6.9×10^5 m^3) was measured or indicated reserves, and 700,000,000 yd^3 (5.4×10^8 m^3) was inferred (Holmes and others, 1948). About half of the total reserves was estimated to contain more than 9 percent asphalt.

Much of the asphaltic sandstone produced from the quarries on the south face of Bruin Point was transported to the county road in Whitmore Canyon by a spectacular aerial tramway about 3 miles (5 km) long having a vertical drop of about 1,750 ft (530 m). The material was transferred to trucks at the lower end of the tramway and hauled to a railroad loading facility near Sunnyside.

Several attempts were made by oil companies to mobilize the asphalt sandstone in place by injecting hot water or steam into long drill holes so that it could be pumped up other drill holes. At the time of our last examination in 1969, small quantities of asphalt were extracted, but the process apparently had not proved to be commercially feasible.

OIL

Several small shows of oil are known in the Sunnyside district. Several feet of oil-saturated sandstone core was obtained in 1959 from an exploratory hole drilled for coal in Pasture Canyon (pls. 1, 2), probably from a sandstone-filled channel in the Blackhawk Formation above the Sunnyside coal seam (J. T. Taylor, oral commun., 1961). Oil began to seep into a mine opening from a channel-fill sandstone in the roof in 1964 during development work in the Sunnyside No. 3

Mine (Maberry, 1971, p. 40–41). Although the seeping has long since stopped, enough oil oozed into mine workings to alert mining personnel to possible commercial exploitation. The oil probably was derived from organisms that inhabited the coal-forming marshes or swamps or from the carbonaceous sediments that surround the coal seam and probably migrated as discrete particles into the porous channel sands above the coal after deep burial (Maberry, 1971, p. 40). Compaction of silts, clays, and muds adjacent to the sand-filled channels probably was greater than that of the stratigraphic intervals containing the channels, hence the more porous sandstones became reservoirs into which the oil could move after being expelled from adjacent finer grained sediments.

Although the possibility of finding commercial quantities of oil in the Blackhawk Formation at Sunnyside probably is small, any future shallow exploration should be concentrated on sandstone-filled channel systems above the coal, especially where such sandstones pinch out into less permeable mudstones (Maberry, 1971, p. 40). The oil in the Sunnyside No. 3 Mine is not an isolated occurrence; similar incidents have occurred elsewhere in the Book Cliffs Coal Field. One such locality in the Castlegate Mine north of Helper, Utah (fig. 1), leaked enough oil to make movement of haulage locomotives difficult (D. J. Varnes, oral commun., 1959).

NATURAL GAS

Methane is common in coal mines throughout the world, mostly as a result of gas exsolved from organic molecules in the coal. Concentrations of methane constitute a major explosion hazard to coal mining, and extensive ventilation systems are necessary to reduce concentrations in mine atmospheres to safe levels. Early miners in the Sunnyside mines noticed that considerable gas was evolved from the coal during mining (Taff, 1906, p. 295). Although average methane content in the Sunnyside mines is now kept to 0.5 percent or less, local concentrations do occur that are above this level.

Additional methane is added to the atmosphere in the Sunnyside mines from sandstones in the roof and floor. We observed methane bubbling upward through a pool of water at the bottom of the exhaust air shaft for the Sunnyside No. 1 Mine, in Whitmore Canyon, apparently coming from the thick sandstones of the Sunnyside Member below the Sunnyside coal bed. Large amounts of methane flowed into the Sunnyside No. 3 Mine in 1966. These inflows, resembling smoke because of the different indices of refraction of air and methane, were easily visible with miners' cap lights. According to miners, the gas came from a sandstone-filled channel above the coal, and was in sufficient quantity to cause evacuation of the mine (John Peperakis, oral commun., 1966). The large inflows ceased after a few weeks when the supply of methane in the channel was exhausted.

URANIUM

Much of the district, particularly the western part, has been extensively prospected for uranium since 1943 (Johnson, 1959, p. 50). Most of this prospecting was done during the 1950's, but hundreds of additional claims were staked during a minor "rush" in 1968. During the earlier prospecting period, as many as a few thousand claims for uranium were staked and many miles of access roads built in the western part of the Sunnyside district and in adjacent areas, probably because the outcrop belt of sandstones of the Salt Wash Member of the Morrison Formation crosses the district around the margin of the San Rafael Swell (fig. 1, pl. 1). The Salt Wash and other members of the Morrison Formation are favorable host rocks for uranium deposits throughout much of the Colorado Plateau (for example, Finch, 1967, p. 39). Many of the claims probably were staked because of locally increased radioactivity or because small amounts of secondary uranium minerals were found on outcrops. None of the claims we examined contained any visible uranium minerals, although we made no attempt to examine all the claims.

Less than 100 tons (9×10^4 kg) of ore apparently was shipped from the Rock Island group of claims north of the Price River, about 0.75 mile (1.2 km) upstream from its junction with Grassy Trail Creek (pl. 1), near the center of sec. 8, T. 17 S., R. 13 E., before June 1955 (Johnson, 1959, p. 51). This group of 13 claims was staked on several sandstone-filled channels in the Brushy Basin Member of the Morrison Formation, about 1,000 ft (300 m) north of a prominent east-trending fault that dips steeply north. At the time of our examination in May 1971, radioactivity equal to about twice normal background was measured on a lens of iron-stained clay about 1 ft (0.3 m) thick and 15 ft (4.5 m) long, but no other radioactivity or visible uranium minerals could be found.

Renewed prospecting for uranium in 1968 resulted in exploration for possible deposits in sandstone-filled paleostream channels in the Salt Wash, where they were thought to curve northward and northwestward around the north end of the San Rafael Swell (James Osburn, oral commun., 1968). This exploration also was stimulated by the fact that the Salt Wash is only 5 ft (1.5 m) thick on the west side of the swell (Gilluly, 1929, p. 111) but is as much as 200 ft (60 m) thick on the east side. Johnson (1959, p. 35-36, 50), however, indicated that thick channel systems in the Salt Wash trend northwest, across the axis of the swell. Many of the claims staked during this exploration period were located on outcrops of Mancos Shale or on Quaternary units, in the hope that economic deposits could be found at shallow depths by drilling. Many holes were drilled along the flank of the swell northwest from the vicinity of Coon Spring to beyond the boundary of plate 1. No development work followed the drilling; hence we assume that the drilling was unsuccessful.

METALLIC MINERALS

We saw a few occurrences of metallic minerals in the district. Coarse-grained siltstones in the lower part of the Colton Formation northwest of the mouth of Bear Canyon (sec. 20, T. 14 N., R. 14 E.) contain small clots and veinlets of pyrite and a few scattered grains of a light-colored gray sulfide mineral. Field tests with HCl suggest that the light-colored mineral contains copper. The siltstone is moderate brownish gray in color, tightly cemented, and contains veinlets of calcite.

A semiquantitative spectrographic analysis by J. C. Hamilton of the U.S. Geological Survey of green mudstone from the Colton Formation near the summit of the Horse Canyon-Range Creek road (pl. 1) indicated that the rock contained 0.015 percent copper.[1] The copper content of other mudstones from the Colorado Plateau ranges from 0.002 to 0.0051 percent (Newman, 1962, p. 418-426, tables 33, 34), suggesting that the Colton mudstone contains more copper than many similar rocks in the region.

We found small amounts of sulfide minerals along a large fault about 1 mile (1.6 km) northwest of Cedar. Near the eastern end of the exposed trace of the fault, a shaft, now caved, was sunk in a light-tan conglomeratic sandstone bed, probably part of the Dakota Sandstone. The shaft is about 20 ft (6 m) deep and has only a small dump. Conglomeratic sandstone in the upthrown block of the fault is brecciated and silicified, is weakly impregnated with iron oxides and pyrite, and contains scattered grains of chalcopyrite, galena, and unidentified dark metallic minerals. About three-quarters of a mile (1.2 km) west of Cottonwood Creek, conglomerates and sandstones of the Buckhorn Conglomerate Member in the upthrown block of the same fault are in contact with the Brushy Basin Member of the Morrison Formation to the south, where a small prospect pit was sunk along the fault in sandstone of the Buckhorn. Near the fault, the sandstone is bleached white, locally stained with iron oxides, and brecciated. Black metallic mineral grains are scattered in the matrix of the rock and along small fractures.

[1]This value indicates only that the copper content was within a range of values. Such semiquantitative results are reported in percent to the nearest number in series such as 1, 0.7, 0.5, 0.3, 0.2, 0.15, 0.1, which represent approximate midpoints of group data on a geometric scale. The assigned groups for semiquantitative results include the quantitative value about 30 percent of the time.

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