UNITED STATES DEPARTMENT OF THE INTERIOR
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Incomplete manuscript on stratigraphy and structural geology and uranium-vanadium and copper deposits of the Lisbon Valley area, Utah-Colorado

By

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This report is preliminary and has not been edited or reviewed for conformity with U.S. Geological Survey standards.

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INTRODUCTION

LOCATION AND EXTENT OF AREA

The Lisbon Valley area includes about 720 square miles lying mainly in northeastern San Juan County, Utah; a small strip on the eastern edge of the area lies in Montrose and San Miguel Counties, Colorado (fig. 1).

GEOGRAPHY

The geography of large parts of the Lisbon Valley area has been described in detail by Baker (1933), C. B. Hunt (1958), Richmond (1962) and Sumsion (1971). Gregory (1938), Tanner (1937) and A. P. Hunt (1953, 1956, 1960) have written engaging accounts of the aboriginal occupance and early exploration and settlement of the area. To these reports the interested reader is referred, for only an outline of the geography of the Lisbon Valley area will be given here.

Most of the area is a desert that consists of rock plateaus studded with mesas and trenched by narrow canyons. The plateaus generally lie near two elevations--about 6,000 and 7,000 feet. The higher plateaus, exemplified along the southern border of the area by Peters Point and other projections of the northern edge of the Sage Plain, is mostly covered by sagebrush, juniper and pinyon. The lower plateaus, exemplified by Dry Valley, are sparsely covered by desert grasses and sagebrush. The pinyon and juniper woodlands of the higher plateaus grade into scrub oak and aspen and yellow pine forests above 8,000 feet on the slopes of the La Sal Mountains along the northeastern edge of the area.

Total relief in the Lisbon Valley area is almost 8,000 feet. The low point is in Kane Springs Canyon (4,600 feet); the summit of Mount Tukuhnikivatz (12,483 feet) is the high point. More than 90 percent of the Lisbon Valley area, however, lies between 5,500 and 7,500 feet. The only large area below this interval is the floor of Spanish Valley; the La Sal Mountains include all the higher elevations.

The semiarid climate of the Lisbon Valley area is characterized by large daily and yearly ranges in temperature and a total annual precipitation of about 10 to 15 inches, mostly as sporadic, intense thundershowers. Snow is infrequent at altitudes below 6,500 feet and usually melts in a few days. The La Sal Mountains have a generally cooler and moister climate than the rest of the area, and near the summits snow commonly persists from November through April.

The only sizable perennial streams in the Lisbon Valley area are the South Fork of Mill Creek and Pack Creek near the north boundary. Cane Creek, East Coyote Creek, and West Coyote Creek and some of their smaller tributaries are in part perennial and in part intermittent. Dry washes, however, are the characteristic "streams" of the area. Insignificant appearing gullies may be converted for a few hours into impassable torrents by a single rainstorm.

The Lisbon Valley area is thinly populated. At the time of mapping, only a few hundred people resided in the area, mostly in semi-permanent trailer houses and shelters near active mines. The largest settlement is the town of

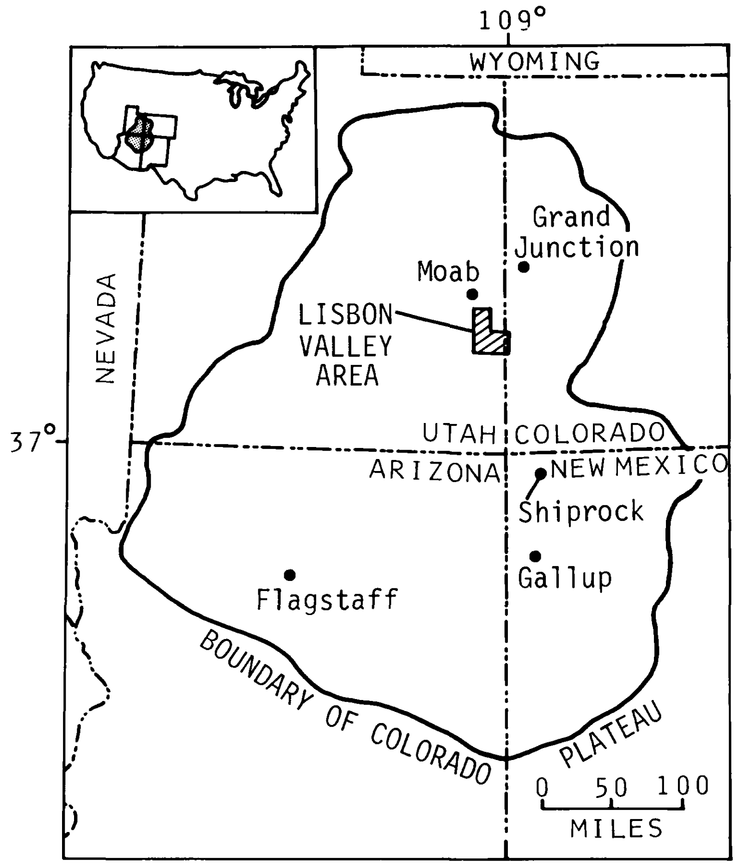


Figure 1.--Index map showing the Colorado Plateau and and the location of the Lisbon Valley area, Utah-Colorado, U.S.A.

La Sal on the east edge of the area. Many workers in the area make their homes in the nearby towns of Moab (population, 1960 census: 4,682) and Monticello (population 1960 census: 1,845). Most of the workers are engaged in uranium mining, oil exploration, and stock raising.

U. S. Highway 160 passes through the western part of the area and connects Moab and Monticello, the chief supply points. Utah Highway 46 in the northern half of the area connects La Sal with the main highway. Several improved roads in the central part of the area lead to the principal uranium mines and oil wells. Dirt roads and trails are numerous, and only parts of the La Sal Mountains and some deep canyons are relatively inaccessible.

Both Moab and Monticello have airports, and landing strips for light airplanes have been built near some mines and ranches in the area. Moab, 6 miles north of the area, is the nearest rail point.

PURPOSE AND SCOPE OF WORK

Field study of the Lisbon Valley area was undertaken by the U.S. Geological Survey on behalf of the Raw Materials Division of the U.S. Atomic Energy Commission to obtain geologic data that would aid the search for uranium. These data are also useful in the appraisal of other mineral resources.

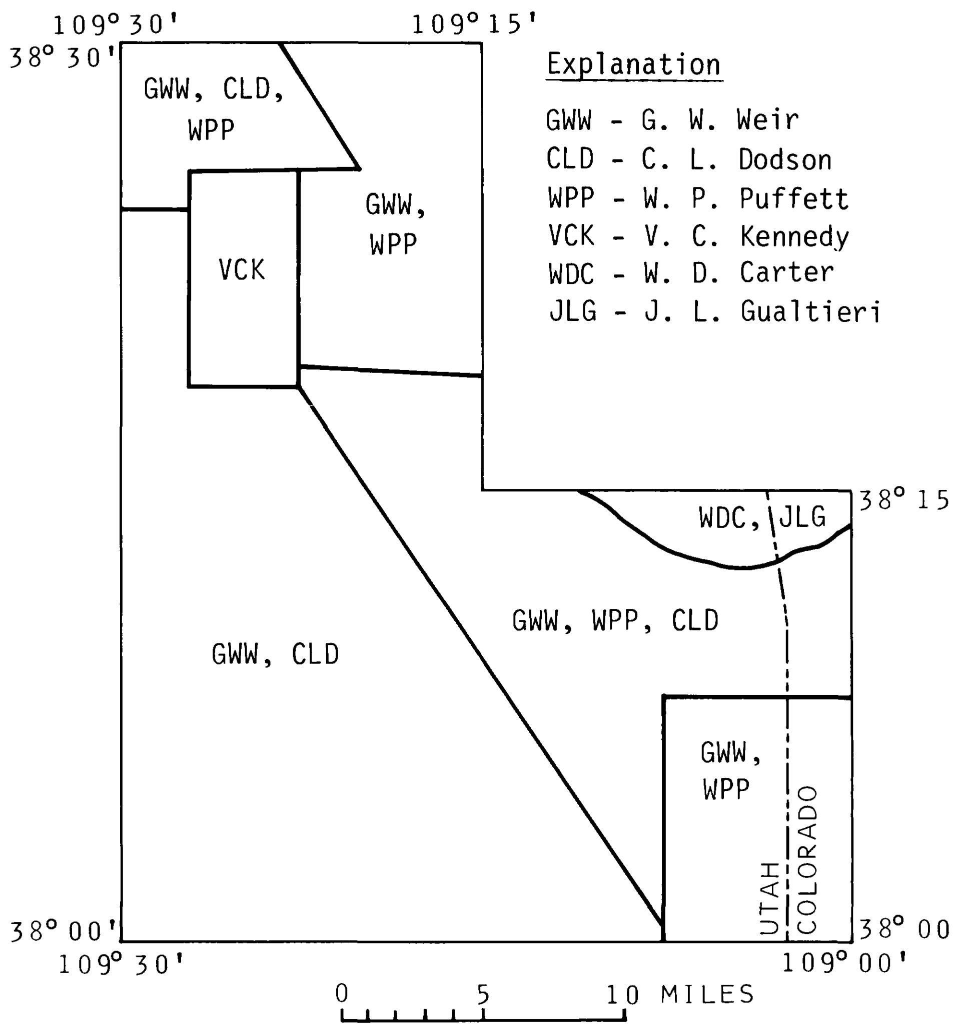
The Lisbon Valley area was long known to contain deposits of uranium and vanadium minerals, and since 1952 it has become a major uranium producing area. Successful test wells for potash were completed in 1958 and 1959, and in early 1960 oil and gas were first produced in this area. Copper, manganese, and coal have been mined on a small scale in the past.

This report describes the rocks, structure, and mineral deposits of the Lisbon Valley area. The uranium deposits--their distribution, habits, and possible origin--are discussed in detail.

FIELD WORK

Geologic mapping of the Lisbon Valley area began in the spring of 1954 and was completed in the summer of 1959. The mapping was done by G. W. Weir, W. P. Puffett, C. L. Dodson, and V. C. Kennedy assisted for short periods by A. R. Conroy, L. F. Emmett, I. G. Hendrickson, W. L. Newman, J. R. Shappirio, and W. E. Sharp. Figure 2 shows in a general way the areas of chief responsibility and when the work was done. The area north of East Coyote Creek was mapped by W. D. Carter, J. L. Gualtieri, J. C. Warman, and W. R. Barton as part of a geologic study of the La Sal Creek area (Carter and Gualtieri, 1965).

Mineral deposits were examined in a reconnaissance by Weir in 1953 and during the course of the geologic mapping by the above-mentioned geologists. Most mapping of active mines was done in the summer of 1956 and 1957 by Weir, Dodson, Puffett, Theodore Botinelly, and R. P. Fischer assisted by Conroy and P. L. Williams. Botinelly also studied the mineralogy of the uranium deposits in Triassic rocks. Kennedy (1962) made a geochemical study of the mineral deposits in the area. Developments of oil, gas, and potash were mostly later than our field work in the area; we have drawn on published reports for a brief description of these deposits.



~~Figure 2.--Outline map of the Lisbon Valley area, Utah-Colorado~~ showing areas of chief responsibility for geologic mapping.

ACKNOWLEDGMENTS

First, we should like to express our appreciation to our co-workers in the field whose names are listed in the preceding paragraphs. Our colleagues on the U.S. Geological Survey who were working on similar or related problems have contributed many ideas that have stimulated our thinking. We are particularly indebted to the geologists who studied nearby areas: W. D. Carter, J. L. Gualtieri, E. N. Hinrichs, L. C. Huff, R. Q. Lewis, D. R. Shawe, and I. J. Witkind. Counsel on stratigraphic problems was also given by L. C. Craig, J. H. Stewart, and J. C. Wright.

Geologists of the Grand Junction, Coloado, Operations Office of the Raw Materials Division of the Atomic Energy Commission supplied much critical data on the uranium-vanadium deposits in the area. We especially thank M. A. Lekas, N. E. Salo, H. M. Dahl, Y. W. Isachsen, and Karl Ruhe.

We acknowledge with pleasure the generous cooperation of the many property owners and mining men in the area. Special thanks are due to W. B. Loring of the Hidden Splendor Mining Co. and J. D. Bell of the Hecla Mining Co. for informative discussions on the geology of the northwestern part of the Big Indian mining district.

PREVIOUS WORK

The main geologic features of the Lisbon Valley area have been long known from reconnaissance studies of the region and detailed studies of adjacent areas.

J. S. Newberry (1876, p. 90-93), the geologist of the Macomb expedition to the junction of the Green and Colorado Rivers in 1859, was the first to describe part of the Lisbon Valley area. The expedition descended from the Sage Plain near the head of East Canyon and proceeded northwesterly through the canyon to near Casa Colorado rock and then, leaving the area, turned westerly to the canyon of Indian Creek and the Colorado River. Newberry described the topography and rocks along the route and noted the presence of igneous rocks in the La Sal Mountains.

Reconnaissance by the U.S. Geological and Geographical Survey of the Territories (the Hayden Survey) led to publication of a generalized geologic map of Colorado and part of Utah, including the Lisbon Valley area (Hayden, 1877, pls. 4 and 14; 1878). Peale (1877), a geologist of the Hayden Survey, described the geology of the La Sal Mountains in the northeast part of the Lisbon Valley area, but attack by Indians prevented reconnaissance to the south.

Cross (1907) traversed the Lisbon Valley area in a stratigraphic reconnaissance of Colorado and Utah; he correlated the Plateau rocks with the section then known in the San Juan Mountains. Later studies by Gilluly and Reeside (1928), and Baker and others (1927, 1933, 1936) established much of the current nomenclature of the formations in this region.

Butler and others (1920, p. 614-615, pl. 4) described some copper deposits along the Lisbon Valley fault and showed the general character of the area on a small-scale geologic map of Utah. The Colorado part of the Lisbon

Valley area was mapped by Coffin (1921) as part of the radium-, uranium-, and vanadium-producing region of southwestern Colorado. Gould (1927) published a small-scale map of the La Sal Mountains and described the laccolithic intrusions.

The search for oil in the Colorado Plateau resulted in publication of many papers dealing with the stratigraphy, structural geology, and oil possibilities of southeastern Utah in the late 1920's. Most of these papers are cited by Baker (1933, p. 11) in his detailed report on the geology and oil possibilities of the Moab district, Utah, which includes the western part of the Lisbon Valley area.

During World War II reconnaissance geologic maps of parts of the Lisbon Valley area were made by geologists for the Manhattan District to help appraise the carnotite deposits (Kirkpatrick, R. K., Union Mines Development Corp., written commun., 1944, 1945, and Wardwell, H. R., Union Mines Development Corp., written commun., 1946). R. D. Sample, H. H. Sullwold, Jr., and E. E. Gould (U.S. Geological Survey, written commun., 1943) made a reconnaissance map of the Lisbon Valley anticline as part of a study of the copper deposits in the area. This unpublished map was incorporated in regional maps compiled by Fischer (1944) and by Andrews and Hunt, C.B., (1948). Photogeologic maps of most of the Lisbon Valley area and the adjoining La Sal, Utah-Colorado area were open-filed in 1952-53 and in part published in 1956-57 (Hackman, 1952, 1956a-f; Hackman and Tolbert, 1956; Tolbert, 1952, 1957a-c). The bedrock geology of the La Sal Mountains was studied by Hunt, C. B., (1958); the surficial deposits, by Richmond (1962).

The generalized geologic map of the present report (fig. 3) was compiled from preliminary 1:24,000 scale geologic quadrangle maps, whose locations are shown in figure 4. The geologic setting of the Lisbon Valley area is well shown on the Moab 2° quadrangle (Williams, P. L., 1964). Steen and others (1956), Dix (1953a) and Lekas and Dahl (1956) were among the first to describe the large uranium deposits in Upper Triassic rocks. Other significant papers concerned with the general geology and mineral deposits of the Lisbon Valley area are cited under specific topics of this report.

STRATIGRAPHY

CONCEALED ROCKS

Beneath the upper member of the Hermosa Formation of Pennsylvanian age is buried a thick sequence of Paleozoic formations resting on the Precambrian basement. This sequence is known chiefly from widely spread drill holes, for with few exceptions, it does not crop out on the Colorado Plateau. The following sketch of the character of the buried rocks is based mainly on data published before 1960; however, the stratigraphy has been updated so that it is current as of December 1977. The buried formations are of importance because they contain host rocks for oil, gas, and potash, and because some units strongly influenced the development of the geologic structure of the area.

Precambrian rocks

A Precambrian complex crops out on the flanks of the Uncompahgre Plateau about 40 miles northeast of the Lisbon Valley area. It is separable into an

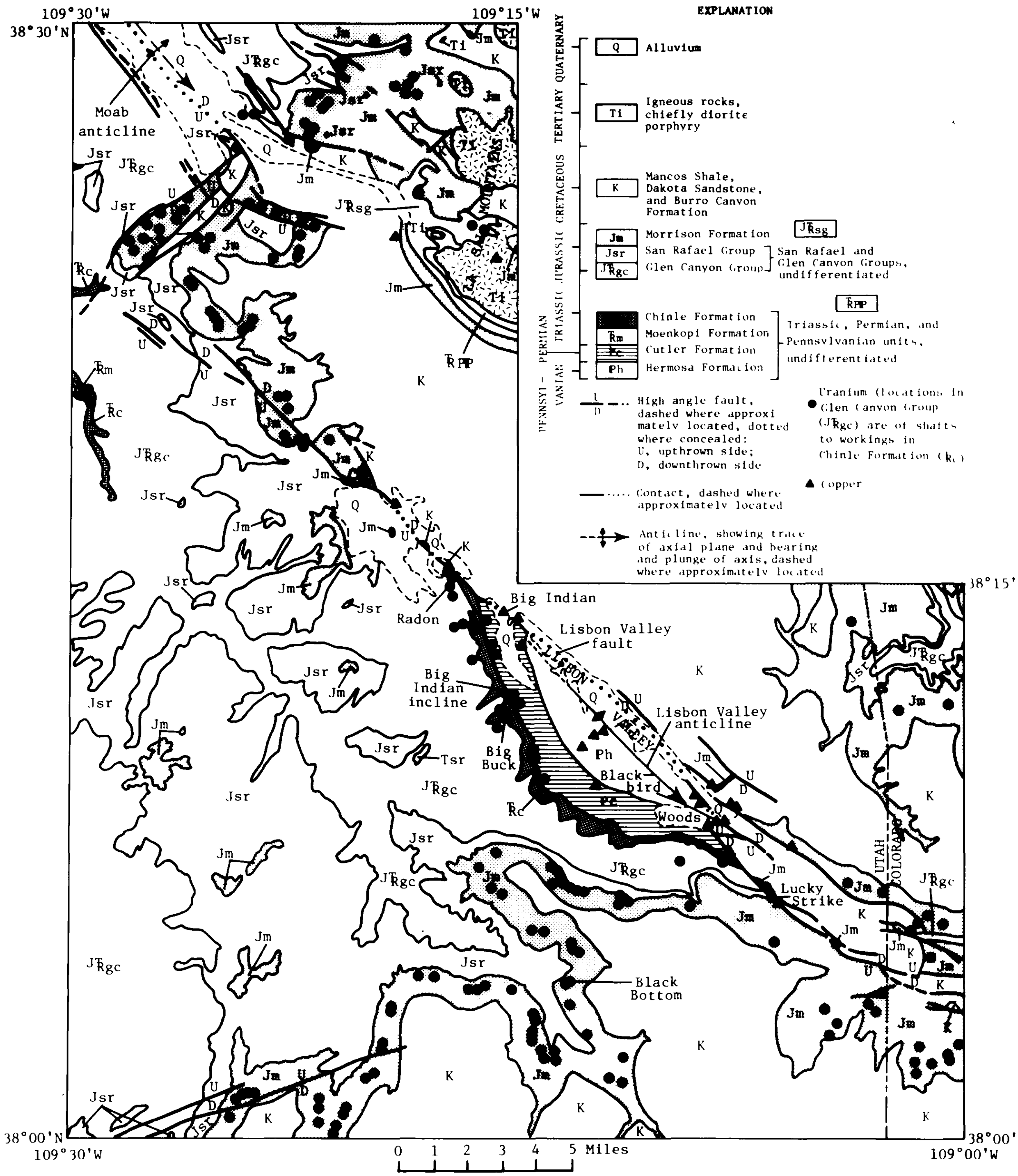


Figure 3.--Generalized geologic map of the Lisbon Valley area.

Mount Peale 2 NW (Weir, Kennedy, Dodson, and Puffett, 1961)	Mount Peale 2 NE (Weir and Puffett, 1960)		
Mount Peale 2 SW (Weir and Kennedy, 1958)	Mount Peale 2 SE (Weir, Dodson, and Puffett, 1960)		
Mount Peale 3 NW (Weir and Dodson, 1958)	Mount Peale 3 NE (Weir and Dodson, 1958)	Mount Peale 4 NW (Weir, Dodson, and Puffett, 1961)	Mount Peale 4 NE (Weir, Carter, Puffett, and Gualtieri, 1960)
Mount Peale 3 SW (Weir and Dodson, 1958)	Mount Peale 3 SE (Weir and Dodson, 1958)	Mount Peale 4 SW (Weir and Dodson, 1958)	Mount Peale 4 SE (Weir and Puffett, 1960)

Figure 4.--Outline map of the Lisbon Valley area, Utah-Colorado showing location of published 1:24,000 scale MF maps.

older gneiss and schist complex and younger granites (Dane, 1935, p. 20-24; Cater, 1955; Shoemaker, 1956). The older complex is strongly foliated and consists of gray, fine- to medium-grained, gneissic biotite granite that has engulfed masses of biotite and hornblende schist and gneiss, and quartzite. The younger complex is less widespread and consists of pink coarse-grained and porphyritic biotite granite, in places cut by a probably comagmatic light-gray granite and by pegmatite and aplite dikes. The younger complex is less altered than the older complex, but locally all the Precambrian rocks are sheared and crushed.

Cambrian system

Maps and sections by Baars (1958) and Lochman-Balk (1972) suggest that Cambrian rocks in the Lisbon Valley area are about 900 to 1000 feet thick and consist chiefly of coarse- to fine-grained sandstone and minor conglomerate, shale, and siltstone, probably in large part resembling the Ignacio Quartzite of the San Juan Mountains (Baars and See, 1968). The top 80 feet of the Cambrian sequence in the Lisbon Valley area consists of dark-gray argillaceous dolomite and thin beds of shale and resembles the Lynch Dolomite of central Utah (Budd, 1960).

Devonian system

Unconformably overlying the Cambrian rocks of southeast Utah are sedimentary rocks of Late Devonian age. The unconformity has little expression in the subsurface or in the nearest outcrops in the San Juan Mountains of southwestern Colorado (Baars, 1958, p. 96-97; Baars and See, 1968, p. 337). The Devonian of the Lisbon Valley area includes the Elbert Formation and the Ouray Limestone. These formations together are as much as 400 feet thick; they thin northeastward (Baars, 1972, p. 94, 95).

The basal member of the Elbert Formation in the Lisbon Valley area consists mostly of dolomitic sandstone and sandy dolomite and is as much as 120 feet thick (Budd, 1960). The unit is generally correlated with the McCracken Sandstone Member of Knight and Cooper (1955) who described the unit from cores from southeastern Utah. The upper member of the Elbert Formation is dolomite and minor shale grading near the top to sandy limestone and minor shale; it is as much as 180 feet thick (Budd, 1960). Gradationally overlying the Elbert is the Ouray Limestone which is as much as 100 feet thick in the Lisbon Valley area. It consists of medium-crystalline to microcrystalline limestone and dolomitic limestone and minor shale (Budd, 1960; Anon., 1960). The upper part of the Ouray may include some beds of Early Mississippian age (Knight and Baars, 1957; Baars and See, 1968).

Mississippian system

Mississippian rocks in the Lisbon Valley area are mostly carbonates that range in thickness to about 500 feet; they thin eastward and are truncated by an irregular karst-like unconformity. They were commonly assigned to the Leadville Limestone (Neff and Brown, 1958; Ohlen and McIntyre, 1965), because of similarity of the subsurface section to the Leadville Limestone in outcrops in the San Juan Mountains of southwestern Colorado described by Burbank (1940) and Baar and See (1968). At present, however, many would correlate these rocks with the Redwall Limestone to the south and west.

Several brief descriptions of Mississippian rock from wells in the northwest-central part of Lisbon Valley area have been published (Budd, 1960; Anon., 1960). The most detailed description is given by Mitchell (1961) who subdivided the Mississippian into four units. The basal unit, about 100 to 120 feet thick, is relatively fine grained dolomite, originally an oolitic and pelletal limestone, and contains aphanitic limestone and oolitic limestone at top and bottom of unit. Above the basal unit is a carbonate unit, about 90 to 130 feet thick, which is chiefly a vuggy dolomitized calcarenite composed of crinoid, bryozoan, brachiopod, and other skeletal material; contains white replacement chert. Unconformably above is a unit, about 130 to 230 feet thick, of crinoidal limestone and vuggy dolomite derived from crinoidal limestone. The top unit is as much as 80 feet thick and is made up of aphanitic limestone and minor oolitic and pisolitic limestone, in part dolomitized; it contains light-brownish to bluish chert.

Pennsylvanian system

Molas Formation

The Molas Formation crops out only in the San Juan Mountains of southwestern Colorado where it is chiefly red silt and clay with rock fragments of chert and limestone derived from Mississippian and Devonian formations. The distinctive lithology of the Molas Formation makes it an easily recognizable subsurface marker in much of the eastern Colorado Plateau. The thickness of the formation differs from place to place because of its irregular bottom and its gradational top. The Molas rests on a fossil karst surface and grades upward into the Hermosa Formation. The Molas is generally regarded as Early Pennsylvanian, but Merrill and Winar (1958) suggested that Molas sedimentation may have begun in the Late Mississippian and persisted into the early Middle Pennsylvanian.

In the central part of the Lisbon Valley area about 20 to 50 feet of beds have been assigned to the Molas (Neff, 1960, p. 61). In the Elliot No. 1-C Lisbon Valley well the Molas consists of 18 feet of reddish-brown and grayish-purple shale, light-gray bentonitic shale and pale-green sandy shale (Anon., 1960).

Hermosa Formation

The Hermosa Formation is not completely exposed on the Colorado Plateau, and the outcrops at its type locality in the San Juan Mountains near Durango, Colorado, are not fully representative of the formation in the subsurface of the Plateau region (Cross and Spencer, 1900; Roth, 1934; Bass, 1944a, b). The Hermosa Formation of the Colorado Plateau was divided into three members by Bass (1944a, b): a lower member, chiefly limestone; the Paradox Member, an evaporite sequence; and an upper member, chiefly limestone. In the Lisbon Valley area only a part of the upper member crops out.

As a result of exploration in the 1950s for oil and gas in the Paradox basin, the nomenclature of the Hermosa and related formations was refined and elaborated by Wengerd and Strickland (1954), Wengerd and Matheny (1958), Malin (1958), and Baars and others (1967).

Lower member

The lower member of the Hermosa Formation ranges in thickness from about 180 to 240 feet in the central part of the Lisbon Valley area (Four Corners Geological Society, 1960, p. 151; Anon., 1960), but it may pinch out in the eastern part of the area (Neff, 1960, p. 61). In the Elliot Production Co. No. 1-C Lisbon Valley well in sec. 9, T. 30 S., R. 24 E. the lower member of the Hermosa is 192 feet thick and consists of grayish-brown and grayish-green dense limestone with some gray and brown shale and chert in the lower part, and grayish-brown, dense, clayey, and anhydritic dolomite at the top (Anon., 1960).

Similar gray limestone units, resting on the Molas Formation and overlain by the evaporites, were correlated by Wengerd and Strickland (1954, p. 2168-2169) with Pennsylvanian rocks exposed on Pinkerton Trail, 12 miles north of Durango, Colorado. For this lower member of the Hermosa Formation they proposed the name "Pinkerton Trail Formation" (of the Hermosa Group). Baars and others (1967, p. 397) designated an alternate type section for the Pinkerton Trail Formation of Wengerd and Strickland (1954) in the Shell No. 1 Bluff well in southeastern San Juan County, Utah. The lower member of the Hermosa is gradational and probably intertongues with the red shale of the underlying Molas Formation. The contact with the overlying Paradox is a regional disconformity (Wengerd, 1958, p. 118).

Paradox member

The Paradox Member of the Hermosa Formation is not exposed in the Lisbon Valley area, but it has been penetrated by many deep holes and is partly though poorly exposed near Moab, a few miles north of the area. The type locality is in Paradox Valley, Colorado, about 20 miles east of La Sal; but as all outcrops are poor and incomplete, the Paradox member is known mainly from drill holes. Baars and others (1967, p. 400) proposed a subsurface type section for the Paradox in the Reynolds Mining Company No. 1 Egnar well in western San Miguel County, Colo.

The Paradox was named as a formation by Baker (1933), but was considered a member of the Hermosa Formation by Bass (1944a, b). Wengerd and Strickland (1954) and Baars and others (1967) proposed that the Paradox be accorded formational rank within a "Hermosa Group".

The outcrops of the Paradox Member near Moab consist of jumbled masses of grayish-white gypsum with small amounts of black shale and gray limestone (Baker, 1933, p. 14). These masses have intruded younger formations, and the stratigraphic relations are obscured. In the subsurface the Paradox consists of cyclic deposits of salts, anhydrite, gypsum, and minor black shale, siltstone, dolomite, and limestone.

A threefold division of the subsurface Paradox is made by Wengerd (1958). In the central part of the depositional basin the lower unit consists of black shale, dark-gray siltstone, earthy anhydritic and gypsiferous dolomite, gypsum, and anhydrite.

The middle unit is an evaporite sequence--mainly salt with some interbedded black shale and siltsone, gypsum, anhydrite, and dolomite. The evaporite sequence is made up of cyclothems that show a pattern of increasing, then decreasing salinity. A complete cyclothem consists in ascending order of black shale, limestone and dolomite, anhydrite, halite, potassium and magnesium salts, halite, anhydrite, dolomite and limestone, and finally black shale (Herman and Barkell, 1957, p. 867-869; Hite and Gere, 1958, p. 221; Hite, 1960). The cyclothems are commonly incomplete; the potassium and magnesium salts, and the anhydrite and carbonate rocks above the salt are frequently missing. The individual cyclothems can be identified in vertical succession, and by their position with relation to a few key beds. They can be traced from well to well.

Above the salt is a penesaline unit, lithologically similar to the lower unit and not separable from it where salt is absent. This upper unit is composed of black, silty, calcareous to dolomitic shale, anhydrite, gypsum, and brown, argillaceous, finely crystalline dolomite and limestone. These beds are referred to the "Ismay and Desert Creek zones" of the Paradox by many geologists (H. H. Brown, 1960, fig. 1; Four Corners Geol. Soc. Nomenclature Comm., 1960). The upper unit of the Paradox is transitional with the normal marine clastic-carbonate upper member of the Hermosa Formation. Wengerd and Strickland (1954, p. 2173) suggest that the upper contact of the Paradox Member be placed at the top of the uppermost thick bed of jet-black shale or, where this is lacking, at the top of the uppermost bed of anhydrite.

Reported thicknesses of the Paradox Member in the Lisbon Valley area range from about 1,100 to 5,300 feet. These thicknesses include about 350 to 400 feet of gray limestone and dolomite, black shale, and anhydrite at the top of the member. The bulk of the Paradox Member in the area is an evaporite sequence consisting chiefly of salt with lesser amounts of anhydrite, potassium salts, black shale, and dolomitic limestone.

The maximum thickness of the Paradox Member in the area is probably much greater than the greatest reported thickness, for no well has penetrated the entire member near the crest of the anticlines of Lisbon Valley or Spanish Valley. Scattered wells on salt anticlines in adjacent areas show that the Paradox Member is anomalously thick along the axes of the anticlines. For example, along the axis of the Paradox Valley anticline the Continental Oil Company No. 1 Scorup well (sec. 8, T. 47 N., R. 18 W. Montrose Co., Colo.) penetrated more than 14,000 feet of Paradox salt-bearing rocks whereas the depositional thickness of the member adjacent to the core of the anticline has been estimated to be only 7,000 feet (Elston and Shoemaker, 1960, p. 51). Such recorded abnormal thicknesses of the Paradox Member result in part from the original greater thickness of salt laid down in troughs along the trends of the anticlines, but result mainly from the intense deformation of incompetent salt beds. Drill holes penetrating the cores of the anticlines show that the beds are steeply dipping, locally duplicated by recumbent folding, and to some extent, thickened by salt flowage (Hite, 1960, p. 88).

The Paradox Member is abnormally thin near McIntyre Canyon in the eastern part of the Lisbon Valley area. In the Pure Oil Company SE Lisbon No. 1 well, about one mile east of the edge of the area, only 1,162 feet of section is assigned to the Paradox and of this only about 800 feet is reported to be salt (Four Corners Geol. Soc., 1960, p. 153). The thinness of the member is ascribed to deposition across an Early Pennsylvanian high (Neff, 1960, p. 61).

Upper member

About one-third to one-half of the upper member of the Hermosa is exposed in the central part of the Lisbon Valley area, and therefore, this member is described with the exposed rocks on the following pages. The unexposed part of the member consists chiefly of gray and grayish-brown limestone, in part sandy and cherty (H. H. Brown, 1960).

EXPOSED ROCKS

Consolidated rocks that crop out in the Lisbon Valley area range in age from Late Pennsylvanian to early Pleistocene. As in the previous section on concealed rocks, the stratigraphy has been updated as much as possible so that it is current as of December 1977. The oldest exposed consolidated rock is the upper member of the Hermosa Formation; the youngest, siltstone and poorly cemented gravel near the La Sal Mountains. Rocks of Jurassic and Cretaceous age, however, account for fully 90 percent of the outcrops. The bedrock is locally mantled with thin patches to thick sheets of surficial deposits of Pleistocene and Holocene age. The exposed rocks are dominantly continental. Marine fossils are found only in the upper member of the Hermosa Formation of Middle and Late Pennsylvanian age and in the Mancos Shale of Late Cretaceous age.

Deposition in this part of the Colorado Plateau was relatively continuous. The most profound break is an angular unconformity between the Cutler Formation of Early Permian age and the Chinle Formation of Late Triassic age. Regional disconformities are found at the top of the Navajo Sandstone of Triassic(?) and Jurassic age and at the top of the Burro Canyon Formation of Early Cretaceous age, but the time significance of these breaks is probaly small. No sedimentary rocks of undoubted Tertiary age are found in the area, and the unconformity at the top of the remnant Cretaceous rocks records a long period of erosion. Glacial deposits cover much of the slopes of the La Sal Mountains. Alluvial and eolian surficial material is extensive in the mesa lands and broader valleys.

Pennsylvanian system

Hermosa Formation, Upper member

Distribution and thickness

The Hermosa Formation crops out only in the central part of the Lisbon Valley area. Limestone beds in the exposed part of the upper member forms a series of dip slopes on the Lisbon Valley anticline between Lisbon Valley and Big Indian Valley. Deep drill holes indicate that the upper member of the Hermosa is about 1,400 to 2,100 feet thick in the Lisbon Valley area (H. H. Brown, 1960, fig. 1). An estimated 900 feet of the Hermosa is exposed.

Lithology

The exposed part of the Hermosa Formation consists of shale and non-fissile mudstone (55 percent), sandstone (30 percent) and limestone (15 percent). Logs of wells in the area suggest that the buried part of the upper member of the Hermosa contains little sandstone and a much higher percentage of limestone (Baker, 1933, p. 92; Brown, H. H., 1960, fig. 1). The section given below illustrates in detail the lithology of the upper member of the Hermosa Formation exposed near Lisbon Valley. Comparison of this section with that published by Baker (1933, p. 20-21), describing outcrops of the Hermosa Formation on the Colorado River about 30 miles west of the Lisbon Valley section, shows a westward increase in the number and thickness of the limestone units. The following section, measured with hand level and tape by the writers in 1957, was described from outcrops along main gullies southwesterly from Lisbon Valley to Big Indian Valley.

Partial section of the upper member of the Hermosa Formation measured along a southwesterly traverse beginning in SW1/4 sec. 16 and ending in SW1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah

Thickness (feet)

Cutler Formation:

Basal units of Cutler Formation consist of about 8 ft of grayish-red (10R 4/2)[1] and yellowish-gray (5Y 7/2) shale,

[1] Color names with numbers based on rock color chart by Goddard and others (1948).

very fine sandy and micaceous; overlain by more than 20 feet of sandstone, pale-red (10R 6/2), moderate-orange-pink (5YR 8/4), medium to very fine grained; composed of clear quartz, feldspar, muscovite, and biotite; crossbedded in low-angle trough sets, contorted; forms minor ledges.
Not measured..........

Hermosa Formation:

Upper member:

37. Limstone, medium-gray (N 5); weathers medium bluish gray (5B 6/1); very fine to medium crystalline; horizontally stratified in two units, each about 12 in. thick; contains a few crinoid fragments; forms a ledge and dip slope in creek.......... 2.0

36. Shale (75 percent) and sandstone (25 percent). Shale, grayish-red (10R 4/2), very fine sandy at top; forms basal part of unit. Sandstone, grayish-red (10R 4/2), locally weathers greenish-gray; silty and very fine grained with abundant fine mica flakes; horizontally stratified in thin beds. Unit forms slope; poorly exposed.......... 5.5

35. Sandstone, pale-reddish-brown (10R 5/4); mottled, especially at top of unit, with pale greenish yellow (10Y 8/2); very fine grained, silty, micaceous; horizontally stratified in thin units at base, more thickly bedded at top; forms irregular dip slope in creek; obsured by limestone fragments........................19.3

34. Limestone (90 percent) and mudstone (10 percent). Limestone, light-gray (N 7), weathers greenish gray (5GY 6/1), micrograined; in beds a few inches to more than 1 ft thick; irregularly horizontally stratified; top 12 in. contains streak of red mudstone; weathered surface is pitted, suggesting eroded mudstone pebbles; fossiliferous, USGS collection no. 16782. Mudstone, yellowish-gray (5Y 7/2) and (5Y 8/1); at base and about 2 ft below top. Nodules of limestone in mudstone at base contain foraminifera, USGS collection no. f-12488. Unit forms minor ledges and dip slope........................10.8

33. Shale, pale-brown (5YR 5/2), in part mottled with pale yellowish gray (5Y 7/2); silty, becoming very fine sandy at top; forms slope littered with small fragments 1/8 to 1 in. across...3.2

32. Sandstone, pale-red (10R 6/2), pale-olive (10Y 6/2), and pale-greenish-yellow (10Y 8/2); reddish color dominant, streaked with green, yellow, and gray; generally similar to sandstone in unit 31 but crossbedded in trough sets and commonly contorted; forms ledge..........................12.1

31. Sandstone (70 percent) and shale (30 percent). Sandstone, pale-greenish-yellow (10Y 8/2) and pale-red (10R 6/2); weathers pale red (10R 6/2); fine to very fine grained silty, poor sorted; composed of angular clear and reddish-stained quartz and feldspar and biotite; firmly to poorly cemented, calcareous; lowermost sandstone bed about 1 ft thick, contorted; most sandstone in thin horizontal beds; sandstone grades upward to shale. Shale, light-browish-gray (5YR 6/2) and greenish-gray (5GY 6/1); brownish shale is clayey and is interbedded with sandstone in lower two-thirds of unit; greenish shale, very fine sandy; contains abundant mica flakes, at top of unit.........45.2

30. Sandstone (80 percent) and shale (20 percent). Sandstone, grayish-yellow (5Y 8/4) and pale-olive (10Y 6/2); fine to very fine grained and silty; poor sorted; composed of subangular clear quartz, feldspar, orange chert, and biotite, with abundant green and black accessory minerals; firmly to poorly cemented, calcareous; horizontally stratified; splits to thin plates about 1/4 in. thick. Shale, light-olive-gray (5Y 6/1); at base of unit and interbedded with sandstone. Unit forms series of minor ledges and dip slope.......................................14.5

29. Limestone, light-olive-gray (5Y 6/1) and light-bluish-gray (5B 7/1), especially in bottom 5 ft; very finely crystalline and silty to medium to coarsely crystalline, coarser in bottom 5 ft; bottom 5 ft forms single ledge upper part horizontally bedded in units a few inches to a few feet thick; forms gully wall and dip slope. Fossils common in beds above basal 10 ft; USGS collection no. 16781. Upper 5 ft contains irregular masses few inches to several feet across of silicified limestone, light-olive-gray (5Y 6/1); weathers moderate yellowish brown (10YR 5/4)....................................32.3

28. Sandstone (75 percent) and shale (25 percent). Sandstone, grayish-orange-pink (5YR 7/2) to very pale orange (10YR 7/2), fine grained to very fine grained, fair sorted; composition similar to sandstone in unit 27; firmly cemented, calcareous; very thin to medium bedded; forms minor ledges and slope; thin-bedded portion shaly weathering; mostly covered. Shale, grayish-red (10R 4/2); forms slope; mostly covered. Top 5 ft is shale, yellowish-gray (5Y 8/1) and pale-olive (10Y 6/2); mostly covered..38.9

27. Sandstone, pinkish-gray (5YR 8/1); weathers pale orange (10YR 7/4), medium to fine grained, fair sorted; composed of angular clear quartz, pink feldspar, orange chert, and biotite, and common green accessory minerals; firmly cemented, calcareous; horizontally bedded, beds about 1 in. thick; forms minor ledge................................1.0

26. Shale (75 percent) and sandstone (25 percent). Shale, pale-yellowish-gray (5Y 8/1) and grayish-red (10R 4/2); very fine grained sandy, micaceous. Sandstone, pale-yellowish-gray (5Y 8/1); weathers pale orange (10YR 8/2), very fine grained, fair sorted; composed of angular grains of quartz, feldspar, and biotite, and abundant orange and black accessory minerals; forms structureless lens about 5 ft above base, 1 to 2.5 ft thick. Unit forms irregular slope.........12.7

25. Limestone, light-olive-gray (5Y 6/1), micrograined; horizontally bedded in irregular knobby beds 3 to 8 in. thick; forms prominent ledge and dip slope. Contains megafossils and conodonts, USGS collection no. 16787......................8.6

24. Shale, pale-olive (10Y 6/2); very fine silty and clayey with very fine muscovite flakes, very fine iron-stained quartz; poorly to firmly cemented, calcareous, with small gray calcareous concretions at top of unit; thinly laminated and unlaminated; forms moderate slope covered with very small shale fragments; base obsured, may contain limestone similar to unit 23....................................37.1

23. Limestone, pale-yellowish-brown (10YR 6/2) to light-olive-gray (5Y 6/1); weathers grayish yellow (5Y 8/4); very

finely crystalline; irregularly horizontally bedded; forms minor ledge and dip slope littered with limestone fragments. Top is poorly defined; thickness approximate. Abundant megafossils, USGS collection no. 16780. At base is conspicuous limonite band, about 1/4 in. thick moderate yellow (5Y 7/6)..1.0

22. Sandstone (50 percent) and shale (50 percent). Sandstone, light-olive-gray (5Y 6/1), dusky-yellow (5Y 6/4) and yellowish-gray (5Y 6/1), fine-grained and silty, poorly sorted; composed of subangular quartz, biotite, muscovite, and silt particles; firmly cemented, calcareous; horizontally stratified, in thin flaggy units; thin-splitting; macerated plant fossils occur as limonite impressions on bedding planes in dusky-yellow sandstone; field collection no. W-10/1/7-Fl. Shale, mostly light olive gray (5Y 6/1), sandy, silty, generally similar to sandstone but much finer grained. Unit forms steep cliff above dip slope of limestone.................................36.8

21. Limestone, light olive gray (5Y 6/1), very finely crystalline; irregularly horizontally bedded; forms low ledge in dip slope; contains abundant fusilinids in top 4 in., USGS collection no. f-12491...4.5

20. Calcareous shale, yellowish-gray (5Y 7/2); weathers grayish orange (10YR 7/4); firmly cemented, calcareous, thin bedded, horizontally stratified; weathers to form steep slope littered with irregularly curving plates. Top part is very fine sandy, locally with abundant biotite; common gray calcareous concretions. Contains rare scattered fossils, USGS collection no. 16786; a single nautiloid was collected from this unit.................................59.3

19. Limestone, yellowish-gray (5Y 7/2); weathers same and grayish yellow (5Y 8/4); very finely crystalline, irregularly horizontal bedded; forms prominent ledge. Contains abundant fusilinids, USGS collection no. f-12490..............3.0

18. Shale (90 percent) and sandstone (10 percent). Shale, pale-brown (5YR 5/2) and very pale-orange (10YR 8/2); brown shale is clayey, weathers to very small chips, and is probably gradational with unit 17; orange shale is very fine sandy and forms upper one-fourth of unit. Sandstone, grayish-red (10R 4/2), weathering same, and pinkish gray (5YR 8/1) weathering grayish orange (10YR 7/4). Grayish-red sandstone very fine grained, silty, with abundant fine mica flakes; very thin bedded, probably discontinuous lens in lower third of unit. Pinkish-gray sandstone, fine to medium grained, fair sorted; composed of angular quartz, feldspar, and muscovite, with abundant green accessory minerals; firmly cemented, calcareous; forms minor ledge about 1 ft thick near middle of unit. Whole unit forms slope; in part poorly exposed..............30.5

17. Covered. Abundant calcareous siltstone float near base, yellowish-gray (5Y 8/1), weathers grayish orange (10YR 7/4); contains fossil fragments; forms slope litter of platy fragments. (Section corner 16-17-20-21 near top of covered interval)................................36.5

16. Sandstone, very pale orange (10YR 8/2); weathers dark gray (N 3) and grayish orange (10YR 7/4); fine to coarse grained, poorly sorted; composed of angular to subangular clear quartz and feldspar, orange chert, and biotite with abundant green accessory micaceous minerals; firmly cemented, calcareous; bedding obsure; forms minor ledge exposed in gully in generally covered area..............2.0

15. Covered..5.5

14. Limestone, light-olive-gray (5Y 6/1), very finely crystalline; forms double ledge with middle part more platy, less resistant; irregular horizontal beds. Common in upper part is pale reddish brown (10R 5/4) and lighter, weathers grayish orange (10YR 7/4) commonly with black to brown iron oxide stain; in irregular tubular and ball-like masses chert, generally a few inches in diameter and as much as 1.5 ft long. Fossils abundant in lower part of unit, sparse in upper part, USGS collection no. 16785........11.0

13. Shale, grayish-yellow-green (5GY 7/2), silty and very fine sandy with abundant very fine mica flakes; firmly to firmly to poorly cemented, calcareous; laminated. Forms slope between top of sandstone cliff and limestone bed at base of unit 14...11.0

12. Sandstone, pinkish-gray (5YR 8/1) to grayish-orange-pink (5YR 7/2) and moderate-yellow (5Y 7/6); generally similar to unit 10 but has fewer mudstone flakes and fewer chert pebbles. About 25 feet above base is poorly exposed shale, olive gray (5Y 4/1), 1 to 3 ft thick. Unit forms prominent ledge on rim of Lisbon Valley......................40.0

11. Mudstone (20 percent), shale (70 percent), sandstone (10 percent). Shale, grayish-red (10R 4/2), silty and very fine grained sandy; firmly cemented, calcareous; laminated. Mudstone, same color as shale and yellowish gray (5Y 7/2); firmly cemented, calcareous. Sandstone grayish-yellow (5Y 8/4), fine to medium grained, fair sorted; composed of clear quartz, feldspar and biotite with minor muscovite and orange chert; firmly to poorly cemented, calcareous; irregularly bedded, commonly contorted; forms poorly exposed ledge, about 5 ft thick, about 33 ft above base of unit; may pinch out along strike. Unit poorly exposed except for red shale at base, sandstone in middle, and mudstone at very top..........63.0

10. Sandstone, pinkish-gray (5YR 8/1) and yellowish-gray (5Y 8/1); weathers same and grayish orange (10YR 7/4); coarse to fine grained, medium to very fine grained; poorly sorted; composed of subangular clear quartz and feldspar, orange chert, greenish-black biotite, with common colored accessory minerals, sparse to common scattered, yellowish-gray mudstone flakes 1/4 to 3 in. in diameter, sparse orange chert and black chert pebbles 1/8 to 1/4 in. in diameter; firmly cemented, calcareous, irregularly crossbedded in planar and trough sets, bedding obscure; forms irregular ledge..13.5

9. Shale (70 percent) and sandstone (30 percent). Shale, greenish-gray (5GY 6/1) and pale-red (10R 6/2); silty and clayey, very fine sandy with abundant fine biotite flakes; firmly to poorly cemented, calcareous; very thinly bedded to laminated with irregular cuspate ripple marks. Sandstone, pale-red (10R 6/2), very fine grained and silty, fair sorted; composed of angular clear quartz, feldspar, and mica flakes; firmly cemented, calcareous; stratification similar to shale. Unit forms slope littered with platy fragments; red color limited mainly to 5-foot interval beginning 10 ft above base. No fossils found..28.1

8. Limestone, silty and sandy, very light olive gray (5Y 7/1); weathers same and greenish gray (5GY 6/1); very finely crystalline, silty and very fine sandy; weathered surfaces finely punctate; some crinoid and other fossil fragments partly or wholly replaced by reddish-orange chert; irregularly horizontally bedded, knobby weathering; forms minor irregular ledge with more silty portions being less resistant; base is transitional with unit below; abundant megafossils, USGS collection no. 16784....................................6.0

7. Shale, light-olive-gray (5Y 6/1) and yellowish-gray (5Y 8/1); weathers light olive gray (5Y 6/1), silty and micaceous, firmly cemented, calcareous; very thinly bedded and laminated; forms slope; contains sparse ostracodes, USGS collection no. 16779........................26.6

6. Covered...10.9

5. Sandy limestone, light-olive-gray (5Y 5/2); weathers dusky yellow (5Y 6/4); very fine grained sandy and finely crystalline with greenish-gray mudstone pebbles 1/8 to 1 in. in diameter; forms minor ledge in covered interval in gully; sparsely fossiliferous, USGS collection no. 16778..1.0

4. Covered, probably shale as in unit 3............................3.0

3. Limestone (50 percent) and mudstone (50 percent). Limestone, light-olive-gray (5Y 6/1) and (5Y 5/2); weathers light gray (N 7) and yellowish gray (5Y 7/2); mostly very finely crystalline with irregular darker gray patches, 1/8, to 1-1/2 in. across; some beds partly a jumble of broken shells; contains pelecypods and other megafossils, USGS collection no. 16777, and fusilinids, USGS collection no. f-12487. Mudstone, yellowish-gray (5Y 7/2), silty with common muscovite; no fossils; poorly exposed. Unit forms irregular slope; limestone forms minor ledges and benches............................49.5

2. Shale (80 percent) and sandstone (20 percent), light-olive- (5Y 5/2) and pale-olive (10Y 6/2), weathers same. Sandstone fine-grained to very fine grained, poorly sorted, micaceous, firmly cemented, calcareouos; laminated; outcrop yields small plates 1 to 4 in. in diameter. Shale, clayey, fluffy-weathering. Unit forms steep slope littered with platy sandstone and limestone fragments...........17.9

1. Sandstone, yellowish-gray (5Y 7/2), greenish-gray (5GY 6/1) and dusky-yellow (5Y 6/4), coarse to very fine grained and silty, poorly sorted; composed of angular to subangular clear quartz and feldspar, orange chert, biotite and minor muscovite and sparse black accessory minerals; coarse-grained sandstone contains pebbles of black chert about 1/2 in. maximum diameter; firmly to poorly cemented, calcareous; coarse-grained units are in beds 1 to 4 ft thick, cross-stratified irregularly in trough sets; finer grained units generally thin to very thinly bedded, horizontally stratified, with ripple-marked beds beds in some silty units. Weathers to series of small ledges with coarser grained and thicker units forming tops of ledges. Some fine-grained, thin-splitting, micaceous sandstone about 15 ft above base contains flakes of carbonaceous plant material about 1/8 to 1/4 in. in diameter. Base of local exposure................39.6

Total exposed Hermosa Formation.......743.4

Shale and mudstone units, though making up more than half of the exposed Hermosa, generally crop out poorly. Yellowish and greenish gray, pale brown and grayish red are the dominant colors. The mudstone and shale units range from fluffy-weathering claystone to firmly cemented sandy siltstone, which in places grades into fine-grained sandstone. Biotite flakes are abundant on bedding planes. Most units are calcareous, and some contain limestone concretions and grade upward into limestone. Calcareous shale and mudstone locally contain marine fossils. The shale and mudstone units are fairly persistent along strike and several units were traced about 9 miles, the length of the Hermosa outcrop in Lisbon Valley, without showing much change in lithology or thickness.

Sandstone, generally yellowish gray or grayish red, occurs as thin interbeds in slope-forming shale and mudstone units and as resistant ledge-forming units as much as 40 feet thick. The sandstone ranges from silty and very fine grained to coarse grained and pebbly. Most units are fine grained and poorly or only moderately well sorted. They are arkoses composed of clear quartz, clear and pinkish feldspar, and variable amounts of gray and orange chert, biotite and muscovite, and a green micaceous mineral. Most sandstone is horizontally bedded or structureless; some medium- and coarse-grained units are crossbedded. Cuspate ripple marks are locally common in very fine grained and silty units. Marine fossils are very sparse in sandstone; fragments of plant fossils are sparse to common in a few sandstone units and are especially abundant in a conspicuous fine-grained, yellowish-gray sandstone unit in the upper part of the exposed section.

Limestone beds form a small but conspicuous part of the exposed Hermosa Formation. They make up the largest part of the outcrop of the Hermosa, because they commonly form extensive dip slopes, especially on the southwest side of the Lisbon Valley anticline. Most of the limestone is light olive or bluish gray and finely to medium crystalline. Irregular dark spots, 0.1 to 1.5 ins. in diameter, in crystalline matrix are trashy accumulations of broken shells and scattered sand grains. Orange and reddish-gray chert occurs as irregular nodules and veinlets in some beds. Marine fossils, dominantly brachiopods and fusulinid foraminifera, are common to abundant in most of the limestone units; a few beds, such as the top limestone of the Hermosa, contain only sparse crinoid and shell fragments.

Contacts

The base of the upper member of the Hermosa Formation is not exposed in or near the Lisbon Valley area. According to Wengerd and Strickland (1954, p. 2173) the base of the upper member of the Hermosa, the top of the Paradox Member, is "generally chosen at the uppermost thick jet-black shale associated with stringers of gypsum, or where the black shale is absent, at the first appearance of anhydrite."

The Hermosa Formation is conformably overlain by the Cutler Formation in the Lisbon Valley area. The top of the Hermosa Formation is the top of the highest persistent limestone unit. This uppermost limestone bed is bluish gray, only a few feet thick and, except for crinoid stem fragments, generally contains few fossils. In a few places thin lentils of marine limestone lie within the red beds assigned to the Cutler above the limestone bed, but the contact is generally definite and easy to locate. In a broad sense, the exposed Hermosa is transitional with the Cutler Formation, for the clastic units in the Hermosa are generally similar to those in the Cutler, and near the top of the Hermosa they are indistinguishable from those in the lower part of the Cutler.

Fossils and age

Most of the limestone beds and some of the calcareous shale and mudstone units are more or less fossiliferous along their entire outcrop. Our collections were taken from the measured section previously described. These collections are probably fairly representative of the fauna of the exposed Hermosa Formation in the central part of the area but other forms would be added by search in other parts of the area. Bryozoans, for example, seem to be much more abundant in the upper limestone beds cropping out opposite the head of Lisbon Canyon than in equivalent beds along the line traversed.

In the following lists the numbered sedimentary units referred to are described in measured section. The macrofossils were identified mainly by E. L. Yochelson and Helen Duncan. Thomas Dutro identified some of the brachiopods and checked the identification of others. D. H. Dunkle identified a fish tooth in collection 16788. The nautiloid in collection 16783 was identified by Mackenzie Gordon, Jr., and the ostracodes in collection 16799 by I. G. Sohn. The fragmentary conodont specimens of collection 16787 were identified by W. W. Hass, and the plant fossils in unit 22 by S. H. Mamay. The foraminifera were identified by R. C. Douglass; the thin sections were prepared by John Hutchison.

USGS collection 16777. Foraminifera: USGS collection f-12487. Collected from limestone beds of unit 3 of measured section on north bank of gully in SW1/4SW1/4 sec. 16, T. 30 S., R. 25 E., San Juan County, Utah.

Climacammina sp.
Endothyra?
Bradyina sp.
Triticites sp. aff. T. springvillenis Thompson, Verville and Bissell, 1950
Dibunophylloides sp.
Crinoid stems
Echinoid spines
Derbyia crassa (Meek and Hayden)
Enteletes hemiplicatus (Hall)
Lissochonetes sp.
Linoproductus sp. indet.
Juresania nebrascensis (Owen)
Composita subtilita (Hall)

USGS collection 16778. Collected from sandy limestone, unit 5, on flats below prominent cliff in SW1/4SW1/4 sec. 16, T. 30 S., R. 25 E., San Juan County, Utah.

Lophophyllidid coral
Productid brachiopod cf. Juresania

USGS collection 16779. Collected from calcareous shale, unit 7, forming slope about 500 feet northeast of prominent cliff in SW1/4SW1/2 sec. 16, T. 30 S., R. 25 E., San Juan County, Utah.

Sansabella
Healdia
Gen. aff. Aechminella?

USGS collection 16784. Collected from silty and sandy limestone, unit 8, on steep slope about 500 feet northeast of prominent cliff in SW1/4SW1/4 sec. 16, T. 30 S., R. 25 E., San Juan County, Utah.

Crinoid stems
Echinoid spines
Fistulipora sp. (branching species)
Polypora sp.
Linoproductus cf. *L. pratteniansus* (Norwood in Norwood and Pratten)
Allorisma sp. indet.
Phillipsid trilobite indet.

USGS collection 16785. Collected from platy limestone, unit 14, on flats above rim of Lisbon Valley near the head of prominent gully draining to northeast in SW1/4SW1/4 sec. 16, T. 30 S., R. 25 E., San Juan County, Utah.

Crinoid stems
Derbyia crassa (Meet and Hayden)
Neochonetes granulifer Owen
Linoproductus sp. indet.
Antiquatonia cf. *A. hermosanus*? (Girty)
Hystriculina cf. *H. Wabashensis* (Norwood and Pratten)
Composita subtilita (Hall)
Neospirifer sp. indet.

USGS collection f-12490. Collected from thin limestone bed, unit 19, forming short dip slope in NE1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah.

Bradyina sp.
Millerella sp.
Triticites sp. aff. T. *cullomensis* Dunbar and Condra, 1928.

USGS collection 16786. Collected from yellowish, platy-weathering, limy sandy shale, unit 20, in NE1/4 NE1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah.

Wellerella cf. *W. osagenis* (Swallow)
Schizodus(?) sp. indet.
Pharkidonotus cf. *P. percarinatus* (Conrad)
Bellerophontid gastropod indet.
Straparollus (Euomphallus) sp. indet.
Low-spired gastropod indet.
Indeterminate organic object

USGS collection 16783. Collected from same unit as USGS 16786, about 2,000 feet northwest of line of measured section, in gully near small hill in NW1/4 sec. 17, T. 30 S., R. 25 E., San Juan County, Utah.

Peripetoceras sp.

USGS f-12491. Collected from upper part of limestone, unit 21, near bend of draw draining to southwest in NE1/4 NE1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah.

Tetrataxis sp.
Bradyina sp.
Millerella sp.
Triticites sp. aff. T. cullomenis Dunbar and Condra, 1928.

Field number: W-10/1/7-Fl. Collected from distinctive light-colored sandstone, unit 22, in floor of draw in NE1/4 NE1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah.

Calamites fragments

USGS 16780. Collected from limestone, unit 23, in main gully draining to the southwest in NE1/4 NE1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah.

Enteletes sp.
Juresania sp.
Cancrinella cf. C. boonenesis (Swallow)
Hystriculina cf. H. wabashensis (Norwood and Pratten)
Composita subtilita (Hall)
Neospirifer cf. N. dunbari R. H. King
Permophorus sp.
Fasciculiconcha? sp. indet.
Bellerophontid gastropod indet.
Euconospira cf. E. planibasalis Ulrich

USGS 16787. Collected from linestone, unit 25, in main gully draining to southwest in NE1/4 NE1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah.

Pelecypods indet.
Low-spired gastropods indet.
Streptognathodus sp.

USGS 16781. Collected from limestone, unit 29, in several places on long dip slope near main drainage in central part of sec. 20, T. 30 S., R. 25 E., San Juan County, Utah.

Crinoid stems
Fistulipora sp. (Massive species)
Tabulipora sp. (ramose species)
Stenoporoid bryozoan (incrusting)
Rhombotrypella sp.
Fenestella sp.
Rhabdomeson sp.
Cystodictya? sp.
Neochonetes granulifer Owen
Hystriculina wabashensis (Norwood and Pratten)
Echinoconchus? sp. indet.
Dictyoclostus sp. cf. "Marginifera" lasallensis Worthen
Phricodothyris sp. indet.
Composita subtilita (Hall)
Neospirifer sp.
Rhynchopora n. sp. cf. R. taylori Girty
Allorisma terminale Hall

USGS Megafossil collection 16782; foraminifera: USGS collection f-12488. Collected from limestone beds and limestone nodules in mudstone interbedded with limestone, unit 34, on northwest bank of main gully in NE1/4 SW1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah.

Ammodiscus sp.
Triticites sp. aff. T. *cullomensis* Dunbar and Condra, 1928
Crinoid stems
Derbyia crassa (Meek and Hayden)
Juresania nebrascensis (Owen)
Cancrinella boonensis (Shallow)
Composita subtilita (Hall)
Neospirifer dunbari R. H. King
Phricodothyris perplexa (McChesney)
Punctospirifer sp. indet.
Allorisma cf. *A. terminale* Hall

Concerning the larger invertebrate fossils of these collections Yochelson and Duncan (written commun., 1957) stated:

> "The fauna as a whole is indicative of a Middle or Upper Pennsylvanian age, comparing it to the Mid-Continent section. In that area, essentially the same fauna also ranges up into the lower Permian. On the basis of the larger invertebrates it is not now possible to exclude a possible Permain age for at least some of the beds, though this seems unlikely. Similarly, the larger invertebrates found in both the Rico and Hermosa Formations appear to be conspecific. We cannot at this time clearly separate one formation from the other on the basis of the larger invertebrates. At the same time, there is no reason to question the field identifications of the formations. There are no "critical" fossils listed in this report."

The *Calamites* fragments in the sandstone and mudstone unit at the base of the upper part of the exposed Hermosa are of little age significance because this genus has a wide time range. They are of interest, however, in being probably the first plant fossils recorded from the upper member of the Hermosa Formation.

The dating of the Hermosa Formation in the Lisbon Valley area rests mainly on the determination of the fossil fusulinids. The foraminifera fauna, collection f-12487, in unit 3 of the measured section is of Late Pennsylvanian, probably Missourian, age; the faunas of collection f-12490 in unit 19, collection f-12491 in unit 21 and collection f-12488 in unit 34 are of Late Pennsylvanian, probably Virginian age (Douglass, written commun., 1958). Unit 34 is the highest abundantly fossiliferous limestone in the section and is only about 20 feet below the top of the Hermosa as mapped in the Lisbon Valley area. Thus, probably all of the upper member of the Hermosa Formation is Late Pennsylvanian in age.

Comparison with faunas of the top limestone bed of the Hermosa Formation in the northern part of the Moab district

Two collections were made for comparative purposes in the top limestone bed of the Hermosa Formation as this formation was mapped by Baker (1933, pl. D) on the Cane Creek anticline. Baker's collection 5949 apparently came from this same bed about one-half mile southeast of our locality (Baker, 1933, p. 22).

USGS collection 16788. Collected from sandy limestone just below access road to Cane Creek exploration wells. Limestone forms bench overlain by red beds of Rico Formation in NW1/4 NE1/4 sec. 36, T. 26 S., R. 20 E., Grand County, Utah.

Caninia sp.
Crinoid stems
Crinoid calyx cf. *Delocrinus*
Fistulipora sp.
Rhombotrypella (*Rhomboporella*) sp.
Tabulipora
Ascopora? sp.
Derbyia crassa (Meek and Hayden)
Neochonetes granulifer (Owen)
Lissochonetes) cf. *L. geinitzianus* (Waagen)
Linoproductus sp. indet.
Juresania cf. *J. nebrascencis*
"Marginifera" lasallensis (Worthen)
Hystriculina cf. *H. wabashensis* Norwood and Pratten
Hustedia mormoni (Marcou)
Phricodothyris perplexa (McChesney)
Composita subtilita (Hall)
Wellerella osagensis (Swallow)
Rhynchopora n. sp. *R. taylori* Girty
Punctospirifer sp.
Edmondia? sp. indet.
Peripristis semicircularis (Newberry and Worthen)

USGS collection f-12486. From top of same unit and from same location as preceding collection.

Bradyina sp.
Millerella sp.
Triticites sp. aff *T. cullomensis* Dunbar and Condra, 1928

The megafossil collection (USGS 16788) cannot be precisely correlated with any of the collections from Lisbon Valley: (E. L. Yochelson and Helen Duncan, written commun., 1957).

> "Though it contains most of the faunal elements found in the other collections as a whole, individually it has a far more varied fauna. This may be a matter of facies or may be a matter of age difference."

As to the microfossils, R. C., Douglass (written commun., 1958) says:

> "Comparison of the Moab area sample, f-12486, with those from Lisbon Valley indicates that no precise correlation is justified. The Moab sample could be correlated with any of the three upper fusuline horizons. It is most similar to samples f-12490 and f-12491 from 396 ft [unit 19 of the Lisbon Valley section] and 460 ft [unit 21 of measured section] above the base of the section." Yochelson, E. L., and Duncan, Helen, written commun., 1957.

Regional stratigraphic relations

The upper member of the Hermosa Formation is partly exposed along the Colorado River southwest of Moab, along the San Juan River west of Bluff, and in several faulted salt anticlines, but the basal part of the member is known mainly from drill holes. Because the contacts are transitional and key beds of regional extent are lacking, the thickness of the upper member is often interpreted differently by different geologists. Published isopach maps, though varying in many details, show the upper member of the Hermosa as an irregular wedge that thins southwesterly (Wengerd and Matheny, 1958, fig. 17; Wengerd, 1958, fig. 15; Fetzner, 1960, fig. 11). Irregularities in composition and thickness of the member result from a complex tectonic framework of the Paradox basin in Late Pennsylvanian time, during which arkosic red beds filled a trough on the southwest side of the rising Uncompahgre highland and interfingered further southwest with normal marine sediments on the bordering shelves (Wengerd and Mathney, 1958; fig.f 15; Fetzner, 1960, fig. 11).

The exposed part of the Hermosa in Lisbon Valley is composed of clastic sediments and minor limestone and may be considered transitional between the marine carbonate section of the buried part of the Hermosa and the continental sediments of the Cutler Formation. The exposed Hermosa is divided into two parts on the geologic map (fig. 3). The contact selected to divide the exposed Hermosa is the base of a distinctive yellowish-gray unit of fossil plant-bearing fine-grained sandstone and shale, unit 22 of the measured section about 280 feet below the top of the formation. This basal unit overlies a thin but persistent fusulinid-bearing limestone bed. The upper part is generally coarser grained and contains less shale and more reddish units than the lower part and thus, except for interbedded limestone, generally resembles the Cutler Formation. On the basis of field comparisons of this upper unit with outcrops of the Hermosa, Rico, and Cutler Formations near Moab, we judge that it should be included as a clastic facies of the Hermosa rather than assigned to the Rico or Cutler. Most of the Rico Formation of the Moab district (Baker, 1933) is probably correlative with the lower part of the Cutler Formation in the Lisbon Valley area.

Permian system

Cutler Formation

Distribution and thickness

The Cutler Formation crops out only in the central and northeastern parts of the Lisbon Valley area. On the southwest flank of the Lisbon Valley anticline the lower two-thirds of the Cutler forms the floors of Big Indian Valley and other smaller valleys northwest of Three Step Hill; the upper third commonly forms a corrugated slope that becomes increasingly steep near the contact with the overlying Chinle Formation. Around the southwest side of South Mountain red beds assigned to the Cutler are relatively nonresistant and form rough slopes that are mostly covered by surficial material.

On the southwest flank of the Lisbon Valley anticline the Cutler Formation is about 1,480 feet thick near Little Valley, but due to truncation by the unconformity at the base of the Chinle Formation, the Cutler is several hundred feet thinner at the head of Big Indian Valley. The Cutler apparently thickens southwestward off the flank of the Lisbon Valley anticline; Kunkel (1958, fig. 1) reports a thickness of more than 1,700 feet of Permian clastics in the Gulf No. 1 Hart Point well in the southwest part of the area, in T. 31 S., R. 22 E., San Juan County, Utah.

Lithology

The Cutler Formation in the central part of the Lisbon Valley area is an assemblage of red beds consisting mainly of arkosic sandstone and conglomerate and micaceous siltstone and mudstone. A representative section of the Cutler Formation describing the rocks characteristic of the formation in the Lisbon Valley area is given below. Comparison of this section with that given for the Hermosa Formation, beginning on page 33, shows that clastic units in the two formations are much alike. The following section, measured with hand level and tape by G. W. Weir and C. L. Dodson in 1954, was described from exceptionally fine exposures of the Cutler along a prominent ridge about 0.5 mile northeast of Little Valley.

Section of the Cutler Formaton measured along a south-southwesterly traverse in secs. 21 and 29, T. 30 S., R. 25 E., Sand Juan County, Utah

Thickness (feet)

Cutler Formation:

39. Sandstone (50 percent) and silstone (50 percent). Sandstone, light-greenish-gray (5GY 8/1), pale-olive (10Y 6/2) and pale-reddish-brown (10R 5/4); weathers white (N 9) and pale reddish brown (10R 5/4); fine to very fine grained and silty; fair sorted, composed of quartz, feldspar, and minor white mica with common black accessory minerals; poorly cemented, partly calcareous. Siltstone, grayish-red (10R 4/2) and dark-yellowish-orange (10YR 6/6); contains fine grains of quartz and small flakes of muscovite; poorly cemented, noncalcareous. Unit forms slope. Dark-yellowish-orange siltstone, 6.5 in. thick at top. Unconformably overlain by light-gray, cross-stratified conglomerate and sandstone of the Moss Back Member of the Chinle Formation....................................12.3

38. Sandstone, dark-reddish-brown (10R 3/4) and pale-greenish-yellow (10Y 8/2); weathers dark reddish brown (10R 3/4) and grayish orange (10YR 7/4); fine to medium grained, fair sorted; composed of subangular grains of quartz, feldspar, and colored chert and flakes of muscovite and abundant black accessory minerals; firmly cemented, calcareous; cross stratified in planar sets of low-angle cross laminae; forms minor ledge..3.0

37. Siltstone (70 percent), sandstone (25 percent), and limestone (5 percent) similar to unit 35 but near middle of unit are thin beds of greenish-gray (5GY 6/1) silty limestone, containing abundant green and white mica. Siltstone is micaceous; grades locally to silty limestone. Upper 50 ft of unit forms steep earthy slope and has reddish-brown cast; basal 20 ft of unit forms bench and has orange cast...73.9

36. Sandstone, moderate-reddish-brown (10R 4/6) and yellowish-gray (5Y 8/1); weathers moderate reddish brown (10R 4/6) and moderate reddish orange (10R 6/6); medium to fine grained, fair-sorted; composed of quartz, feldspar, colored chert, and white and green mica; firmly to well cemented, calcareous; medium- to small-scale cross lamination with much-contorted lamination; not fissile; forms knobby rounded cliff..10.2

35. Sandstone (80 percent) and siltstone (20 percent). Sandstone, pale-reddish-brown (10R 5/4) and light-greenish-gray (5GY 8/1); weathers dark reddish brown (10R 3/4) and moderate reddish brown (10R 4/6); fine to very fine grained and silty, fair sorted; composed of amber-stained quartz, feldspar(?), and white mica with abundant orange and black accessory minerals; firmly cemented, calcareous. Basal 6 in. of sandstone is poorly sorted and contains medium- to coarse-grained quartz and chert. Siltstone, dark-reddish-brown (10R 3/4), micaceous; forms discontinuous beds 2 to 5 in. thick in middle part of unit. Unit forms irregular ledge....................................5.8

34. Siltstone (70 percent), sandstone (25 percent), and limestone (5 percent). Same as unit 33 except contains thin beds of limestone, pale-red (5R 6/2) and grayish-yellow-green (5GY 7/2); weathers moderate reddish orange (10R 6/6), very finely crystalline; in beds 1 to 2 in. thick. Unit forms earthy rounded slope. Poorly exposed...41.2

33. Sandstone, pinkish-gray (5YR 8/1); weathers very pale orange (10YR 8/2); fine grained, fair sorted; composed of clear quartz and feldspar with abundant orange, yellow and black accessory minerals; well cemented, calcareous; very low angle cross stratification; lenticular; not fissile; forms conspicuous minor ledge..2.1

32. Siltstone (60 percent) and sandstone (40 percent). Siltstone, dark-reddish-brown (10R 3/4); contains fine grains of subrounded quartz and mica flakes as much as 1 mm in diameter; poorly cemented, calcareous; stratification obscure; nonresistant, forms earthy slopes. Sandstone, moderate-reddish-brown (10R 4/6) and light-greenish-gray (5GY 8/1); weathers moderate reddish brown (10R 4/6) and grayish orange (10YR 7/4); very fine grained, fair sorted; composed of subrounded quartz, feldspar, and biotite and muscovite with abundant orange and green accessory minerals; firmly cemented, calcareous; stratification obscure; platy splitting; generally forms thin ledges 2 to 4 in. thick; mostly in upper half of unit. At 6 ft is lenticular bed of red sandstone about 3 ft thick which thickens immediately south of line of section to more than 4.5 ft.................15.7

31. Sandstone (60 percent), mudstone (25 percent), and limestone (15 percent). Sandstone, similar to unit 30; forms prominent ledge at top of unit, and thin beds at base of unit. Siltstone, pale-reddish-brown (10R 5/4), very fine sandy and micaceous; grades into limestone by increasing lime content and decrease in average grain size; well cemented, very calcareous; horizontally laminated. Interbedded wtih thin limestone and sandstone beds in lower half of unit. Limestone, pale-reddish-brown (10R 5/4), very finely crystalline, very silty and in part fine sandy; grades to siltstone; horizontally thin bedded; intercalcated with mudstone and sandstone at base of unit. No identifiable fossils, but poorly preserved irregular structures are possibly organic in origin...8.1

30. Sandstone, dominantly very pale orange (10YR 8/2), minor pale-reddish-brown (10R 5/4), fine-grained, well-sorted; composed of subrounded clear quartz and feldspar with minor orange chert and biotite with common black and orange accessory minerals firmly cemented, calcareous. Cross laminated in small-to medium-trough sets. Forms prominent light-colored irregularly rounded to sheer cliff. This conspicuous unit is truncated by the unconformity at the base of the Chinle Formation at the outcrop about 4 mi northwest in Big Indian Wash from where northwestward in the subsurface it underlies the unconformity beneath many of the uranium ore bodies in the Chinle Formation..............................46.8

29. Mudstone, grayish-red (5R 4/2); weathers same and moderate reddish brown (10R 4/6), dominantly silty, very fine sandy, very micaceous; poorly to firmly cemented, calcareous and clay binding. Horizontally stratified; thinly laminated. Forms gentle slope............21.2

28. Mudstone (85 percent) and sandstone (15 percent). Mudstone, moderate-reddish-orange (10R 6/6), similar to mudstone of unit 27. Forms steep slopes under thin sandstone cap. Sandstone, very pale orange (10YR 8/2) and pale-reddish-brown (10R 4/2), very fine grained, silty, fine to medium grained, and silty to medium grained, fair to poorly sorted; composed of clear to red-stained quartz and feldspar and mica with abundant colored accessory minerals; poorly to firmly cemented, calcareous. Structureless, and cross laminated and contorted in upper sandstone. Interbedded with mudstone in upper half of unit. Top set of beds of sandstone, about 7 ft thick, is red with pale-orange cap and forms a conspicuous ledge...........69.9

27. Sandstone (70 percent) and mudstone (30 percent). Sandstone, moderate-reddish-orange (10R 6/6) and very pale orange (10YR 8/2), fine-grained; composed of clear and white quartz and feldspar, very minor biotite and muscovite with abundant colored accessory minerals; firmly cemented, calcareous. Cross laminated in medium-scale trough sets of low-angle cross laminae; in part structureless. Mudstone, moderate-reddish-orange (10R 6/6), silty and very fine sandy; firmly cemented, calcareous and clay binding; laminated. Unit forms irregular dip-slope bench with irregular ledges of sandstone...65.0

26. Sandstone (75 percent) and mudstone (25 percent). Sandstone, grayish-red (10R 4/2), minor light-yellowish-gray (5Y 9/1) and minor pale-red (5R 6/2), fine-grained and fine to very fine grained, fair to poorly sorted; composed of subangular to angular clear and red-stained quartz and feldspar and mica; firmly cemented, calcareous. Cross laminated and structureless. Upper 20 ft of unit is sandstone cliff. Patches of light yellowish gray occur irregularly on top surface of unit. Pale-red sandstone is interbedded with mudstone at base. Mudstone, pale-reddish-brown (10R 5/4), moderate-reddish-orange (10R 6/6), and very pale green (10G 8/2), commonly silty, very fine sandy, and micaceous; laminated. Persistent layer of pale-green mudstone about 0.9 ft thick at 6.5 ft above base contains irregular calcareous nodules 1/4 to 1-1/2 in. in diameter. Mudstone mainly in lower part of unit, forming cliff or steep slope below thick sandstone cap..............27.5

25. Mudstone (80 percent) and sandstone (20 percent). Mudstone, moderate-reddish-brown (10R 4/6) and dark-reddish-brown (10R 2/4), silty and very fine sandy, poorly to firmly cemented, calcareous. Sandstone, very dusky red (10R 2/2) with patches of yellowish gray (5Y 8/1), very fine grained silty, poorly sorted; similar in composition to sandstone of underlying unit; forms minor ledges near middle and at top of unit..............................34.1

24. Sandstone (85 percent) and mudstone (15 percent). Sandstone, grayish-red (5R 4/2), moderate-reddish-brown (10R 4/6), and white (N 9); weathers moderate reddish brown, white at top; fine to very fine grained, poorly sorted; composed of subangular quartz, clear and pinkish feldspar, biotite, and muscovite; mica more common in grayish-red sandstone; firmly cemented, calcareous. Cross stratified and irregularly bedded. Forms low ledges and dip-slope benches. Grayish-red sandstone forms ledge 10 ft thick, 42 ft above base. Mudstone, moderate-reddish-brown, similar to mudstone of unit 23, interbedded with sandstone.................................69.7

23. Limestone and chert (60 percent), mudstone (40 percent). Limestone, medium-olive-gray (5Y 5/1) and pale-red (10R 6/2), very fine sandy and very finely crystalline and silty, micaceous; mainly in thin beds, interstratified with mudstone. More than one-half of the limestone is replaced by white (N 9), dark-gray (N 3), and moderate-reddish-orange (10R 6/6) chert; replacement is parallel to bedding with thin skin of limestone surrounding chert. Mudstone, moderate-reddish-brown (10R 4/6), silty and very fine sandy. Unit forms bench and low slope strewn with chert fragments...15.9

22. Sandstone (65 percent), mudstone (34 percent), and limestone (1 percent). Sandstone, pale-reddish-brown (10R 5/4) and moderate-reddish brown (10R 4/6) and white (N 9); weathers mainly moderate reddish brown (10R 4/6) and pale grayish orange (10YR 8/4); white common at tops of beds on dip-slope benches; fine and fine to medium grained, fair sorted; composed of subangular clear quartz and feldspar with minor biotite with abundant colored accessory minerals; firmly cemented, calcareous. Mainly cross stratified in small- to medium-trough sets in moderate- to low-angle cross laminae. Mainly thinly laminated to thin bedded. Forms ledges and dip-slope benches--8 ft thick at 34 ft above base, 5 ft thick at 58 ft, 7 ft thick at 92 ft, and 26 ft thick at 103 ft, plus minor beds interbedded with mudstone. Mudstone, moderate-reddish-brown (10R 4/6), commonly very silty and very fine sandy, micaceous, poorly to firmly cemented, calcareous.

Horizontally laminated, commonly contorted near base of overlying sandstone. Forms slopes and bases of cliffs capped by sandstone. Limestone, light-olive-gray (5Y 6/1); weathers medium olive gray (5Y 5/1); finely crystalline; irregularly lensing; weathered surface is finely punctate. Limestone partially replaced parallel to bedding by light-bluish-gray (5B 7/1) and moderate-red (5R 4/6) chert. Limestone and chert in beds 0.5 to 1.5 ft thick at 97 ft above base of unit..129.6

21. Sandstone, dusky-red-purple (5RP 3/2) and light-brown (5YR 6/4); weathers same and grayish orange (10YR 7/4); very coarse to medium grained, poorly sorted; composed of angular to subrounded clear quartz, clear and pink feldspar, greenish biotite and rock fragments; firmly cemented, calcareous. In trough sets of low-angle cross laminae; some cross laminae contorted. Forms vertical cliff and bench on point. Nodular concretions, about 2.5 in. in diameter, common on surface.................34.3

20. Sandstone (40 percent) and mudstone (30 percent), and silty limestone (30 percent). Sandstone, grayish-red-purple (5RP 4/2), grayish-red (10R 4/2), very pale orange (10YR 8/2), and pale-reddish-brown (10YR 5/4), very fine grained and fine-grained and fine- to medium-grained, fair-sorted; composed of clear quartz and clear and pink feldspar and greenish biotite with abundant colored accessory minerals; firmly cemented, calcareous. Cross laminated and thin bedded in lenses forming thin ledges mainly in lower two-thirds of unit. Mudstone, pale-reddish-brown (10R 4/6), dominantly silty, some very fine sandy; gradational with limestone; micaceous. Sparse ripple marks, laminated. Forms slopes between sandstone and limestone beds; poorly exposed. Silty limestone, pale-red (10R 6/2), pale-reddish-brown (10R 5/4), and very light gray (N 8); weathers pale red (10R 6/2); very finely crystalline with abundant silt and common very fine sand; very thin bedded; weathered surface finely punctate. Unit forms irregular benches and slopes...........94.5

19. Limestone (75 percent) and chert (25 percent). Limestone, medium-olive-gray (5Y 5/1), weathers olive gray (5Y 4/1) with spots of dark greenish gray (5GY 4/1); very finely crystalline. Forms dip-slope bench. Weathered surface finely punctate. Sparse poorly preserved, unidentifiable fossils. Chert, medium-dark-gray (N 4) and white (N 9); in veins along joints and as irregular masses in limestone. Unit is persistent................................2.5

18. Mudstone, moderate-reddish-orange (10R 6/6), similar to unit 14...6.0

17. Sandstone (70 percent) and mudstone (30 percent). Sandstone, white (N 9) and very light gray (N 8) with rare moderate-reddish-brown (10R 4/6), very fine grained, well-sorted; composed of subangular to subrounded clear quartz and feldspar and greenish-black biotite with common colored accessory minerals; firmly cemented, calcareous. Obsurely cross stratified in trough sets of very low angle thin cross laminae. Forms thin conspicuous ledges--1.3 ft thick at base, 0.7 ft thick in center, and 2 ft thick at top. Mudstone, moderate-reddish-orange (10R 8/6), similar to mudstone in unit 14...6.8

16. Mudstone (90 percent) and sandstone (10 percent). Mudstone, moderate-reddish-brown (10R 4/6), silty and very fine sandy; sparse to common mica; very thin bedded; mostly poorly exposed. Sandstone, similar to mudstone, very fine grained, silty................37.2

15. Sandstone (95 percent) and mudstone (5 percent). Sandstone, pale-reddish-brown (10R 5/4) and light-greenish-gray (5GY 8/1), weathers pale reddish brown (10R 5/4), similar to unit 12. Forms prominent cliff on point..26.9

14. Mudstone (95 percent) and sandstone (5 percent). Mudstone, moderate-reddish-orange (10R 6/6) and pale-red (5R 6/2), slightly micaceous; poorly to firmly cemented, calcareous; laminated and very thinly bedded; forms steep slope. Sandstone, yellowish-gray (5Y 8/1), very fine grained, silty; composed of subangular quartz and feldspar; firmly cemented, calcareous; very thin bedded; forms inconspicuous thin ledges in mudstone......................................59.3

13. Mudstone and fossiliferous limy siltstone (90 percent) and sandstone (10 percent). Mudstone, pale-reddish-brown (10R 5/4), silty and very fine sandy, commonly micaceous, poorly to firmly cemented, calcareous, laminated, poorly exposed. Limy siltstone contains very poorly preserved fossil fragments, probably crinoid stems; occurs as float about 35 ft above base. Sandstone, moderate-reddish-orange (10R 6/6) and grayish-yellow (5Y 8/4), very fine grained and medium- to coarse-grained, fair to poorly sorted; composed of clear quartz, clear and pink feldspar, green biotite, rock fragments with abundant colored accessory minerals; firmly cemented, calcareous; laminated and thin bedded; forms conspicuous ledges at 44 to 47.5. ft and at 63 to 66 ft; from 83 ft to top is a sandstone with some mudstone, forming dip slope............................102.6

12. Sandstone (90 percent) and mudstone (10 percent). Sandstone, grayish-red (10R 4/2), very pale orange

(10YR 8/2), light-greenish-gray (10YR 8/1); weathers pale reddish brown (10R 5/4) with a few streaks of dark yellowish orange (10YR 6/6), medium to fine grained, fair sorted; composed of subangular, clear quartz and clear and pink feldspar with greenish-black biotite and minor muscovite and kaolinite with abundant colored accessory minerals; poor to fair cemented, calcareous with some clay binding; laminated and thin bedded, in part cross laminated with common contorted laminations. Mudstone, pale-red (5R 6/2), dominantly clayey; occurs as thin lenses and seams along partings in sandstone. Unit as whole forms prominent ledge on point and long irregular dip-slope bench............22.3

11. Mudstone (65 percent), sandstone (30 percent), and limy siltstone (5 percent). Mudstone, pale-reddish-brown (10R 5/4), silty and very fine micaceous, firmly cemented, calcareous and clay binding; thin to thickly laminated; forms slope between sandstone units. Sandstone, pale-reddish-brown (10R 5/4) with pale-greenish-gray (5G 8/1) blotches, fine to very fine grained, fair-sorted; composed of clear quartz and feldspar and greenish biotite; firmly cemented, calcareous; laminated, irregularly interbedded with mudstone. Limy siltstone, pale-reddish-brown (10R 5/4), in part very fine sandy, micaceous; well cemented; in very thin beds, weathering to nodular fragments on dip slope. Abundant trace fossils in sandstone in upper part of unit..............................65.0

10. Sandstone (80 percent) and mudstone (20 percent). Sandstone, light-greenish-gray (5G 8/1) and pale-reddish-brown (10R 5/4), weathers pale reddish brown (10R 5/4); fine to medium grained, fair sorted; composed of subangular clear quartz and feldspar and greenish-black biotite with common colored accessory minerals; fair cemented, calcareous. Laminated in bottom part, upper 9 ft structureless. Sandstone occurs as ledge 3 ft thick at bottom and ledge 10.8 ft thick at top and as thin beds of sandstone irregularly intercalated in mudstone. Mudstone, pale-reddish-brown (10R 5/4); weathers same with some spots of greenish gray (5G 6/1); silty with abundant very fine mica giving high luster to surface of laminae; well cemented, calcareous...33.8

9. Mudstone, dark-reddish-brown (10R 3/4); weathers moderate reddish brown (10R 4/6); silty and micaceouos. Forms slope. Poorly exposed. Unit may contain some thin beds of reddish fine-grained sandstone..........................54.2

8. Sandstone and conglomeratic sandstone, grayish-red (5R 4/2) and pale-reddish-brown (10R 5/4) with blotches of pale reddish orange (10YR 8/2), medium-

to coarse-grained and conglomeratic; poorly sorted; composed of subangular clear quartz, clear pink and weathered pale-orange feldspar, greenish biotite and small rock fragments with abundant colored accessory minerals. Pebbles dominantly 0.5 to 1.5 in. in diameter; consist of igneous and metamorphic rocks similar to those noted in unit 5; pebbles occur irregularly in pockets throughout unit; poorly to firmly cemented, calcareous. Cross-stratified in medium-scale trough sets of low-angle cross-laminae. Forms irregular slope and dip-slope bench....................25.9

7. Mudstone (75 percent), sandstone (20 percent), limy siltstone (5 percent). Same as unit 6 but contains limy siltstone, pale-red (10R 6/2); weathers same or lighter; very fine sandy with sparse medium grains of quartz, mica, and feldspar; well cemented with fine to medium crystalline calcite; weathered surface finely punctate; unidentifiable small fragments possibly fossils.............................44.0

6. Sandstone (70 percent) and mudstone (30 percent). Sandstone, pale-reddish-brown (10R 5/4) with minor pale-red-purple (5RP 6/2) and blotches of pale greenish yellow (10Y 8/2), very fine grained and silty, fair sorted; composed of angular clear quartz and feldspar with common mica flakes; well cemented, very calcareous; irregularly bedded. Forms two ledges 10 ft and 4 ft thick separated by 8 ft of mudstone. Mudstone, moderate-reddish-orange (10R 6/6), silty, firmly cemented, very calcareous, poorly exposed..................................22.0

5. Mudstone (80 percent) and sandstone (20 percent). Mudstone, dark-reddish-brown (10R 3/4), silty and very micaceous; thinly horizontally laminated. Forms slopes covered with chips 0.5 in. across. Sandstone pale-red (10R 6/2) and grayish-red (10R 4/2) and pale-greenish-yellow (10Y 8/2), fine- to medium-grained; composed of red-stained quartz and feldspar and greenish-black biotite with abundant colored accessory minerals; firmly cemented, calcareous; cross-stratified in medium-scale trough sets of low-angle cross laminae. Forms low irreglar ledge ranging from about 1 to 6 ft thick..................................46.7

4. Sandstone (90 percent), mudstone (7 percent), and conglomerate (3 percent). Sandstone, pale-reddish-brown (10R 5/4) and grayish-red (10R 4/2); weathers same with common lighter streaks; coarse- and medium- to fine grained, poorly sorted; composed of clear quartz, clear and pink feldspar, greenish-black biotite minor clear muscovite and rock fragments with common colored accessory minerals; poorly to firmly cemented, calcareous and clay binding. Abundant medium-scale trough sets of cross laminae, cross laminae commonly contorted. Mudstone, moderate-brown (5YR 3/4) and dark-reddish-brown

(10R 3/4), micaceous and fine sandy; occurs as irregular lens about 2 ft thick in line of section in upper half of unit; thickens northwestward. Conglomerate, moderate-reddish-orange (10R 6/6); weathers moderate reddish (10R 4/6); coarse-grained matrix similar to sandstone described above. Pebbles dominantly about 1.5 in. but as much as 3 in. in diameter, consist of pink granite, light-gray aplite, clear and white quartz, white gneissic granite, gray hornfels, schist, sandstone and well-cemented, calcareous claystone. Occurs as irregular pods and lenses up to 1 ft thick at base of unit. Unit as a whole forms prominent double ledge with nick point at mudstone layer..42.0

3. Mudstone (75 percent) and sandstone (25 percent) and fossiliferous limestone. Mudstone, moderate-reddish-brown (10R 4/6) and grayish-red (5R 4/2), silty, clayey and very fine sandy with abundant very fine grained mica; poorly to firmly cemented, calcareous and clay binding; forms slopes; poorly exposed. Sandstone, pale-red (10R 6/2); weathers pale reddish brown (10R 5/4), medium grained, poor to fair sorted; in thin beds, partly cross stratified grouped in isolated lenses which form irregular ledges. Limestone, light-olive-gray (5Y 6/1) to olive-gray (5Y 4/1), very finely crystalline; contains common crinoid fragments; weathered surface is very finely punctate; found only as float..70.9

2. Sandstone, pale-grayish-red (5Y 5/2) and light-greenish-gray (5G 8/1); weathers same and moderate greenish yellow (10Y 7/2) and pale greenish yellow (10Y 8/2), fine to medium grained, fair sorted; composed of clear quartz, clear and pink feldspar, greenish-black biotite and minor clear muscovite with common green, orange, and black accessory minerals; firmly cemented, calcareous. Irregularly bedded, partly horizontal and partly cross stratified. Forms rough ledge and dip-slope bench..7.0

1. Mudstone (70 percent) and sandstone (30 percent). Mudstone, pale-red (5R 6/2) and grayish-red (10R 4/2); common pale-olive (10Y 6/2) streaks in lower part, dominantly silty near base and dominantly clayey near top; poor to fair cemented, clay binding and calcareous cement; laminated; forms slope. Sandstone, pale-red (10R 6/2) and grayish-red (10R 4/2) with minor light greenish gray (5G 8/1), fine grained to very fine grained and silty, fair sorted; composed of angular white quartz, white and orange feldspar, greenish-black biotite and clear muscovite with abundant red, green, and black accessory minerals; firmly cemented, calcareous, and clay binding; in thin beds and thin sets of laminae in mudstone; forms prom-

inent minor ledges. Contact between Cutler Formation and Hermosa Formation is placed at top of a sparsely fossiliferous marine limestone that forms a conspicuous and persistent hogback and dip-slope...............24.5

Total Cutler Formation........1,480.4

The dominant colors of the Cutler Formation are pale to dark reddish brown and grayish red. Reddish-purple and dark reddish-brown coarse-grained units are common in the lower part of the formation. Very pale orange, fine-grained sandstone units are conspicuous because of their light color in the upper part of the formation.

Conglomerate beds probably make up less than 2 percent of the formation but they form prominent outcrops in the lower part of the Cutler. The pebbles are as much as 3 inches in diameter, and consist of clear and white quartz, pink granite, white gneissic granite, light-gray aplite, gray hornfels,gray schist, sandstone, and claystone. Sandstone units range from silty, fine grained to very coarse grained. All contain abundant feldspar and, except for light-colored, fine-grained units in the upper part of the formation, most are micaceous. Siltstone and mudstone make up more than half the formation and commonly are darker and more micaceous than adjacent sandstone units.

Thin, discontinuous beds of gray and pale-red limestone, commonly less than a foot thick, occur sparsely in the lower part of the formation. Most of these limestone beds are sandy and silty, partly converted to gray and red chert, and show no trace of fossils. A few isolated lenses of gray limestone and limy siltstone mostly near the base of the formation contain marine fossils.

The name Culter Formation in this report is also applied to a poorly exposed sequence of red beds in South Mountain that in part is similar to the Cutler Formation exposed along Big Indian Valley. Conglomerate and coarse-grained sandstone, which are conspicuous in the Cutler outcrops of Big Indian Valley, are not present in the South Mountain exposures. The mountain sequence is more than 500 feet thick and consists mainly of reddish-and yellowish-gray, fine-grained arkosic and micaceous sandstone and micaceous grayish-red siltstone with some red mudstone-pebble conglomerate and yellowish-brown, solution-pitted, unfossiliferous, very finely crystalline linestone containing grains and chips of red mudstone. Possibly this sequence contains unrecognized equivalents of the Moenkopi Formation of Triassic age or of the Hermosa Formation of Pennsylvanian age.

Contacts

The basal contact of the Cutler Formation in the Lisbon Valley area is the top of the highest persistent fossiliferous marine limestone of the Hermosa Formation. Along the northeast side of Big Indian Valley this limestone is commonly 2 to 4 feet thick and generally forms a short but conspicuous dip slope. It contains scattered shell and crinoid stem fragments. Clastic beds above and below this persistent limestone bed are much alike, and if the persistent limestone beds of the Hermosa were lacking, the Cutler Formation could not be readily differentiated from the upper part of the Hermosa.

The basal part of the Cutler Formation contains a few thin fossiliferous marine limestone and limy siltstone lenses. Most of these lenses are less than a foot thick and less than 100 feet long. The lenses occur sporadically and, although not confined to particular horizons, are mostly in the basal 100 feet of the Cutler. The highest fossiliferous marine limestone noted in the field occurs about 300 feet above the base of the formation. Because of their thinness and discontinuity, these limestone lenses in the lower part of the Cutler are not easily confused with the top limestone bed of the Hermosa Formation.

The base of the Cutler Formation is not exposed in the La Sal Mountains. The formation is intruded by the diorite porphyry of South Mountain.

The Cutler Formation is separated from the Chinle Formation by a regional unconformity in the central part of the Lisbon Valley area and probably also in the La Sal Mountains. In the subsurface of the western part of the area, where the Cutler is overlain by the Moenkopi Formation, the contact is also probably erosional.

Age

Most thin lenses of limestone in the lower part of the Cutler Formation in the Lisbon Valley area are unfossiliferous or contain only a few broken bits of shells and crinoid stems. About 300 feet above the base of the Cutler Formation a fossiliferous limestone lens, less than 1 foot thick and only a few hundred feet long, crops out about 1.2 miles northeast of Big Indian Rock in SW1/4, sec. 18, T. 30 S., R. 25 E., San Juan County, Utah. This lens yielded the following forms, identified by E. L. Yochelson (written commun., 1960):

Juresania cf. *J. nebrascensis* (Owen)
Allorisma terminale (Hall) (abundant)
myalinid? pelecypod indet.
Aviculopecten sp. indet.
parallelodontid? pelecypod, indet.
Schizodus sp. indet.
Knightites (*Retispira*) cf. *K.* (*R.*) *eximia* Yochelson, (abundant)
moderately high-spired gastropod cf. *Yunnania*
euomphalid gastropod, indet.
bone fragment, undet.

Yochelson compared this collection with earlier collections made near Moab by Baker (1933) and McKnight (1940) and noted that the fauna resembles that of their "Shafer limestone" of the Rico Formation.

The Rico Formation is presently considered to be of Late Pennsylvanian and Permian age. Fossil foraminifera from the Rico of the San Juan Mountains, Colorado and from near Moab, Utah indicate a Late Pennsylvanian age (Henbest, 1948), although macrofossils from these areas have been interpreted as possibly or probably Permian (Williams, J. S., 1949, p. 21-24; Baker, 1933, p. 26; Baker, 1946, p. 35). In the subsurface about 25 miles west of Moab marine limestone interstratified with red beds is reportedly of Wolfcampian (Permian) are (Herman and Sharps, 1956, p. 82). The transitional facies of the Rico apparently rises in the time scale from its type area toward the west and southwest (Henbest, 1948).

The Cutler Formation on the Colorado Plateau is regarded as Permian largely on the basis of its stratigraphic position between Pennsylvanian-Permian and Triassic units, for it has yielded few fossils. Because the Cutler rests on the Hermosa Formation at its type locality on the San Juan Mountains and at many localities along the front of the Uncompahgre uplift (Herman and Sharps, 1956, p. 82), part of the Cutler in southwestern Colorado and southwestern Utah has long been recognized as possibly Pennsylvanian. Fossil vertebrates collected from the Cutler Formation near Placerville, Colo., just north of the San Juan Mountains, indicate that the formation is either very Early Permian or latest Pennsylvanian (A. S. Romer and G. E. Lewis, quoted by Bush and others, 1959, p. 313). Fossil plants collected from the Cutler in Indian Creek Valley about 6 miles west of the Lisbon Valley area, also suggest either a Pennsylvanian or Permian age (Baker, 1933, p. 33). Fossil plants and fragmental vertebrate remains collected from the upper part of the Cutler in Monument Valley near the Arizona-Utah line were determined as Permian in age (Baker, 1936, p. 35). The red beds of the Cutler in the Lisbon Valley area contain only a few pieces of silicified wood and very sparse bone fragments. Because the Cutler of the Lisbon Valley area rests conformably on Upper Pennsylvanian limestone and contains beds probably equivalent to the Rico Formation of the Moab district, the Cutler Formation of the Lisbon Valley area perhaps contains the Permian-Pennsylvanian time surface, but it seems reasonable to infer that most of the red bed sequence above the highest limestone lens in the section in Early Permian in age.

Regional stratigraphic relations

Rico Formation

The regional stratigraphy and age determination of the Cutler Formation of Lisbon Valley involve the stratigraphy of the Hermosa and Rico Formations. The possibility that the Rico is represented in large part by what is called Hermosa Formation in the Lisbon Valley area has been previously mentioned. Here it is appropriate to discuss the definition, regional stratigraphy and fossil content of the Rico, for though this formation is not recognized in the Lisbon Valley area, outcropping beds both to the east (Cater, 1955b; Withington, 1955) and to the west (Baker, 1933) have been assigned to the Rico Formation.

The Rico Formation consist in its type area of the Rico Mountains in southwestern Colorado of about 300 feet of dull-red sandstone and conglomerate and minor amounts of interbedded shale and sandy fossiliferous marine limestone (Cross and Spencer, 1900; Cross and Ransome, 1905). The formation is a transitional unit between the dominantly marine Hermosa and the continental Cutler, but lithologically the Rico more closely resembles the Cutler than the Hermosa. The base of the formation was designated as the top of the highest limestone that contains Hermosa faunas, which are composed mainly of brachiopods in contrast to Rico faunas that contain a relatively larger proportion of pelecypods. The top of the formation was defined as the highest fossiliferous limestone in the dominantly red bed sequence. In and near the type area exposures are poor and the occurrence of fossils sporadic, so that the upper contact of the Rico is admittedly of only local significance and does not mark an otherwise recognizable lithologic or stratigraphic break. Despite difficulties in defining consistently the contacts of the Rico, the formation is said to be a readily recognizable lithologic unit near the type area and to be valuable in working out details of structure (Eckel, 1949, p. 13).

About 20 miles east of the Lisbon Valley area Cater (1955b) mapped a sequence of beds, which overlie fossiliferous marine limestone and thin shale beds of the Hermosa Formation, as "Cutler and Rico Formations undivided". The lower part of this sequence consists of alternating beds of marine limestone and arkosic material, lithologically similar to the Rico Formation of the San Juan Mountains; the upper part consists of red and maroon arkosic sandstone and conglomerate and reddish-brown sandy mudstone and corresponds lithologically and in stratigraphic position to the Cutler Formation.

About 12 to 20 miles west of the Lisbon Valley area along the Colorado River, Baker (1933) applied the name "Rico Formation" to a sequence of coarse-grained to conglomeratic arkosic sandstone, red to lavender shale, and several thin layers of limestone. The basal contact is placed at the base of a limestone containing a Rico fauna characterized by an abundance of pelecypods in contrast to the brachiopod fauna of the underlying Hermosa (Baker, 1933, p. 25-26). Baker mapped the upper contact of the Rico as the top of the "Shafer limestone" of local usage, which over a large part of the Moab district is the highest marine limestone in the section. This limestone bed pinches out near Moab, and northeast of Moab the Rico Formation is not recognized, because the equivalent clastic beds are indistinguishable from the Cutler formation (Dane, 1935, p. 35). In other parts of the Moab district other marine limestone beds, more than 120 feet apart and lying both below and above the horizon of the "Shafer limestone", are the highest fossiliferous units in the section and mark the local top of the Rico. Generally, the limestones of the upper Rico increase in prominence toward the southwest (McKnight, 1940, p. 27).

In summary, the Rico Formation has been long recognized on the Colorado Plateau and its type area as a unit lithologically transitional between the Hermosa and Cutler Formations but having generally a closer resemblance to the Cutler. The base of the formation has frequently been placed at a faunal break in the fossiliferous limestone beds, though Williams, J. S., (1949, p. 24) minimized the importance of this break and reported that in the San Juan Mountains faunas of so-called Hermosa aspect have been collected above faunas of so-called Rico aspect. The upper contact of the Rico at the top of the highest fossiliferous limestone differs from locality to locality.

The Rico formation is not recognized in the Lisbon Valley area, because no major faunal or lithologic break was detected in the fossiliferous limestone sequence that was mapped as the Hermosa Formation, and the marine limestone beds in the lower part of the Cutler were too few and too discontinuous to warrant subdivision. The red bed sequence containing the limestone lenses, however, probably correlates with the Rico Formation of the Moab district.

Cutler Formation

The Cutler Formation at its type locality on Cutler Creek near Ouray in the San Juan Mountains, Colorado, is a red-bed sequence consisting mainly of coarse-grained sandstone and conglomerate and some shale (Cross and Howe, 1905). It retains this conglomeratic character throughout southwestern

Colorado and into part of southeastern Utah. Farther west in most of southeastern Utah and in northern New Mexico and Arizona the Cutler is finer grained and made up of red beds alternating and interfingering with light-colored cross-bedded sandstone (Baker and Reeside, 1929) and is divided into as many as seven members (Stewart and others, 1959, p. 495-496; Kunkel, 1958).

In the southern part of the Moab district near the southwest corner of the Lisbon Valley area, Baker (1933, p. 32; 1946, p. 43) divided the Cutler Formation into two members, in ascending order, the Cedar Mesa Sandstone Member, consisting mostly of light-colored cross-bedded sandstone, and the Organ Rock Tongue, consisting mainly of red siltstone and fine-grained sandstone. These members cannot be recognized in the northern part of the Moab district or in the Lisbon Valley area, where the Cutler is much like the conglomeratic facies of the formation at its type locality. Some light-colored cross-bedded and massive sandstone in the upper part of the Cutler of the Lisbon Valley area strongly resembles beds characteristic of the Cedar Mesa Member, and some sequences of fine-grained sandstone and siltstone are much like the Organ Rock Tongue.

Triassic system

Lower and Middle (?) Triassic series

Moenkopi Formation

Distribution and thickness

The Moenkopi Formation is exposed only in Hatch Wash and Kane Springs Canyon at the western edge of the Lisbon Valley area. It is missing in the Big Indian Valley, Three Step Hill, and the South Mountain outcrops of Triassic rocks. These localities are probably near the eastern edge of the Moenkopi; if the formation was deposited here, it was removed during pre-Chinle erosion. Possibly it is present in the subsurface in the Lisbon Valley are, for reddish-brown shale and interbedded sandstone from drill-holes southwest of Big Indian Valley have been tentatively identified as Moenkopi (Lekas and Dahl, 1956, p. 161; Anon., 1960). Similar rocks, however, occur within the Cutler Formation of Permian age.

The maximum exposure of the Moenkopi Formation in the area is about 100 feet in Hatch Wash. In the nearest exposures of the complete formation in the valley of Indian Creek and in Lockhart Canyon, about 10 miles west of the Lisbon Valley area, the Moenkopi is about 200 feet thick (Stewart and others, 1959, fig. 71).

Lithology

The exposed part of the Moenkopi formation in the Lisbon Valley area consists of grayish-red and minor moderate-reddish-brown, thin-bedded, fine-grained rocks that range from clayey mudstone to silty, very fine grained sandstone. The rocks are horizontally stratified in units generally only a few inches thick. Most bedding planes have a distinct sheen owing to the presence of finely divided mica flakes. Ripple marks, mudcracks, and veinlets of silty sandstone in mudstone units are common sedimentary structures. The Moenkopi Formation is less resistant than the overlying Chinle Formation and commonly forms a recess and a steep slope beneath the coarse-grained rocks at the base of the Chinle.

Contacts

The contact between the Moenkopi Formation and the underlying Cutler Formation is not exposed within the Lisbon Valley area. In nearby areas this contact in places is erosional but commonly it is difficult to recognize, because the formations are lithologically similar and concordant (Shoemaker and Newman, 1959, p. 1837; Stewart, 1959, p. 1862, 1965).

The upper contact of the Moenkopi Formation is a regional unconformity. The contact is emphasized by the color contrast between the brown, fine-grained rocks of the Moenkopi and the gray, coarser grained rocks of the basal Chinle, and in most places by conspicuous scours and discordance of beds.

Age and stratigraphic relations

The Moenkopi Formation, named for exposures at the mouth of Moenkopi Wash in northeastern Arizona (Ward, 1901), extends over most of the Colorado Plateau. It thins eastward from a maximum thickness of more than 2,000 feet in southwestern Utah (McKee, 1954, p. 5-10). Marine fossils from limestone beds mainly in southwestern and central Utah and vertebrate remains from red beds mainly in northeastern Arizona indicate that the Moenkopi Formation over most of the Colorado Plateau is probably of Early and Middle Triassic age (McKee, 1954, p. 10-11, 67-75).

The distribution of the Moenkopi in the salt anticline region, which includes the Lisbon Valley area, has been likened to that of a blanket of irregular thickness with several large holes in it, due to erosion prior to deposition of the Chinle or to nondeposition (Shoemaker and Newman, 1959, p. 1837). The formation is well exposed to the west and locally to the north and northeast of the Lisbon Valley area; it probably pinches out in the subsurface east of the area in southwestern Colorado.

The Moenkopi formation in and near the salt anticline region has yielded few fossils, but a poorly preserved ammonite, probably the Early Triassic genus <u>Meekoceras</u>, has been found in limestone beds in the Salt Valley anticline (Dane, 1935, p. 43; Shoemaker and Newman, 1959, p. 1849) and on the Green River (McKnight, 1940, p. 57-58). Shoemaker and Newman (1959, p. 1849-1850) conclude that most of the Moenkopi Formation in the salt anticline region of Colorado and Utah is probably older than the Moenkopi of the type section, although the uppermost beds in this region may be as young as Middle Triassic. The Moenkopi near the Lisbon Valley area is considered to be of Triassic(?) and Early and Middle(?) Triassic age (Stewart, 1959, p. 1854).

The Moenkopi Formation over much of the Colorado Plateau is a combination of marine and continental sediments. The Moenkopi in and near the Lisbon Valley area is probably entirely continental. Sedimentary structures such as ripple marks, mud cracks, raindrop impressions, and casts of salt cubes indicate that the even-bedded, fine-grained red rocks of the Moenkopi were probably laid down on broad flood plains and tidal flats (McKnight, 1940, p. 58-60; McKee, 1954).

Upper Triassic series

Chinle Formation

Distribution and thickness

The Chinle Formation is exposed in the central, western, and northeastern parts of the Lisbon Valley area. The principal outcrops are on the southwest flank of the Lisbon Valley anticline extending from Big Indian Valley to Lower Lisbon Valley. The Chinle also crops out near the west edge of the area in the deep canyons of Hart Draw and Hatch Wash and in Kane Springs Canyon. In the La Sal Mountains the formation is poorly exposed for several miles on the southwest side of South Mountain and in Gold Basin. In all these areas of outcrop most of the Chinle generally forms a fairly steep slope interrupted by minor ledges and benches.

The thickness of the Chinle Formation in the western and central parts of the area averages about 400 and 450 feet. Drill-hole data from the central part of the area indicate that the buried Chinle ranges from about 340 and 480 feet in thickness (Lekas and Dahl, 1956, p. 163). Departures from the average are probably related to the variable deepness of scours at the base of the formation and to irregular internal thinning on the flanks of the Lisbon Valley salt anticline. The formation is thickest in the La Sal Mountains where in Lackey Basin it attains an estimated thickness of 600 feet.

In most of the Lisbon Valley area the Chinle Formation is divisible into two units. The lower unit in the central and western parts of the area is assigned to the Moss Back Member of the Chinle Formation. The Moss Back is a relatively thin but persistent unit characterized by gray, coarse-grained sediments. The basal member of the Chinle in the La Sal Mountains is an unnamed pebbly quartz grit, probably younger than the Moss Back Member. The upper part of the Chinle throughout the area is assigned to the Church Rock Member. It is characterized by reddish fine-grained sediments and constitutes the bulk of the formation in the Lisbon Valley area. Assignment of the lower and upper parts of the Chinle Formation of the Lisbon Valley area to the Moss Back and Church Rock Members is based largely on work published by Stewart (1957; Stewart and others 1959, p. 512-515, 517-520) but subsequently Stewart and others (1972, p. 31, 42) have cautioned that the affinity of these units in and near the Lisbon valley area to the type sections of the Moss Back and Church Rock may be questioned.

The section given below illustrates the general aspect of the formation in the central and western part of the area where it is divisible into the Moss Back and Church Rock Members. Comparison of this section with sections published by Shawe and others (1968; p. A29-A32) shows that the lithologic character of the Chinle in the central part of the Lisbon Valley area persists southeasterly into the Slick Rock district of southwestern Colorado. The following section, measured with Abney level and tape by G. W. Weir assisted by W. H. Starrett in 1953, was described from outcrops along ridges about 0.3 mile northeast of Little Valley. It is a continuation of the section in which the Cutler Formation was described on page 62.

Section of chinle Formation, measured in secs. 29, 31, T. 30 S., R. 25 E., San Juan County, Utah

Thickness (feet)

Wingate Sandtone (incomplete):

13. Sandstone, grayish-orange (10YR 7/4); weathers moderate reddish orange (10R 6/6), fine grained, composed of subangular quartz and feldspar(?) and abundant black accessory minerals; basal few feet contains laminae of coarse grains; of clear quartz and dark-gray chert; well cemented, noncalcareous; moderate-scale low-angle trough cross stratification in part, some irregular horizontal bedding; fine-grained sandstone of mud-crack fillings extends several inches into siltstone of the Chinle; forms vertical cliff; only basal few feet examined; not measured..........................

12. Siltstone (80 percent) and sandstone (20 percent). Siltstone, pale-reddish-brown (10R 5/4); abundant very fine flakes of mica; poorly cemented, partly calcareous; finely cross laminated in part, ripple marks and small contortions common; outcrop yields small chips; veinlets of calcite common in siltstone in top few feet; locally bleached to light greenish gray in top 6 in., especially around mud-crack fillings of Wingate Sandstone. Sandstone, moderate-reddish-orange (10R 6/6) and light-greenish-gray (5G 6/1); weathers moderate reddish brown (10R 4/6) with minor light greenish gray (5G 6/1), very fine grained and silty, composed of amber-stained quartz, feldspar(?) and white mica; firmly cemented, calcareous mostly horizontally laminated, in part cross laminated; forms discontinuous ledges, as much as 1.5 ft thick, mostly in upper half of unit. Whole unit forms steep rubbly slope with minor ledges..............................47.2

11. Mudstone (30 percent), sandstone (60 percent), and conlomerate (10 percent). Mudstone, grades to sandstone, pale-reddish-brown and pale-greenish-yellow (10Y 8/2); clayey to silty; contains abundant very fine to medium grains of quartz, claystone, and mica flakes; firmly cemented, calcareous; forms slope; mostly in upper half of unit. Sandstone, calcitic, pale-red (5R 6/2); weathers reddish brown (10R 5/4) with blotches of very pale green (10G 8/2), very fine grained, well cemented; in low-angle cross laminae; mud cracks and trace fossils abundant; forms ledges; most abundant in lower two-thirds of unit. Sandstone bed about 2 ft thick forms top of unit. Conglomerate, light-greenish-gray (5GY 8/1) and pale-reddish-brown (10R 5/4);

weathers moderate reddish orange (10R 6/6); pebbles, 5 to 50 mm in diameter, composed of claystone, gray and brown chert and quartzite; matrix is fine to very fine grained quartz sandstone grading to mudstone, forms rough spheroidal-weathering ledges; restricted to lower half of unit. Pods of crystalline calcite 1 to 4 in. across, in both conglomerate and reddish sandstone. Lower half of unit forms rough vertical cliff; upper half forms a sloping bench and steep earthy slope. Lithology and topographic expression change along strike. Abundant well-preserved fossil fish in sandstone in roof of small overhang about 25 ft above base of unit; fossil phytosaur(?) teeth scattered in sandstone and conglomerate beds in lower part of unit; silicified wood fragments common in upper part of unit................................99.8

10. Mudstone (60 percent), conglomerate (10 percent), and sandstone (30 percent). Mudstone, pale-reddish-brown (10R 5/4); contains fine to medium grains of quartz and rare clay pebbles up to 4 mm diameter, poorly cemented, calcareous. Conglomerate, pale-reddish-brown (10R 5/4); weathers same and light greenish gray (5 GY 8/1); contains granules and pebbles of chert and claystone up to 5 mm diameter, matrix is medium- to coarse-grained sandstone and calcareous mudstone; well cemented, very calcareous; forms beds 3 to 12 in. thick in middle part of unit. Sandstone, moderate-reddish-orange (10R 6/6), weathers same and light greenish gray (5G 8/1); fine grained and silty; composed of quartz, rare white mica; firmly cemented, calcareous clay binding; horizontal thin beds; ripple marks common. Unit forms rubble-covered slope; in part poorly exposed. Fossil phytosaur(?) tooth noted in conglomerate..............53.3

9. Mudstone (60 percent), sandstone (30 percent), and limestone (10 percent). Mudstone, pale-red (5R 6/2) and light-olive--gray (5Y 6/1); contains very fine grains of quartz; forms gentle to steep slope; poorly exposed. Sandstone, pale-red (5 R 6/2) and light-greenish-gray (5 GY 8/1), fine to very fine grained and silty, poorly sorted; composed of quartz, feldspar(?) and muscovite with abundant orange and black accessory minerals, firmly cemented, calcareous; in horizontal beds less than 12 in. thick; cuspate ripple marks common; outcrop yields platy fragments; forms minor ledges. Limestone, pale-yellowish-orange (10YR 8/6) and light-greenish-gray (5GY 8/1), medium crystalline; contains coarse grains and granules of quartz and feldspar and pebbles, and as much as 10 mm diameter, of chert and claystone. Unit poorly exposed...32.2

8. Siltstone (70 percent), and sandstone (30 percent). Siltstone, pale-red (10R 5/4); contains very fine grains of quartz, chert, and muscovite; poorly

cemented, calcareous; forms earthy slope. Sandstone pale-red (10R 6/2) and light-gray (N 7); weathers pale reddish brown (10R 5/4), fine to very fine grained, fairsorted; composed of amber-stained quartz, feldspar, green chert and muscovite and abundant black accessory minerals; firmly cemented; in low-angle cross beds; forms ledges as much as about 3 ft thick. Unit forms steep earthy slope with minor ledges..42.8

7. Conglomerate (50 percent), and sandstone (50 percent). Conglomerate, medium-light-gray (N 6); weathers moderate yellowish brown (10YR 5/4); irregular spheroidal to discoidal pebbles, as much as 2 cm in diameter, of mudstone, laminated siltstone, and sandy limestone; matrix poorly sorted very coarse to medium-grained sandstone, composed of gray chert, quartz, feldspar, and muscovite; firmly cemented; calcareous; stratification obscure; calcified wood common; mostly in lower part of unit. Sandstone, light-greenish-gray (5GY 8/1); weathers grayish orange (10YR 7/4); fine grained, fair sorted; composed of angular quartz, colored chert, and muscovite and abundant black and colored accessory minerals; firmly cemented, calcareous; horizontal thin bedding and low-angle crossbedding; platy to flaggy splitting; outcrop of top sandstone beds yield irregular small chips. Unit forms ledge with bench developed on top; pinches out in red siltstone a few hundred feet southeast of section..7.0

6. Sandy mudstone grading to silty sandstone, grayish-yellow-green (5GY 7/2) to dark-greenish-gray (5GY 4/1), composed of clay, silt and very fine grains of quartz, feldspar(?), white mica, and dark mica or carbonaceous specks; poorly cemented, calcareous; weathers to form fluffy earthy slope; poorly exposed.........................26.6

5. Sandstone (95 percent), and conglomerate (5 percent). Sandstone, pale-olive (10Y 6/2) and light-olive-gray (5 Y 6/1), fine- to medium-grained, poorly sorted; composed of quartz, feldspar, chert, and white mica and abundant black accessory minerals and carbonaceous flakes; firmly cemented, calcareous clay binding; in horizontal laminae and low-angle cross laminae. Conglomerate similar to sandstone except contains pebbles, as much as 8 mm diameter, of claystone and chert; most abundant at base of unit. Unit forms vertical cliff with a few thin ledges at top................10.0

4. Sandstone (25 percent), conglomerate (5 percent), mudstone (40 percent), and siltstone (30 percent). Sandstone, light-greenish-gray (5GY 8/1); weathers grayish orange (10YR 7/4); fine to medium grained fair sorted; com-

posed of quartz and feldspar and abundant black accessory minerals; firmly cemented, calcareous; horizontally laminated; platy to flaggy splitting; moderately resistant, forms thin ledges in lower half of unit. Conglomerate, light-gray (N 7) and grayish-orange (10YR 7/4), weathers very pale orange (10YR 8/2); contains well-rounded pebbles and granules of claystone and chert; matrix is sandy mudstone; firmly cemented, calcareous; forms thin rough ledges in lower one-quarter of unit. Mudstone, clayey, pale-olive (10Y 6/2), nonresistant; contains mica flakes as much as 0.5 mm diameter; outcrop yields thin, small chips; forms bench and earthy slope; mostly in lower two-thirds of unit. Siltstone, grayish-red (10R 4/2), abundant very fine to fine grains of quartz; weakly cemented, calcareous; ripple marked in part; outcrop yields small chips; forms steep slope; most abundant in upper third of unit. Lowermost third of unit forms steep slope and narrow bench; upper two-thirds of unit forms shaly slope. Member contact placed at base of lowest mudstone unit with common reddish colors....................................37.4

Total Church Rock Member........356.3

Moss Back Member:

3. Sandstone, yellowish-gray (5Y 8/1), fine-grained, fair-sorted; weathers grayish orange (10YR 7/4); composed of subangular quartz, feldspar, orange clay and dark mica and abundant black accessory minerals; well cemented, calcareous; in horizontal laminae and low-angle cross laminae; forms prominent cliff................................9.2

2. Mudstone (90 percent), and sandstone (10 percent). Mudstone, silty, medium-dark-gray (N 4), poorly cemented, calcareous. Sandstone, pale-olive (10Y 6/2), very fine grained and silty, micaceous, poorly cemented, calcareous; small-scale cross lamination and ripple marks common; abundant small limonite specks. Unit forms shaly slope between two resistant units......................16.2

1. Conglomerate (60 percent) and sandstone (40 percent). Conglomerate, very light gray (N 8) to light-gray (N 7); pebbles as much as 40 mm diameter, average about 8 mm diameter; consist of rounded, irregularly shaped claystone and quartz and chert; matrix is fine- to medium-grained silty sandstone; firmly cemented, very calcareous; crystal faces of calcite common; irregularly stratified, partly cross bedded; clay pebbles weather out leaving pits in the rock face. Sandstone, same colors as conglomerate, coarse- to medium-grained, poor-sorted; composed of quartz, feldspar, dark-colored chert, light-

orange clay flakes and with interstitial light-orange clay as common; firmly cemented, calcareous and clay binding; mostly in low-angle cross laminae, but at top of unit in horizontal thin beds; mostly in upper part of unit. Carbonaceous flakes abundant throughout unit. Unit thins south of section and possibly pinches out. Basal contact is irregular with channels having local relief of about 1 ft, an unconformity with an angular discordance about 3^{o} between basal beds of Chinle Formation and upper beds of Cutler Formation.......................................13.7

Total Moss Back Member.........39.1

Total Chinle Formation........395.4

Lithology

Moss Back member

The Moss Back Member of the Chinle Formation consists chiefly of light-colored sandstone and conglomerate and minor interbedded greenish-gray mudstone. Proportions of the different lithologic types may vary greatly in short distances along the outcrop between Big Indian and Lower Lisbon Valleys. Locally as near Lower Lisbon Valley, the sandstone and conglomerate lens out so that gray mudstone and siltstone are dominant. The member weathers to form a prominent cliff or series of ledges. Its grayish color contrasts strongly with the dominantly reddish hues of the underlying and overlying rocks.

The coarse-grained rocks of the Moss Back range from silty fine-grained sandstone to cobble conglomerate. Sand grains consist of clear quartz, gray chert, pink and clear feldspar, grayish-yellow and gray calcareous siltstone and limestone, and clear and black mica. Pebbles and cobbles consist mainly of clear quartz, gray chert and yellowish-gray limy mudstone. The most abundant rock of the Moss Back Member is pinkish-gray, poor- to fair-sorted, fine- to medium-grained sandstone composed chiefly of subangular quartz and feldspar. Most of the sandstone units in the Moss Back are feldspathic and many are arkoses. Some units, however, are nearly barren of feldspar and are made up almost entirely either of quartz or of calcareous siltstone and limestone. The units made up mostly of quartz tend to be fine grained and micaceous; those made up of calcareous siltstone and limestone are frequently coarse grained and pebbly. Carbonaceous material occurs spordically in both types of sandstone. Interstitial clay and silt are abundant and are similar to the material making up the interstratified mudstone.

The clay content of samples of the Moss Back Member from the section near Little Valley, described on pages 100-110, and from outcrops near the La Sal uranium mine near Big Indian Valley was studied by Schultz (1963, pl. 3, secs. 30 and 24). Illite makes up about 50 percent of the clay minerals in the outcrop samples. Other clay minerals present in various proportions are mixed-layer illite, mixed-layer illite-montmorillonite, mixed-layer chlorite and chlorite. This assemblage of clay minerals differs from that characteristic of the Moss Back Member in having no kaolin and more chlorite. The chlorite, Schultz (1963, p. C 36) noted, is characteristic of the member in its eastern area of outcrop, which includes the Moss Back exposures near Little Valley. Some of the sandstone and siltstone in the Moss Back of the Lisbon Valley area is tuffaceous. The volcanic material is altered rhyolite tuff, perhaps mixed with altered latitic tuff (Schultz, 1963, p. C 63; pl. 3, secs. 24, 25, 30).

At many localities several varieties of sandstone are interstratified in both broad sheet-like beds and small lenses. Commonly the varieties intergrade, but layers of calcareous grains are more or less discrete. Local variations in composition and bedding are common. Thus, near the head of Big Indian Wash the sandstone of the Moss Back Member is coalesced into a single fairly uniform bed of fine- to medium-grained arkose; near southern Lisbon Valley thin lenses of quartzose sandstone and conglomerate interstratified in mudstone are the characteristic lithology. Much sandstone is cross-stratified in small- to medium-scale, thin trough sets of low-angle cross-laminae. In the Lisbon Valley area and adjoining areas the cross strata of the Moss Back dip mainly to the northwest (Poole and Williams, 1956, fig. 50B). Many of the sandstone units are made up of irregularly lensing, horizontal beds.

Mudstone in the Moss Back Member ranges from claystone to very sandy siltstone but is chiefly siltstone. The mudstone is grayish-green except for a few patches of grayish red, found near the top of the member. Coalified plant debris is locally common in mudstone and is especially abundant in mudstone overlying sandstone near the top of the member. At most localities mudstone is interstratified throughout the Moss Back in thin lenticles and broad irregular lenses but it is most abundant in the upper half of the member.

The Moss Back Member of the Chinle Formation ranges between 30 and 50 feet in thickness over most of the area. It reaches a maximum thickness of about 90 feet in Kane Springs Canyon where, however, it may include some beds younger than typical Moss Back (Stewart and others, 1972, p. 31). Regional studies indicate that the northeast limit of the Moss Back Member lies a few miles northeast of Lisbon Valley (Stewart and others, 1959, fig. 77). Variations in the thickness of the Moss Back Member in the Lisbon Valley area are in part related to minor scouring at the base of the Chinle Formation. Most of the variation, however, is related to differences in placing the upper contact of the member which separates gray, dominantly coarse-grained rocks from reddish, dominantly fine-grained rocks. Lateral changes in grain size and color are frequent and abrupt and may result in differences in placing the upper contact of as much as 10 feet in 100 feet along strike. The upper contact is especially ill-defined and variable locally near Lower Lisbon Valley where the Moss Back is made up mostly of fine-grained rocks which differ chiefly by their gray color from the overlying reddish Church Rock Member.

The Moss Back Member is the main uranium ore-bearing unit in the Lisbon Valley area. Some lithologic features that bear on the mineralization are discussed in the descriptions of the ore deposits.

Lower part of the Chinle Formation in the La Sal Mountains

A pebbly quartz grit marks the base of the Chinle in the La Sal Mountains. This unit is persistent, although poorly exposed, on the southwest side of South Mountain and was traced from near Lackey Basin to the head of Pole Canyon. It is commonly 20 to 50 feet thick, and reaches a maximum thickness of about 85 feet near Lackey Creek. About half the unit consists of cross-bedded, light-brown to grayish-orange and patchy purplish-red, pebbly quartz grit. The matrix consists of subangular to angular, medium- and coarse-grained, clear quartz and minor clear feldspar. The larger clasts are as much as 1.5 inches in diameter and consist of rounded pinkish-gray quartz pebbles and a few subangular light-gray and grayish-red mudstone chips. Pebbly grit is less common in the top part of the unit which is mostly cross-bedded, medium-grained sandstone and red mudstone. The unit as a whole weathers red.

The basal unit of the Chinle in the La Sal Mountains differs from the overlying part of the formation mainly in sandstone content. The red color of this basal unit contrasts with the grayish-green of the Moss Back Member of the western and central parts of the Lisbon Valley area. Pebbly quartz grit characteristic of the basal Chinle in the mountains is uncommon in the Moss Back Member. Because of these differences in color and composition the lower part of the Chinle Formation in the La Sal Mountains is not equated with the Moss Back Member, but is recognized as an unnamed member probably of small extent and probably stratigraphically higher in the Chinle Formation than the Moss Back of Lisbon and Big Indian Valleys.

The possibility that this unit contained a part of the Moenkopi was expressed in preliminary maps covering part of the La Sal Mountains (Weir and Puffett, 1960a; Weir, Dodson, and Puffett, 1960). The pebbly quartz grit and overlying fine-grained red beds were mapped as a single unit labelled "Chinle Formation and Moenkopi Formation(?) undifferentiated." No subdivision of the grit was recognized; thus, probably all of the unit should be assigned either to the Chinle or to the Moenkopi. As a result of further study of the Moenkopi and Chinle Formations in outcrops west, north, and east of the La Sal Mountains we conclude that the pebbly quartz grit of South Mountain is a part of the Chinle Formation.

Church Rock member

The Church Rock Member consists mainly of grayish-red and reddish-brown mudstone and lesser amounts of reddish sandstone and mudstone-pebble conglomerate. Most of the mudstone is impure siltstone that locally grades to fine-grained sandstone; some mudstone is very clayey. Many mudstone units show a faint horizontal stratification but most appear structureless. Contorted bedding is common near the base and top of the member. Small yellowish-gray and reddish-gray limy concretions only a few inches in diameter are common in mudstone. The mudstone units form steep slopes littered with small angular fragments.

Sandstone and conglomerate are pale red or yellowish gray and commonly weather reddish brown. The sandstone ranges from silty and very fine grained to coarse grained but is dominantly fine grained. They are composed chiefly of subangular quartz and chert and lesser amounts of feldspar and mica and variable amounts of mudstone grains. The conglomeratic beds are made up of irregular granules, pebbles and cobbles of yellowish-gray and reddish-gray, limy mudstone in a medium- to coarse-grained sandstone matrix. The sandstone and conglomerate are interstratified in thin to thick irregular beds that coalesce into discontinuous lenses. Such lenses are scattered throughout the Church Rock but are most common near the base of the upper third of the member.

Schultz (1963, pl. 3, sec. 30) studied the clay content of samples of sandstone and siltstone of the Church Rock Member of the Chinle in the section exposed near Little Valley which is described on pages 100-110. The dominant mineral is illite, which generally makes up more than 50 percent of the clay minerals in the samples. Other clay minerals present in varying proportion are kaolinite, mixed-layer illite, mixed-layer illite-montmorillonite, mixed-layer chlorite, and chlorite.

Limestone is scarce in the Chinle, but a few beds less than a foot thick are interstratified sporadically in mudstone of the Church Rock Member along the outcrop between Big Indian and Lower Lisbon Valleys. The limestone is unfossiliferous, gray or grayish-orange, and it ranges from microcrystalline to medium crystalline. Most limestone beds are sandy and contain small flattened pellets of mudstone.

Contacts

Lower contact

The contact at the base of the Chinle Formation is a major unconformity of regional extent. The unconformable nature of this contact is clearest in the central part of the area near Big Indian Wash and Three Step Hill. Here the Moenkopi Formation, if it was ever deposited, was entirely removed, and part of the Cutler Formation was cut away by the pre-Chinle erosion. A conspicuous light-colored sandstone bed in the Cutler rises in the section to the northwest from near Three Step Hill and is truncated at the unconformity just north of Spiller Canyon. The angular discordance ranges from about 1 to 5 degrees and averages about 3 degrees. The contact is marked by broad-scale channeling with local relief as much as 5 feet.

In Hatch Wash and Cane Spring Canyon the Chinle beds are parallel to beds of the Moenkopi Formation. Minor scours into the Moenkopi are the only evidence of an erosional interval at these localities, though Baker (1933, p. 36) noted angular discordance as much as 14^{o} at this contact a few miles farther west. The contact itself is sharp and marked by the change in lithology between the brown, horizontally bedded siltstone of the underlying Moenkopi and the gray, cross-stratified, ledge-forming sandstone and conglomerate of the Moss Back Member of the Chinle.

In the La Sal Mountains the Chinle rests on fine-grained red beds assigned to the Cutler formation. The contact is placed at the base of the lowest persistent bed of grayish-red, pebbly quartz grit. The nature of the contact in the mountain area is not clear, because the contact is mostly covered and the beds dip steeply.

Contact between the Moss Back Member and the Church Rock Member.--The contact between the Moss Back Member and the Church Rock Member is placed at the top of the basal sequence of grayish sandstone and mudstone that is overlain by reddish sandstone and mudstone. In places the contact is indefinite in a gradational sequence characterized by thin lenses of red mudstone near the top of the Moss Back. Lateral tracing of this member contact shows that it is arbitrary, for the rocks near the contact frequently differ only in color and they change color unsystematically within a few hundred feet along strike.

Upper contact

The contact between the Chinle Formation and the Wingate Sandstone is generally sharp, though locally in the western part of the area sandstone lenses at the top of the Chinle are similar to the basal Wingate. In the central part of the area the contact is a distinct diastem.

Age and fossils

Fossil vertebrates from many places on the Colorado Plateau indicate that the Chinle Formation is Late Triassic in age. The age assignment is based principally on a study by Camp (1930) of phytosaur remains. Camp collected mainly from the Chinle of northeastern Arizona but also found vertebrate fossils near Moab and in the valley of Indian Creek, short distances north and west of the Lisbon Valley area.

Fossils found in the Chinle of the Lisbon Valley area include silicified and coalified plant remains, poorly preserved small gastropod and unioid pelecypod shells, waterworn fragments of phytosaur bone and teeth, and fairly well preserved fish. The fossil fish of the Lisbon Valley area and other localities in the western United States are described and compared with Late Triassic fishes elsewhere by Schaeffer (1967). The fish occur in great numbers in assemblages that are sporadically distributed in siltstone in a zone about 125 to 150 feet below the base of the Wingate Sandstone. The collections were made by Y. W. Isachsen of the U. S. Atomic Energy Commission, G. W. Weir, D. H. Dunkle of the U. S. National Museum, and Bobb Shaeffer of the American Museum of Natural History assisted by Walter Sorensen of the American Museum Vertebrate Paleontology Laboratory, F. E. Green of Texas Technological College, G. F. Stucker of the American Museum, and Richard Lund. The fish described by Schaeffer (1967) are, with the exception of _Seminotus_ sp. new genera and species. They are _Cionichthys dunklei_ Schaeffer, _Lasalichthys hills_ Schaeffer, _Synorichthys stewarti_ Schaeffer, _Seminotus_ sp., _Hemicalypterus Weiri_ Shaeffer, and _Chinlea sorenseni_ Schaeffer. Because of the spotty occurrence of the fish and because many of the genera are probably long ranging, the correlation of unit within the Chinle as determined by the phytosaur evidence cannot be corroborated by the fish taxa (Schaeffer, 1967, p. 337).

Regional stratigraphic relations

Gregory (1917, p. 42) named the Chinle Formation for outcrops in Chinle Valley in northeastern Arizona. The Chinle Formation of southeast Utah and adjacent regions is presently subdivided into seven members, in ascending order: Temple Mountain, Shinarump, Monitor Butte, Moss Back, Petrified

Forest, Owl Rock and Church Rock (Stewart, 1957; Stewart and others, 1959). The Temple Mountain Member is a thin siltstone unit confined to the San Rafael Swell (Robeck, 1956). The remaining six members are present in southern Utah but, except for the Church Rock and Moss Back Members, they pinch out or grade out to the north toward the Lisbon Valley area.

The Moss Back Member, grayish sandstone and siltstone, lies above the Monitor Butte and Shinarump Members at its type locality in the White Canyon area (Stewart, 1957, p. 464-465) but forms the basal unit of the Chinle Formation north of the White Canyon area. The name was tentatively extended to the strata exposed near Big Indian Valley by Stewart (1957, p. 453). The member is a thin irregular unit near Big Indian Valley and Three Step Hill and probably pinches out within a few miles to the northeast within the Lisbon Valley area along a line roughly parallel to the northwest-trending axis of the Lisbon Valley anticline. The Moss Back is commonly several tens of feet thick in the Slick Rock district, Colorado, adjoining the Lisbon Valley area on the southeast (Shawe and others, 1968, p. A32). Strata lithologically similar to the Moss Back occur above the member near the junction of the Green and Colorado Rivers (Stewart and others, 1972, p. 31). In places in the Lisbon Valley area, as in Kane Springs Canyon, these higher sandstone layers have probably been included in the Moss Back. Thus the member in this area, though mainly a finer grained facies of the Moss Back (Stewart, 1957, p. 453), may include strata not represented in the type section of the member.

The Church Rock Member of the Chinle Formation in southeastern Utah is characteristically made up chiefly of reddish-orange and brown siltstone. O'Sullivan (1970) found that the Church Rock Member of the type section in Arizona is older than and not continuous with most of the Church Rock Member as used in Utah and recommended that the reddish-orange and brown siltstone unit of southeastern Utah be considered a separate member or facies. The name Church Rock Member is retained in this report in the sense used by Stewart and others (1959) in southeastern Utah, pending further studies of the complex internal stratigraphy of the Chinle Formation.

The Church Rock Member of the Lisbon Valley area contains a higher percentage of sandstone and conglomerate than the Church Rock Member in adjacent parts of southeast Utah. A fairly persistent zone of sandstone lenses at the base of the upper one-third of the member probably correlates with the "black ledge sandstone" an informal unit that marks the base of the reddish-orange siltstone member in the southeastern part of the Green River desert (Stewart and others, 1959, p. 503, 518). The reddish quartz grit at the base of the Church Rock Member in the La Sal Mountains may be equivalent to similar thin units of quartz grit at the base of the Chinle Formation northeast of Moab (Dane, 1935, p. 55-56) and in southwestern Colorado (Cater, 1954), but physical continuity of these grit beds cannot be proved.

The fossil content and the interstratification of lenses of cross-bedded sandstone and conglomerate and horizontally bedded mudstone suggest that the Chinle Formation of the Lisbon Valley area was deposited in streams and lakes. Studies of the cross-strata in the Moss Back Member including localities near Big Indian Valley indicate a northwesterly direction of flow of the streams depositing in channels (Poole and Williams, 1956, p. 230) suggesting source areas lying southeast of southeastern Utah. The source areas according to Stewart and others (1972, p. 93-95) included the volcanic terrance of the

Mogollon highland of southern Arizona and New Mexico and the Uncompahgre highland of southwestern Colorado.

Glen Canyon group

Definition and age

A sequence of interrelated continental sandstone and sandy shale lying between Triassic mudstone and Jurassic marine beds in central southern Utah was formally named the Glen Canyon Group by Gregory and Moore (1931, p. 61-68). In the Lisbon Valley area and adjacent areas the sequence is divided into three formations: Wingate Sandstone, Kayenta Formation, and Navajo Sandstone (Baker and others, 1927, p. 802-803; 1931). In places contacts between these formations are complicated by intertonguing; they are generally somewhat arbitrary in a gradational sequence.

The group has yielded no diagnostic fossils in the Lisbon Valley area and few elsewhere. Stratigraphic relations in the Navajo country of northeastern Arizona and the scanty paleontologic evidence indicate that deposition of the group was virtually continuous from the Late Triassic into the Jurassic (Harshbarger and others, 1957, p. 25-32; Lewis and others, 1961).

Distribution and thickness

The Glen Canyon Group crops out mainly in the western part of the Lisbon Valley area and in the La Sal Mountains but is partly exposed in canyons near the east edge of the area. In most places it forms cliffs and is difficult to measure. The group generally is about 800 to 900 feet thick. Some departures from this average appear to be due to sedimentation on the flanks of topographic highs. Thicknesses of the formations within the group vary more than the group as a whole, largely because of the arbitrary nature of the contacts of the Kayenta Formation.

Wingate Sandstone

Distribution and thickness

The Wingate Sandstone is exposed in sheer cliffs that extend the full thickness of the formation in canyons near the west edge of the Lisbon Valley area. In the La Sal Mountains the Wingate generally forms a prominent hogback of sandstone that is locally converted into block rubble deposits. On the south side of Big Indian Valley and Lower Lisbon Valley the Wingate forms a prominent cliff and a steep, rough rock slope.

The Wingate Sandstone in the area is generally about 300 feet thick, but because of its cliff-forming habit, the formation is generally inaccessible and difficult to measure precisely. Local differences of 40 feet or so may be attributed to differences in placing the top contact in an interfingering sequence.

Lithology

In the cliffs rimming the canyons near the west edge of the area the Wingate Sandstone is commonly dark red to purplish black owing to coatings of iron and manganese stain. Near Spanish Valley the Wingate outcrops are commonly light orange to pinkish buff. In the La Sal Mountains the Wingate outcrops are very light buff, almost white. These noticeable color differences are results of differences in rainfall and in the structural setting. The darker colors, characteristic of the Wingate on the Colorado Plateau, are typically found in the desert country where the rocks are relatively flat lying. The lighter colored Wingate is found at generally higher elevations where the precipitation is greater and in areas where the formation is folded or faulted. In structurally complex areas, such as the fault blocks on the west side of Spanish Valley, the light-colored Wingate resembles younger, light-colored sandstone formations such as the Navajo and Entrada.

The fresh sandstone is grayish orange and consists of well sorted, subangular and subrounded, very fine and fine grains of quartz and minor feldspar. Stringers of well-rounded, frosted coarse grains of clear quartz and gray chert commonly occur near the base of the formation.

The Wingate is characteristically well cemented by calcite so that the sandstone forms but a single massive unit in which bedding is obscure. Close inspection, however, reveals that the Wingate is made up of an alternation of cross-bedded and horizontally bedded units ranging from about 1 to 60 feet thick. Medium-scale planar and large-scale trough crossbedding are dominant, but some thin horizontally bedded units apparently persist for more than 1,000 feet and cosets of the crossbedded units are bounded by horizontal bedding planes. Low-amplitude ripple marks and current lineations are sparse throughout the formation; mud cracks are common at the base.

Basal contact

In the western part of the area the Wingate Sandstone locally intergrades with the underlying Chinle Formation. Lenses of dark-red, horizontally laminated and cross-laminated, fine-grained sandstone occur sporadically in the upper 30 feet of the Chinle Formation. Except for minor seams and splits of red mudstone, these sandstone lenses are lithologically similar to the overlying massive Wingate. The base of the Wingate, however, is characterized by scattered coarse grains of quartz and chert that are lacking in the otherwise similar Chinle sandstone.

Near Big Indian Valley and Lower Lisbon Valley the contact is generally sharp and is characaterized by the truncation of contorted beds of Chinle and by mudcrack fillings of sandstone of the Wingate which extend as much as 12 inches into the mudstone of the Chinle. The interval between the base of the Wingate and a zone of sandstone lenses in the upper third of the Chinle increases southwestward abut 20 feet in half a mile in sec. 35, T. 30 S., R. 25 E. This increase is probably due to internal thickening of the mudstone of the Chinle off a topographic high over the Lisbon Valley anticline; it may also in part be due a local erosional unconformity at the base of the Wingate.

The base of the Wingate Sandstone in the La Sal Mountains is mostly covered by block rubble or solifluction deposits. The contact shown on the geologic map is drawn at the slight break in slope beneath the Wingate cliff.

Age and stratigraphic relations

The type section of the Wingate Sandstone designated by Dutton, (1885, p. 136-137) near Fort Wingate, New Mexico, has been modified by Baker and others (1947, p. 1667) as a result of regional stratigraphic studies. Largely on the basis of fossils found in the Wingate and overlying and underlying formations in the Navajo country of northeastern Arizona, the Wingate is judged to be of Late Triassic age (Harshbarger and others, 1957, p. 8-17, 25-32).

The Wingate is present throughout southeastern Utah and parts of Arizona, New Mexico, and Colorado and over much of this area ranges in thickness from 200 to 350 feet. It thins eastward from the Lisbon Valley area and near the southern part of the Uncompahgre Plateau in southwestern Colorado the formation cannot be recognized. The thinning of the Wingate Sandstone is probably caused both by pre-Entrada erosion and by lateral grading of the sandstone into siltstone of the uppermost beds of the Chinle and Dolores Formations (Stewart, 1956, p. 91).

The dominance of crossbedding, much of it large-scale, and the fineness and good sorting of the subrounded sand grains suggest that most of the Wingate Sandstone is an eolian deposit. Studies of the dip directions of the cross strata by Poole and Williams (1956, p. 228) indicate that the depositing winds blew mainly to the southeast. Part of the Wingate Sandstone in the Lisbon Valley area is water-laid as suggested by the presence of horizontal major bedding planes, horizontally bedded lenses, ripple marks and current lineation.

Kayenta Formation

Distribution and thickness

The outcrop pattern of the Kayenta Formation in the Lisbon Valley area is similar to that of the Wingate Sandstone. Along the canyons in the western part of the area the Kayenta forms steep ledgy slopes between the smooth, nearly vertical cliffs of the underlying Wingate and overlying Navajo Sandstone. In many places the Navajo has been stripped back so that rough, broad benches cut on the upper part of the Kayenta are extensive, as on Iron Mesa, the dip slopes on the south side of Big Indian Valley, and on Three Step Hill. In the La Sal Mountains the Kayenta is poorly exposed in a swale between ridges formed by the Wingate and Navajo.

The thickness of the Kayenta ranges from about 175 to 400 feet. Changes in thickness are nonsystematic, except for a slight eastward thinning. Local changes are due to a sanding up of the lower and upper parts of the formation resulting in differences in placing the Wingate-Kayenta and Kayenta-Navajo contacts.

The greatest change of thickness is between the abnormally thick Kayenta cropping out in Hunters Canyon and the sandy, crossbedded Kayenta, which is difficult to separate from the underlying Wingate, exposed on the cliffs on the southwest side of Spanish Valley. This thinning of over 400 feet in less than 2 miles, is probably result of development of a basin on the flank of a topographic high over the Moab salt anticline during deposition of the Glen Canyon Group.

Lithology

Sandstone units in the Kayenta Formation are pale red or pinkish brown; they weather a darker reddish brown, commonly with a distinct purplish cast. In the lower part of the formation some sandstone is grayish orange and reddish brown similar to the underlying Wingate, and in the upper part of the formation some sandstone units are yellowish gray and very pale orange similar to the overlying Navajo. Siltstone beds in the Kayenta are, with but minor exceptions, pale red to dark grayish red.

Most of the Kayenta is sandstone composed of subrounded very fine to fine-grained quartz and minor feldspar, resembling in these respects the rest of the Glen Canyon Group. The Kayenta, however, is distinguished by the presence of siltstone and conglomeratic beds. The siltstone beds are sandy and commonly grade to very fine sand. Conglomerate beds mostly have a medium-grained matrix; the coarser fraction consists chiefly of pebbles and irregular fragments of red, very fine-grained shaly sandstone and gray, limy siltstone. In the La Sal Mountains and other parts of the area where the Kayenta is poorly exposed, the presence of such conglomerate is a useful criterion to identify the formation.

The Kayenta is firmly to only moderately well cemented. The chief cement is calcite, but clay binding, iron oxide, and silica are locally important. Sandstone units in the lower part of the formation are generally more resistant than those in the upper part. Most of the siltstone units are relatively soft, but some grade into firm, very limy siltstone.

The most distinctive feature of the Kayenta Formation is its bedding. Sandstone occurs in broad complex lenses that commonly have an irregular scour surface at the bottom and a relatively plan surface at the top. The sandstone lenses, a few feet to several tens of feet thick, are made up of many smaller discontinuous units, which consist of small- to medium-scale trough sets of very low to medium-angle cross laminae, whose prevailing dip is southwesterly (Stewart and others, 1959, p. 524). Most conglomerate in the Kayenta is found in scour pockets at the base of sandstone lenses. The interbedded siltstone is in small lenses to fairly persistent units, which are bounded by more or less plane surfaces and which commonly grade into horizontally bedded shaly sandstone. Weathering of the complex irregularly lensing units yields the characteristic ledgy outcrop of the Kayenta, which differs markedly from the more uniform, cliff-forming Wingate and Navajo Sandstones.

Much of the fine-grained sandstone is streaked with current lineation--vague, roughly parallel low ridges of sand grains (Stokes, 1947). Small-scale slump structures and current ripple marks occur sparsely.

Lower contact

The Kayenta Formation rests conformably on the Wingate Sandstone. In some parts of the area the contact is a noticeable diastem marked by a scour surface or a thin seam of siltstone, but more commonly the contact is arbitrarily placed within an intergrading sequence several tens of feet thick. The distinctive irregularly bedded units of the Kayenta generally give way in the lower part of the formation to thick, crossbedded units that except for interstratified siltstone beds are like the underlying Wingate. We placed the contact at the base of the lowest siltstone bed, or conspicuous scour surface or horizontally bedded shaly sandstone. As so drawn, placement of the contact is fairly consistent over small areas, but may differ several tens of feet between neighboring canyons.

Upper contact

The Kayenta is conformably overlain by the Navajo Sandstone. The lithologies are gradational and, on a minor scale, intertonguing. In the canyons of Hatch Wash and Hart Draw the upper 50 to 100 feet of the Kayenta locally contains interbedded with red sandstone and siltstone characteristic of the Kayenta, lenses of smooth-weathering, light-buff, large-scale crossbedded sandstone that strongly resemble the overlying Navajo. In places the basal unit of the cliff-forming Navajo is a horizontally bedded, light-buff sandstone that grades laterally to a reddish sandstone much like the underlying Kayenta. We have generally placed the Kayenta-Navajo contact at the top of this transitional interval so that most of the isolated Navajo-like sandstone units are included in the Kayenta.

Age

Baker (1933, p. 46) made three collections of fossil pelecypods from the Kayenta Formation in the Lisbon Valley area. These fossils from near Kane Springs "were described by J. B. Reeside, Jr. as internal casts of long-ranging types of Unios resembling U. dumblei, U. dockumensis, and U. iridoides." Casts of unioid pelecypods were also found during the present study in the Kayenta within a few tens of feet of the overlying Navajo Sandstone in the SE1/4 sec. 19, T. 29 S., R. 24 E.; in the NW1/4SW1/4 sec. 3, T. 28 S., R. 22 E., and in the NW1/4 sec. 5, T. 27 S., R. 23 E., all in San Juan County, Utah. These fossils support the interpretation of the Kayenta as a fresh-water deposit, but were considered by Baker and others (1936, p. 56) to be of little value in making an age assignment. As pointed out by Harshbarger and others (1957, p. 31), however, if the specific resemblances noted in the poorly preserved fossils by Reeside are considered precise, there is a mixture of forms known from both Triassic and Jurassic deposits. Fresh-water gastropods collected from the Kayenta in northern Arizona have been assigned to the Late Triassic by Yen (1952).

More significant to the dating of the Kayenta are finds of reptilian fossils in the Kayenta Formation of northeastern Arizona (Welles, 1954; Swinton, 1955, p. 134; Harshbarger and others, 1957, p. 30) and vertebrate fossils in underlying and overlying formations. Lewis and others (1961, p. 1437-1438) reviewed the fossil evidence and stratigraphic relations and concluded that they strongly suggest that the Kayenta Formation is of Late Triassic age. At present (December 1977), the Kayenta is considered to be of Late Triassic(?) age.

Regional stratigraphic relations

The type section of the Kayenta Formation is in Comb Ridge near Kayenta in northeastern Arizona (Baker and others, 1936, p. 5). The formation is present throughout southeastern Utah and also in most of the Navajo country in Arizona, where it grades southwestward into a siltstone facies (Harshbarger and others, 1957, p. 18). The Kayenta pinches out east of the Utah-Colorado border in part by internal thinning (Dane, 1935, p. 81-82) and in part by truncation at the pre-San Rafael unconformity (Wright, J. C., and Dickey, 1958, p. 173).

The irregular bedding, scour structures, current lineation and current ripple marks, and the fossil pelecypods found in the Kayenta Formation of the Lisbon Valley area all point to fluvial deposition. Some medium- to large-scale crossbedded sandstone units near the Wingate and Navajo contacts probably are eolian or slightly reworked eolian sands. Orientation of cross-bedding in the fluvial beds indicate that the direction of stream flow was southwestward (Stewart and others, 1959, p. 524). The feldspar content, mica content, and grain size of the Kayenta increase toward the Colorado pinch-out of the formation and suggest that the source of the Kayenta sediments was the Uncompahgre-San Luis highlands area of southwestern Colorado (Baker and others 1936, p. 44; Stewart and others, 1959, p. 567.)

Navajo Sandstone

Distribution and thickness

The Navajo Sandstone crops out in the western and northern canyons of the Lisbon Valley area, in the La Sal Mountains, and Big Indian and Dry Washes; it is partly exposed in Greasewood and McIntyre Canyons near the east edge of the area. Generally, the Navajo crops out as a conspicuous, light-colored cliff at the top of the Glen Canyon Group. The upper part commonly forms a broad rock tableland studded with small mesas and knolls; where the rock is strongly jointed, as on the ridge on the southwest side of Spanish Valley, it is broken into nearly impassable clusters of fin-like towers with narrow rounded tops.

The Navajo Sandstone ranges in thickness from about 175 feet to 600 feet and averages about 300 feet in the Lisbon Valley area. It thins irregularly eastward. The maximum thickness is on the high cliffs flanking the southwest side of Spanish Valley; part of the extraordinary thickness of the Navajo at this locality is at the expense of the markedly thinned, underlying Kayenta Formation. Some variations in thickness are due to variations in placing the basal contact; some are due to irregular truncation at the pre-San Rafael Group unconformity.

Lithology

The Navajo Sandstone is mainly grayish yellow to light grayish orange. A few beds of pale-red sandstone are found near the base and also throughout the formation associated with sporadic thin beds of yellowish-gray, micrograined, very fine sandy, unfossiliferous limestone. The Navajo is composed of well-sorted, subrounded, very find grains of quartz and minor feldspar. The rock is generally well cemented by calcite, but it weathers readily to yield much colluvial sand, which in the western part of the area has locally been heaped by the wind into dunes.

Conspicuous medium- and very large scale trough sets of high-angle cross-beds make up almost the whole formation. The prevailing dip of these cross-beds in the Lisbon Valley area is to the southeast. Southeasterly dip directions of cross-strata are typical of the Navajo Sandstone in Utah (Kiersch, 1950; Stewart and others, 1959, p. 525). Horizontal bedding and parting planes, and small-scale slump structures are uncommon; they are mostly found in the basal part of the formation where the Navajo intertongues and intergrades with the underlying Kayenta, or they are associated with nonmarine limestone higher in the formation. The limestone, in places partly converted to gray chert, occurs in thin lenses, a few inches to a few feet thick and several tens of feet to about a thousand feet long. These limestone lenses are sparsely distributed through the entire thickness of the Navajo in the western part of the area, but none was noted in the Colorado part of the area. Some of the limestone, together with the enclosing sandstone beds, are contorted in small slump structures.

Contacts

The Navajo Sandstone intergrades with the underlying Kayenta Formation and is overlain unconformably by the Entrada Sandstone. The Upper contact of the Navajo is a regional unconformity, commonly marked by a horizon of detrital chert.

Age and regional relations

No fossils were found in the Navajo Sandstone in the Lisbon Valley area. The total known fossil assemblage of the formation is scanty and mostly nondiagnostic. It includes bivalved crustaceans, fragmentary plant material and the incomplete remains of two small dinosaurs, all from outcrops in northeastern Arizona (Harshbarger and others, 1957, p. 28-30). After reviewing the pertinent stratigraphic and fossil evidence, Lewis and others (1961, p. 1439) concluded that the age of the Navajo Sandstone is Late Triassic(?) and Jurassic.

The Navajo Sandstone, named by Gregory (1917, p. 57-59) for its type area, the Navajo country of Arizona, Utah, and New Mexico, has a consistent lithology and appearance over a large part of the Colorado Plateau. It reaches a maximum thickness in southwestern Utah and thins to a vanishing edge in northeastern Arizona and in southwestern Colorado a few tens of miles east of the state line (Baker and others, 1936, p. 47). Most of this thinning is internal, but near its depositional edge the Navajo is truncated at the pre-San Rafael Group unconformity.

The Navajo Sandstone is a wind deposit as evidenced by its large-scale and consistent crossbedding, the uniform fineness, rounding, and composition of its constituent grains, and the scarcity of sedimentary structures that are to be expected in water-laid deposits. The sparse limestone beds and horizontally stratified units in the formation probably testify to the presence of ephemeral lakes. The few fossils found in the Navajo also indicate the presence of some water, but Camp (1936, p. 39-40) interpreted the burial position of a fossil dinosaur as indicating burial by shifting sand dunes. The source of the Navajo Sandstone of southeast Utah apparently lay far to the northwest near the Nevada-Utah border, for the depositing winds blew to the southeasterly dips of cross strata (Stewart and others, 1959, p. 525).

Jurassic system

San Rafael group

Definition

A marine and nonmarine succession above the Navajo Sandstone and below the Morrison Formation was named the San Rafael Group by Gilluly and Reeside (1928, p. 73-80) from exposures in the San Rafael Swell, Utah. In the type area the group consists of four formations, in ascending order: the Carmel, Entrada, Curtis, and Summerville. The Carmel and Curtis Formations grade out in the Green River desert a few tens of miles northwest of Moab so that only the Entrada Sandstone and Summerville Formation are present in the Lisbon Valley area.

Distribution and thickness

The San Rafael Group is widely distributed in the Lisbon Valley area. It is thickest in the western part of the Lisbon Valley area and thins eastward. Thus on Bridger Jack Mesa, Utah, the group is about 600 feet thick, and near Photograph Gap, Utah, it is about 500 feet thick; but in McIntyre Canyon, Colorado, the group is only about 200 feet thick.

Entrada Sandstone

Distribution and thickness

The Entrada Sandstone forms conspicuous benches and cliffs in the western southern, and eastern parts of the Lisbon Valley area; in the La Sal Mountains it forms prominent hogbacks and long dip slopes.

The Entrada is divisible into four members in a large part of the area. In ascending order they are an unnamed lower member, the Dewey Bridge, Slick Rock (Wright, J. C., and others, 1962), and Moab Members (Baker and others, 1927; Wright and others, 1962).

The Entrada Sandstone generally ranges between 400 and 475 feet in thickness in the western part of the Lisbon Valley area. It thins southeastward to about 180 to 200 feet near the east edge of the area. The formation reaches a maximum thickness of about 570 feet on the south side of Bridger Jack Mesa; it thins to a minimum thickness of about 160 feet in McIntyre Canyon. Most of the thinning is apparently internal and fairly regular. The irregular thinning and pinchout of the lower member accounts for about 70 feet of the difference between thicknesses of the formation in northwestern and southeastern parts of the area.

The Entrada Sandstone of this report includes rocks assigned to the Navajo Sandstone and the Carmel Formation by Baker (1933) and most previous workers. The nomenclature and map units used by Baker (1933) in the Moab district were extended to the Lisbon Valley area on the preliminary 1:24,000-scale geologic maps (Weir and Dodson, 1958 a-e; Weir and Kennedy, 1958; Weir and Puffett, 1960a, b; Weir, Dodson, and Puffett, 1960, 1961; Weir and others 1960, 1961). On these maps the lower member was generally included with the Dewey Bridge Member of the Entrada Sandstone and assigned to the "Carmel

Formation." On most maps the Slick Rock and Moab Members of the Entrada were grouped as a map unit labelled "Entrada Sandstone." The Moab Member of the Entrada Sandstone and the Summerville Formation were combined into a single map unit locally in the northwestern part of the area.

Because of limitations of scale, on figure 3, the generalized geologic map accompanying this report, only the San Rafael Group is shown. The San Rafael Group includes the lower member and the Dewey Bridge Member of the lower part of the Entrada Sandstone, the Slick Rock and Moab Members of the upper part of the Entrada Sandstone, and the Summerville Formation.

Lower member

Distribution and thickness

The basal member of the Entrada Sandstone in the Lisbon Valley area crops out as a fairly continuous unit west of U.S. Highway 160 and along East Coyote Creek. It forms rough tablelands from which rise the red rock slopes of the Dewey Bridge Member of the Entrada Sandstone.

The thickness of the lower member differs greatly from place to place within the Lisbon Valley area, chiefly because of internal thinning and broad undulations of the unconformity at the base of the formation. The member drops out well near the head of Muleshoe Canyon, on Bridger Jack Mesa, and on Flat Iron Mesa where it is generally 50 to 70 feet thick. Between La Sal Junction and Lone Cedar Draw the member is very thin and locally pinches out. Farther south it thickens irregularly along Lone Cedar Draw and is as much as 80 feet thick near Photograph Gap from where it thins southward to less than 20 feet at the south edge of the area.

East of U.S. Highway 160 the lower member occurs in scattered patches. Near the junction of Hatch Wash and Big Indian Wash and along East Coyote Creek the member is about 40 feet thick. The member is absent in McIntyre Canyon, along Dry Wash, and on Three Step Hill. It crops out on both sides of the Spanish Valley near Moab but it is absent on the east side of Spanish Valley in the mapped area. It was not recognized in the La Sal Mountains.

The distribution of the basal member may be somewhat wider than indicated above, because the identity of the member in poor and scattered outcrops is masked by its lithologic similarity to the underlying Navajo Sandstone. Possibly some of the lower member of the Entrada Sandstone has been mistakenly included with the Navajo Sandstone on the geologic map of the area.

Lithology

The lithology of the lower member is transitional between the Navajo Sandstone and the Dewey Bridge Member of the Entrada Sandstone. It is grayish-orange, cross-stratified sandstone probably derived from the underlying Navajo. In places the sand so closely resembles the Navajo that the lower member is discriminated only by locating the horizon of chert pebbles marking the unconformity at the base of the Entrada Sandstone. Horizontally stratified and structureless reddish silty sandstone, resembling units in the overlying Dewey Bridge Member, are intercalated with the cross-stratified sandstone of the lower member, especially in the upper part.

Grayish-orange sandstone, characteristic of the member is generally fine to very fine grained, well sorted, composed of subrounded clear quartz and feldspar with black accessory minerals, firmly cemented with calcite cement, and cross stratified in thick, large- to medium-scale trough sets of low-angle cross laminae. The horizontally stratified and structureless units commonly are perceptibly redder--moderate reddish brown to moderate reddish orange; they are much siltier and less calcareous than the cross stratified sandstone.

The following sections measured with tape and hand level by the writers in 1957, show the character of the lower member in the northern part of the Lisbon Valley area. The section exposed on the south side of Bridger Jack Mesa in sec. 3, T. 28 S., R. 22 E. is typical for the member. The section measured near U.S. Highway 160 on the northside of Kane Springs Canyon in sec. 11, T. 28 S., R. 22 E. shows more lithologic subunits within the member.

Section of the lower member of the Entrada Sandstone, measured in NE1/4NE1/4 sec. 3, T. 28 S., R. 22 E., San Juan County, Utah

	Thickness (feet)
Entrada Sandstone (incomplete):	
Dewey Bridge Member (incomplete):	
5. Sandstone, grayish-orange (10YR 7/4), fine-grained, cross-stratified; forms bench; about 2 ft thick. Overlain by very fine grained sandstone, moderate-reddish-brown (10R 4/6), characteristic of Dewey Bridge Member; not measured	
4. Sandstone, moderate-brownish-orange (10R 5/6), very fine grained, horizontally stratified; forms rounded ledge. Base sharp, conformable	12
Lower member:	
3. Sandstone, moderate-reddish-orange (10R 6/6) and grayish-orange (10YR 7/4), fine to very fine grained; cross-bedded in thin to thick planar and trough sets, sparse contorted beds; forms rough cliff	41
2. Sandstone, moderate-reddish-orange (10R 6/6), fine to very fine grained; apparently structureless; forms bench sloping up to parting at base of unit 3. Contact (unconformity) at base is marked by small fragments of gray chert and by truncation of cross beds in underlying unit	20
Total lower member	61
Total Entrada Sandstone (estimated)	570

Navajo Sandstone:

1. Sandstone, grayish-orange (10YR 7/4), very pale orange (10YR 8/2) and moderate-reddish-brown (10R 4/6), fine-grained; large-scale planar and trough sets of cross beds. Reddish color is restricted to anomalous horizontally bedded unit, a few feet thick, about 20 ft below contact; forms rough rock tableland. Not measured; about 50 ft exposed locally..

Section of the lower member of the Entrada Sandstone, measured in NE1/4NE1/4 sec. 11, T. 28, S., R. 22 E., San Juan County, Utah

Thickness (feet)

Entrada Sandstone (incomplete):

Dewey Bridge Member (incomplete):

8. Sandstone, moderate-reddish-brown (10R 4/6), very fine to medium-grained and silty, poorly sorted; composed of subangular to rounded amber-stained quartz and feldspar(?) with abundant black accessory minerals; firmly cemented, calcareous in obscure irregular horizontal beds. Not measured; thin veneer on mesa obscured by eolian sand and silt...........

7. Sandstone, grayish-orange (10YR 7/4), weathers same and light brown (5YR 6/4), medium grained, well sorted; composed of subrounded clear quartz and white feldspar with common medium grains of pink and gray chert and common black accessory minerals; firmly cemented, calareous. In irregular horizontal beds. Forms rough bench. Grades into overlying unit................................10.5

6. Sandstone, moderate-brownish-orange (10R 5/6), very fine to medium-grained with some coarse grains, mostly poor sorted; composed of amber-stained subangular to subrounded quartz and feldspar(?) with common black accessory minerals; firmly cemented, calcareous; bedding slightly crenulated, more planar near top; forms rounded cap above underlying rock slope. Conspicuous because of bedding and color differences from unit below, but lithology is gradational through a thickness of a few inches............5.0

Total Dewey Bridge Member of Entrada Sandstone........15.5+

Lower member:

5. Sandstone, grayish-orange (10YR 7/4) and moderate-reddish-brown (10R 4/6), fine- to very fine- and medium-grained; well to fair sorted except a fair- to poorly sorted moderate-reddish-brown layer about 12 ft below top; very fine to medium grained, composition and cementation similar to lower units. Irregularly horizontally stratified and cross stratified in planar sets, 1 to 2 ft thick, of low-angle cross laminae. Forms bench and rounded rock slope..........41

4. Sandstone (85 percent) and silty sandstone (15 percent) grayish-orange (10YR 7/4) to moderate-reddish-orange (10R 6/6) and pale-reddish-brown (10R 5/4); colors uniform within any one band except for sparse blotches of yellowish gray (5Y 8/1) near top of unit; chiefly fine- to fine grained, silty to fine grained at top of unit; mostly well sorted, poorly sorted in silty beds; composition much like that of beds below for silty intervals; firmly cemented, calcareous, silty beds less calcareous. In obscure irregular horizontal beds and in small- to medium-scale trough and planar sets of low-angle cross laminae. Forms gentle slope with well-developed benches and small ledges; silty units form base of risers.....................15

3. Sandstone, grayish-orange (10YR 7/4) to moderate-reddish-orange (10R 6/6), medium-grained, well-sorted; composed of clear and amber-stained quartz and feldspar with common black accessory minerals; firmly cemented, calcareous. Irregularly horizontally stratified. Surface weathers to small pustules commonly 1/4 in. across. Conspicuous because of greater iron staining than units below or above...1

2. Sandstone, grayish-orange (10YR 7/4) to grayish-orange-pink (5YR 7/2); weathers about same; chiefly very fine grained, well sorted, but at base medium grained to conglomeratic containing pebbles as much as 1/2 in. in diameter; composed chiefly of subangular clear quartz and feldspar with common black accessory minerals. Medium grains, granules and pebbles are light-gray and pinkish-gray chert and are distinctive of contact zone. Firmly cemented, calcareous, probably some siliceous cement. Virtually structureless, some obscure slumped bedding. Minor irregularities a few inches wide and less than an inch deep on basal surface suggest scouring by rivulets on ancient surface of Navajo sands......3

Total lower member......60

Measured Entrada Sandstone (incomplete)...................75.5+

Navajo Sandstone (not measured):

1. Sandstone, grayish-orange (10YR 7/4); weathers about same, fine grained, fair sorted; composed of rounded to subrounded quartz and feldspar with common black accessory minerals; firmly cemented, slightly calcareous. In large-scale trough sets of low- to high-angle cross beds; con-contains some minor slump structures at top of unit. Not measured; only top 50 ft examined.........................

The lower member of the Entrada Sandstone has been included in the Navajo Sandstone in most earlier reports (Baker, 1933; partly in Weir and Dodson, 1958a, b). On most of the preliminary geologic maps of the Lisbon Valley area the lower member was grouped with the overlying red fine-grained sediments (of the Dewey Bridge Member of the Entrada Sandstone) or was assigned to the Carmel Formation. Where the lower member was thick and conspicuous it was mapped separately and called the "lower member of the Carmel Formation" (Weir and others, 1960, 1961). Wright, J. C., and others (1962, p. 2062) included the sandstone of the lower member with the overlying red siltstone and silty sandstone which they removed from the Carmel Formation and assigned, as the Dewey Bridge Member, to the Entrada Sandstone. The lower member is separated from the overlying Dewey Bridge Member because its lithology is different and locally it is much thicker than the Dewey Bridge.

Dewey Bridge member

Distribution and thickness

The Dewey Bridge Member of the Entrada Sandstone crops out widely in the Lisbon Valley area as a conspicuous dark-red, nonresistant unit at the base of light-colored cliffs of the Slick Rock Member of the Entrada Sandstone. The thickness of the Dewey Bridge Member differs from place to place within the area because of eastward thinning of the member and northward intergrading of the upper part of the member with the overlying Slick Rock Member.

The Dewey Bridge Member ranges between 40 and 60 feet in thickness throughout most of the area. It seems to be less than 40 feet thick in the poor outcrops in the La Sal Mountains. It reaches a local maximum thickness of 80 feet on Bridger Jack Mesa. In and near Dry Valley south of Looking Glass Rock the Dewey Bridge includes more beds than to the north and is as much as 100 feet thick.

Lithology

The Dewey Bridge Member is made up chiefly of pale-reddish-brown, silty to fine-grained sandstone composed of subangular to rounded amber-stained quartz grains firmly cemented by calcite, iron oxides, and clay binding. Horizontal beds, a few feet thick, are characteristic, but a few thin planar sets of high-angle cross-laminae are intercalated near the top of the member. North of La Sal Junction contorted beds are common; locally, as along U.S. Highway 160 near Muleshoe Canyon, contortions extend through the whole member and upward into the Slick Rock Member.

Buff sandstone, chiefly very pale orange or grayish yellow, forms a conspicuous layer near the middle of the Dewey Bridge Member in the southwestern part of the area. It is fine-grained quartz and minor feldspar--slightly coarser than the reddish-brown sandstone--and locally contains well-rounded, frosted medium to coarse grains and granules of quartz and chert. Thin trough sets of low-angle cross-laminae are characteristic, but thin horizontal beds also occur. The buff sandstone is the most resistant part of the member; it forms an extensive bench that floors most of Dry Valley.

The lower part of the Dewey Bridge Member is described in previous sections. The following section, measured in 1955 with hand level and tape by G. W. Weir assisted by L. F. Emmett and W. E. Sharp describes the characteristic lithology of the Dewey Bridge and other members of the Entrada Sandstone and of the Summerville Formation in the southwestern part of the Lisbon Valley area. The section is exposed in gullies and cliffs about 0.5 miles west of Photograph Gap.

Section of San Rafael Group, measured in SE1/4NE1/4 sec. 29 and SW1/4NW1/4 sec. 28, T. 31 S., R. 23 E., San Juan County, Utah

Thickness (feet)

Morrison Formation (incomplete):

Salt Wash Member (incomplete):

16. Sandstone, grayish-orange-pink (10R 8/2); weathers pale brown (5YR 5/2); medium to fine grained with common coarse grains, fair sorted; composed of angular to subangular clear quartz with abundant black accessory minerals; well cemented, very calcareous. Cross stratified in small trough sets. In places contains small blocks of limestone, light-brownish-gray (5YR 6/1); weathers olive gray (5Y 6/1); weathered surfaces very finely punctate, from basal bed of Morrison Formation. Broad-scale channeling of basal sandstone of Salt Wash Member is deeper here than in adjacent parts of the area. Top of local exposure. Not measured; about 15 ft exposed..

San Rafael Group:

Summerville Formation:

15. Sandstone (50 percent), siltstone (50 percent). Sandstone, moderate-orange-pink (5YR 8/4); weathers moderate reddish orange (10R 6/6), very fine to fine grained, fair sorted; composed of angular to subangular clear quartz and feldspar, and orange chert with abundant colored and black accessory minerals; firmly cemented, slightly to very calcareous. Siltstone, moderate-reddish-orange (10R 6/6); weathers moderate reddish brown (10R 5/6),

sparse very fine quartz grains. Whole unit contorted, characterized by thin irregularly lensing beds, apparently pinched off by squeezing; contortions fade out at base of unit. Top is a scour surface, a local disconformity..5

Total of Summerville Formation.......5

Entrada Sandstone:

Moab Member:

14. Sandstone, chiefly very pale orange (10YR 8/2), mostly fine grained, in part very fine grained, fair-sorted; composed of subrounded clear quartz and feldspar with sparse colored accessory minerals; friable, calcite cement. Faintly horizontally stratified with wavy crenulations, some obscure cross-stratification in upper one-quarter of unit. Forms smooth cliff. (Continuity with Moab Member in northern part of area is uncertain)..37.5

Total Moab Member.......37.5

Slick Rock Member:

13. Sandstone, chiefly pale-yellow-orange (10YR 8/6), more yellowish than underlying or overlying units; grain size and composition as in unit 14; firmly to weakly cemented, calcareous. Mainly horizontally bedded, in part very obscure. Forms conspicuous cliff, bench at top....................................28.5

12. Sandstone, chiefly grayish-yellow (5Y 8/4), dark-yellowish-orange (10YR 6/6) in top 30 ft; dominantly medium grained, well to fair sorted; composed of rounded to subrounded clear quartz, milky white feldspar with gray chert common as an accessory mineral; firmly to weakly cemented, probably siliceouos cement. Cross stratified in trough sets more than 50 ft long and a few feet thick of cross beds as much as 3 in. thick, most apparently dipping southwest. Forms irregular rock slope along strike; forms rounded cliff..............143.5

11. Sandstone, grayish-orange (10YR 7/4) and of moderate reddish orange (10R 6/6) at top, medium-grained and fine-to very fine grained, fair to poorly sorted; composed of subrounded clear quartz and minor feldspar with common pinkish-orange accessory minerals. Firmly cemented, calcareous. Dominantly cross stratified in wide thin trough sets with cross laminae about 1/2 in. thick

and 5 to 20 ft long; apparent average dip of cross jaminae is westerly. Forms irregular rock bench and slope....................................22.0

10. Sandstone, grayish-yellow (5Y 8/4); a few bands of moderate reddish orange 10R 6/6), mostly in lower part of unit. Dominantly medium grained, poorly sorted, contain stringers of coarse grains; composed of rounded to subrounded clear quartz with minor feldspar with common black accessory minerals; firmly cemented, calcareous and cross stratified. Medium-scale trough and planar sets, cross laminae do not weather out, seem to dip chiefly west; some horizontal bedding near base of upper one-quarter of unit. Forms rounded cliff. Base marked by 0.1 ft thick seam of grayish-red (10R 4/2) laminated shale..69.0

9. Sandstone, light-brown (5YR 5/6) and moderate-reddish-orange (10R 6/6), fine to very fine grained, fair sorted; composed of subangular amber-stained quartz with minor gray chert and feldspar; firmly cemented, calcareous. Stratification obscure, most seems structureless; a few inconspicuous trough sets of west-dipping cross strata. Sparse nodules of calcite. Forms rounded rock slope. Gradational with underlying unit; member contact placed at top of gradation...18

Total Slick Rock Member........281

Dewey Bridge Member:

8. Sandstone, silty, moderate-reddish-orange (10R 6/6), dominantly very fine grained and silty, poorly sorted; composed of subangular to subrounded amber-stained quartz and feldspar(?) and silty; firmly cemented, calcareous; seems structureless, except for a few poorly exposed sets of cross-strata. Mostly covered by eolian and alluvial sand. Interbeds of light-brown sandstone similar to unit 9 in top 5 ft......................34

7. Sandstone, silty, similar to unit 8. Forms rounded rock slope with irregular projecting ledge at top; this unit similar to unit 5.................................22

6. Sandstone, pale-greenish-yellow (10Y 8/2), in part very pale orange (10YR 8/2); weathers very pale orange (10YR 8/2); fine to very fine grained with common coarse grains and granules, fair sorted; composed of subangular to subrounded clear quartz, chert, and feldspar with sparse orange chert and black accessory minerals; coarse grains and granules composed of clear quartz, and light- to dark-gray and light-orange chert, well-rounded, mostly in

individual well sorted laminae but also scattered irregularly. Firmly cemented, calcareous; stratification obscure, in part structureless, in part in trough sets of low-angle cross laminae. Forms irregular ledge and bench................................25

5. Silty sandstone to sandy siltstone, pale-reddish-brown (10R 5/4); weathers same; in part stained dark purplish; very fine grained sandy with 30 percent to 60 percent silt, fair to poorly sorted; composed of subangular limonite-stained quartz and feldspar with sparse mica and yellow and orange accessory minerals; firmly cemented, calcareous and clay binding; obscure horizontal bedding, in part cross-stratified; forms slope and niche below light colored sandstone of unit 6. Lower 10 ft covered on line of section.......................................16

Total Dewey Bridge Member........97

Lower member:

4. Sandstone, grayish-orange (10YR 7/4), fine to very fine grained, fair-sorted; composed of subrounded clear quartz with minor gray and orange chert and white feldspar(?) with common black accessory minerals; well cemented, calcareous; structureless or obsurely contorted. Forms thin irregular ledge................1

3. Sandstone, as in unit 2 but lacks pebbles and cross-stratification. Sparse grains and granules of white weathered feldspar. Most of unit seems structureless, perhaps obscurely contorted; conspicuous parting parting planes at 13 and 22 ft above base, few cross laminae noted dip southerly. Forms smooth round rock slopes with niches along parting planes......................36

2. Sandstone, grayish-yellow (5Y 8/4) with minor dark yellowish orange (10YR 6/6); weathering same and light brown (YR 6/4); fine to very fine grained with sparse thin laminae with coarse grains, granules, and very small pebbles as much as 10 mm but averaging 5 mm diameter; composed of rounded to subrounded clear quartz, and minor feldspar(?) with rare gray and orange chert, green, black and red accessory minerals. Pebbles and coarse grains in coarser laminae consist of clear quartz and light-gray chert, irregularly shaped, frosted in part and subrounded; coarser layers have more black accessory minerals and many are limonite stained. Firmly cemented, calcareous and siliceous. Cross stratified, large trough sets, as much as 75 ft long, 50 ft wide and 10 ft thick, of southerly dipping cross beds, as much as 1 in. thick and 20 ft long. Forms hummocky steep rock

slope. Basal contact obscured by eolian sand; thickness thickness approximate..30

Total lower member (approx)........67

Total Entrada Sandstone (approx.)........482

Total San Rafael Group (approx.)........487

Navajo Sandstone:

1. Sandstone, grayish-yellow (5Y 8/4); fine; grained; cross stratified. Generally like unit 2 but lacks coarse grains and pebbles. Mostly covered by eolian and alluvial sand on line of section. Not measured................

As shown in the foregoing section, the Dewey Bridge Member of the Entrada Sandstone has a distinct three-fold division in the southwestern part of the Lisbon Valley area. Reddish silty sandstone, like that in unit 5, makes up the lower division; buff fine-grained sandstone, like that in unit 6, makes up the middle division, and reddish, silty sandstone, as in units 7 and 8 and much like the lower division, makes up the top division. All these divisions persist southwest into the northern part of the Abajo Mountains where they are described by Witkind (1964, p. 21) as the lower red, middle sandstone, and upper red units of the Carmel Formation [Dewey Bridge Member of the Entrada Sandstone].

Reddish silty sandstone at the base of the member is the most persistent division. The lower reddish silty sandstone pinches out locally, however, over highs on the surface of the Navajo Sandstone in Tank Draw and just west of the junction of Big Indian Wash and Hatch Wash.

Northward from Photograph Gap the upper reddish sandstone grades into brownish and yellowish-gray fine-grained sandstone and becomes more like the underlying buff sandstone in the middle of the Dewey Bridge Member and also more like the brownish and buff sandstone of the overlying Slick Rock Member of the Entrada. Most of this lateral gradation is well displayed on the west side of Rone Bailey Mesa. A thin, dark-red, less resistant bed of sandstone that forms a conspicuous dark band marks the top of the Dewey Bridge Member as far north as the natural arch 2 miles east of Looking Glass Rock where this marker bed forms the sill of the arch. This bed cannot be identified north of La Sal Junction; thus, in the northern part of the area the Slick Rock Member contains beds that are lateral equivalents of the middle and upper divisions of the Dewey Bridge Member exposed near Photograph Gap.

Eastward from Photograph Gap the three-fold division of the Dewey Bridge Member persists to Hatch Wash. The upper two divisions are well exposed on the walls of Church Rock and Sugar Loaf Rock. In eastern Dry Valley the middle buff unit apparently pinches out so that along East Canyon, Dry Wash, McIntyre Canyon, and Coyote Wash, the Dewey Bridge Member consist almost wholly of red, silty to fine-grained sandstone.

Slick Rock member

Distribution and thickness

The Slick Rock Member of the Entrada Sandstone makes up the bulk of the outcrop of the San Rafael group in the Lisbon Valley area. It forms smooth cliffs in the western, southern, and eastern parts of the area; in the La Sal Mountains it forms prominent hogbacks and long dip slopes.

The Slick Rock Member is thickest in the western part of the area and thins eastward. It ranges from about 200 to 280 feet in thickness near the west edge of the area and from about 100 to 120 feet in thickness near the east edge of the area.

Lithology

The Slick Rock Member is a relatively uniform lithologic unit in the Lisbon Valley area. The description of the member in the section near Photograph Gap would with minor exceptions serve as a description of the member in other parts of the area. The member is mostly light orange brown, but in southern Dry Valley and in the La Sal Mountains it grades to very pale yellow, almost white. Thin horizontal, dark-brown and pale-red bands commonly streak the member; in part the bands coincide with horizontal beds but they also transect beds. The member is chiefly composed of fine subrounded grains of clear quartz and minor white feldspar. Most beds are well sorted, but sparse to common well-rounded medium and coarse grains are characteristic of the member. These coarse grains, the "Entrada berries" of Wright, J. C., and others (1962, p. 2063), help distinguish the Slick Rock Member from the overlying Moab Member of the Entrada and are useful in distinguishing the Entrada from similar Navajo Sandstone in isolated fault blocks.

The sandstone is well cemented by calcite. Locally, as near Hole-in-Rock, weathering of differentially cemented beds in the middle part of the formation produces conspicuous rows of irregular pits, a few inches to a few feet in diameter. Because of the nearly uniform sorting and cementation of the Slick Rock Member, stratification is obscure. Some units appear to be structureless but probably most of the member is cross stratified in small- to medium-scale planar and trough sets of low-angle cross-laminae. The dip directions of the cross-laminae show a great range but the prevailing direction was judged to be westerly. Interstratified horizontal beds make up about 10 to 20 percent of the member; they are commonly somewhat finer grained and darker colored than the crossbedded units. Penecontemporaneous faults, which have offsets of only a few feet and which fade out upwards within a few feet, and contorted beds in slump structures are locally common near the base of the member.

The generally homogeneous character of the Slick Rock Member yields a distinctive outcrop--bare, smooth, slightly rounded cliffs that are virtually impassable except along major streams.

Moab Member

Distribution, lithology, and thickness

The Moab Member of the Entrada Sandstone extends throughout the Lisbon Valley area, though it is locally difficult to recognize. The lithology of the member is generally similar to that of the underlying Slick Rock Member, but the Moab Member is better sorted and lacks silty beds. Color banding, solution pits, and contorted bedding, locally common in the Slick Rock Member, are uncharacteristic of the Moab. It is a very pale orange, well-sorted, fine-grained sandstone composed of quartz and minor feldspar. It commonly forms a sheer cliff above the more rounded cliff of the Slick Rock Member. The section measured near Photograph Gap gives a description of a representative outcrop of the member.

In the northwestern part of the area the Moab Member is distinctly lighter colored than the underlying Slick Rock Member and is separated from it by a conspicuous parting or group of partings. Locally, as on the south side of Bridger Jack Mesa, the basal contact of the Moab Member truncates broad wavy beds of the Slick Rock Member. Along the mesa escarpments a few miles north of La Sal Junction, the member ranges from about 100 to 150 feet in thickness. It is only locally recognizable in the generally poor outcrops of the La Sal Mountains, where it probably ranges in thickness from about 50 to 100 feet.

In a large part of the area south of West Coyote Creek the Moab Member is not readily separated from the Slick Rock Member. The color differences between the members are less pronounced or lacking. The parting planes at the base of the Moab occur in a wider interval and locally fade away. In many of the outcrops bordering Dry Valley and East Canyon the basal contact of the member is especially obscure. Wright, J. C., and others (1962, p. 2064-2065) distinguished a questionable Moab Member in sections measured near Wilson Arch, eastern Dry Valley, Three Step Hill, and McIntyre Canyon. Along this southeasterly traverse the Moab Member thins from 110 and 46 feet. Some of this thinning is internal; some of the thinning is the result of intertonguing with the Summerville Formation at the top of the member. The Moab Member intergrades and intertongues with the Summerville Formation near the east edge of the area. Much of the member is represented in the adjoining Slick Rock district by a few tens of feet of thin beds of reddish-brown and greenish-gray, very fine grained sandstone intercalated with very thin layers of reddish-brown to orange-brown siltstone and mudstone in the lower part of the Summerville Formation (Shawe and others, 1968, p. A45-A49). A tongue of sandstone about 20 feet thick splits off the top of the Moab Member near Photograph Gap and persists eastward through the area as a conspicuous, ledge-forming bed of light-colored sandstone near the middle of the Summerville Formation. This tongue of sandstone is probably the same as the marker bed of sandstone, 10 to 35 feet thick, noted by Shawe and others (1968, p. A45-A49), in the upper part of the Summerville Formation in the Slick Rock District.

The Moab Member is locally distinct along the line of outcrops bordering Hart Draw in the southwestern part of the area. In this part of the area the member ranges from about 35 to 60 feet thick. On Rone Bailey Mesa the base of the member truncates broad wavy beds of the Slick Rock Member. Near the head of Hart Draw near the south edge of the Lisbon Valley area the base of the

Moab Member becomes indistinct. The member cannot be recognized in the northern part of the adjoining Abajo Mountains area though it is again a separable unit in the southern part of the Abajo Mountains area (Witkind, 1964, p. 23).

Contacts

The basal contact of the Entrada Sandstone is a disconformity on a wavy surface locally marked by small fragments of orange and gray chert. The contact is generally obscure where the lower memeber is present because of the lithologic similarity of the lower member to the underlying Navajo Sandstone. Where the Dewey Bridge Member forms the base of the Entrada the contact is conspicuous because of the color contrast between the reddish Dewey Bridge and the yellowish-gray Navajo.

The upper contact of the Entrada Sandstone is also generally sharp. The contrast between the light-colored, cliff-forming sandstone of the Entrada and the dark-reddish, slope-forming mudstone of the Summerville Formation make this the most conspicuous contact in the area. In the northeastern part of the area on Brumley Ridge and South Mesa the top of the Entrada is impregnated with dark-brown iron oxides which further accentuate the contact. Complications in this contact are near Photograph Gap where a thin tongue of sandstone splits off the top of the Entrada and near the east edge of the area where the uppermost few tens of feet of the Entrada intertongue and intergrade with the Summerville Formation. In these areas the contact is placed below the lowest bed of mudstone.

Age and regional stratigraphic relations

The Entrada Sandstone is unfossiliferous and it must be dated by its stratigraphic relations to fossil-bearing strata, the Carmel and Curtis Formations in the San Rafael Swell and the Green River desert. The Entrada Sandstone at its type locality at the north end of the San Rafael Swell is a sequence of red, horizontally bedded, earthy siltstone and sandstone that rests conformably on the Carmel Formation. A few miles east of the Green River, shale, gypsum, and limestone of the Carmel Formation grade into earthy siltstone of the Dewey Bridge Member of the Entrada Sandstone (Wright, J. C., and others, 1962, p. 2057). The Entrada is overlain in the San Rafael Swell by the Curtis Formation. On the basis of these relations the Entrada Sandstone is probably of Middle Jurassic age.

Eastward from the type locality red earthy siltstone and minor sandstone of the Entrada grade within a few tens of miles into a light-colored, partly crossbedded, fine- and medium-grained sandstone characteristic of the Slick Rock Member of the Entrada. The sediments of the lower member and the Dewey Bridge Member probably were deposited in shallow marine waters or on tidal flats; the Slick Rock Member may be a composite of dune and shallow-water sands.

The Moab Member intertongues and pinches out to the north in the Summerville Formation in the Green River desert (Baker and others, 1927, p 804-805; McKnight, 1940, p. 94-95). Near the Green River the Summerville in turn partly grades into the Curtis Formation. Thus the Curtis Formation, Moab Member of the Entrada Sandstone, and Summerville Formation, are in part contemporaneous marine, littoral, and continental sediments (Baker, 1933, p. 57). The crossbedding and horizontal bedding of the Entrada suggest alternating wind and water deposition on the area marginal to Middle Jurassic seas.

In the southern part of the Lisbon Valley area, a thin tongue of sandstone splits off the top of the Entrada and forms a conspicuous marker bed interstratified with the Summerville. This tongue or similar tongues off the top of the Entrada apparently persist to the south and southeast and merge with the beds of the Bluff Sandstone of southeastern Utah and the Junction Creek Sandstone of southwestern Colorado (Craig and Cadigan, 1958, p. 186; Shawe and others, 1968, p. A50).

Summerville Formation

Distribution and thickness

The Summerville Formation is a widespread thin unit in the Lisbon Valley area. In the northern and western parts of the area it is generally less than 20 feet thick; it thins to near extinction about 1 mile south of Photograph Gap. In Dry Valley and eastward the Summerville ranges from about 60 to 100 feet in thickness. It is thickest along East Coyote Wash near the east border of the area. Because it is generally thin, the Summerville is grouped with the underlying Entrada on the geologic map accompanying this report (fig. 3), but it is shown as a separate unit on most of the large-scale preliminary maps of the area (Weir and Dodson, 1958a, 1958c, 1958d, 1958e; Weir, Dodson and Puffett, 1960, 1961; Weir and Kennedy, 1958; Weir and Puffett, 1960; Weir and others, 1960).

Lithology

The Summerville Formation consists mainly of red mudstone, and minor amounts of light-colored sandstone, chert, and limestone. The following section is representative of the Summerville in the central and eastern parts of the Lisbon Valley area. It was described in 1954 from outcrops on the west side of East Canyon by G. W. Weir and C. L. Dodson assisted by F. G. Hendrickson.

Section of the Summerville Formation, measured in S1/2 sec. 25, T. 31 S., R. 24 E., San Juan County, Utah

	Thickness (feet)
Summerville Formation:	
6. Siltstone (70 percent) and sandstone (30 percent); mostly covered but apparently similar to unit 4 below; forms slope	22
5. Sandstone, moderate-orange-pink (10R 7/4); weathers moderate reddish orange (10R 6/6); very fine grained, fair sorted; composed of subangular to angular clear quartz and feldspar with rare to common accessory minerals; firmly cemented, calcareous. Basal 5 ft	

apparently structureless; top 1 ft in horizontal thin beds. Forms irregular minor cliff............................6

4. Sandstone (50 percent) and siltstone (50 percent). Sandstone, moderate-orange-pink (5YR 8/4) and moderate-reddish-orange (10R 6/6), very fine grained and silty, fair-sorted; composed of subangular clear quartz and feldspar with common black accessory minerals; firmly cemented, calcareous and clay binding; laminated in sets 1 to 4 in. thick intercalated with siltstone. Siltstone, moderate-reddish-brown (10R 4/6), clayey and very fine sandy; poorly cemented, clay binding. Unit forms slope mantled with colluvium.......................11

3. Sandstone, very pale orange (10YR 8/2) and grayish-orange (10YR 7/4); weathers grayish orange (10YR 7/4) and dark yellowish orange (10YR 6/6); fine to medium grained, poorly sorted; composed of angular to sub-angular clear quartz and feldspar with rare to common black accessory minerals; firmly cemented, calcareous; in part horizontally bedded, as near top, and in part structureless. Unit commonly weathers with a minutely knobby surface. Forms conspicuous ledge throughout East Canyon and Dry Valley....................................14

2. Mudstone (70 percent) and sandstone (30 percent). Mudstone, grayish-red (10R 4/2), silty and very fine sandy but probably dominantly clayey; sand and coarse silt grains are quartz and muscovite; firmly cemented, clay clay binding. Sandstone, pale-reddish-brown (10R 5/4), silty and very fine grained, fair-sorted; composed of subrounded grains of quartz and feldspar; firmly cemented, calcareous; in horizontal beds 0.5 to 3 ft thick irregularly intercalated with mudstone. Poorly exposed..........33.5

Total of Summerville Formation........86.5

1. Sandstone, very pale orange (10YR 8/2) and grayish-orange-pink (5 YR 7/2); weathers about same and light brown (5YR 6/4); very fine and fine grained, well sorted; composed of subangular quartz and feldspar with rare black accessory minerals; firmly cemented, calcareous. Mostly cross stratified in medium- to large-scale sets of low-angle cross-laminae; upper 15 to 25 ft characterized by horizontal bedding and structureless units. Lower part forms rounded, sloping cliff; upper part forms near-vertical cliff; narrow bench on top; conspicuous horizontal niche about 8 ft below top. Not measured; estimated thickness of exposure about 100 ft..........

Mudstone in the Summerville ranges from light brown to dark grayish red, and from fairly pure claystone and calcareous siltstone to poorly sorted mixtures of fine sand, silt, and clay. The mudstone is generally well stratified in very thin continuous beds, but it is commonly contorted near large masses of chert.

Gray and reddish-gray chert in discontinuous layers, a few inches to a few feet thick, and large irregular masses, as much as 40 feet across and 6 feet thick, are conspicuous features near the top of the Summerville in the northern and western parts of the area and make it possible to trace this thin formation in the La Sal Mountains. Chert is sparse and mostly absent in the Summerville in the southern part of the area east of Peters Point. In other words, chert is mainly restricted to the relatively thin Summerville and is uncommon where the formation is more than a few tens of feet thick. The chert is probably a diagenetic replacement of calcareous mudstone and limestone beds.

Beds of bluish-gray limestone, commonly only a few inches thick, occur locally above the chert and sporadically within the Summerville Formation and are partly replaced by chert. Some limestone beds in the Summerville, as for example those exposed along the highway north of Kane Springs, grade into calcareous siltstone.

Sandstone makes up generally less than 10 percent of the Summerville. Most of this sandstone is light colored, fine grained and silty, in thin discontinuous beds. Oscillation ripple marks and mudcracks are locally present. Exceptionally, as in Browns Hole, some lenses of sandstone, a few feet thick, are medium grained and contain scattered granules and small pebbles of red and grayish-green chert.

In the southern part of the area east of Photograph Gap, a minor tongue off the top of the Entrada Sandstone forms a conspicuous ledge near the middle of the formation. This mid-Summerville ledge is made up of fine- to medium-grained quartz and clear feldspar, and commonly ranges between 10 and 15 feet in thickness. Much of it appears structureless; in part it is horizontally bedded. Near the north end of East Canyon and near Photograph Gap it is partly crossbedded. This sandstone, described as unit 3 in the section measured in East Canyon, persists eastward and has been traced by Shawe and others (1968, A45-A50) southeastward from the east edge of the Lisbon Valley area into the Junction Creek Sandstone in the southern part of the adjoining Slick rock district.

The Summerville generally resembles the overlying Salt Wash Member of the Morrison Formation. It differs from the Salt Wash mainly in the presence of masses and beds of chert and in the absence of channeling sandstone lenses.

The general dominance of reddish, even-bedded fine-grained sediments, the presence of oscillation ripple-marks and mudcracks suggest quite-water deposition of the Summerville sediments in a non-marine environment. McKee and others (19567, p. 3) interpreted this lithology of the Summerville as sheet flood and pond deposits on a broad alluvial plain. The mid-Summerville sandstone ledge in the southern part of the area probably represents reworked sands dune deposits.

Contacts

The Summerville Formation conformably overlies the Entrada Sandstone. The contact is sharp generally in the western and central parts of the area except on the west side of Dry Valley, where a few tens of feet of the uppermost Entrada intertongue with the Summerville. Near the east edge of the area where the Summerville intertongues and intergrades with the Entrada, the contact is placed at the base of the lowest bed of red mudstone.

The upper contact of the Summerville is placed at the top of a fairly persistent zone of thin limestone lenses which generally separates the thick channeling sandstone lenses of the overlying Salt Wash Member of the Morrison Formation from the thinner, horizontally stratified sandstone beds of the Summerville.

Age and stratigraphic relations

The Summerville Formation contains no fossils, but its age is Middle Jurassic. Lateral gradation of its basal part into the fossiliferous marine Curtis Formation (Imlay, 1952a, p. 964) occurs. This gradation takes place in the Green River desert, a few tens of miles east of the type section of the Summerville in the northern San Rafael Swell (McKnight, 1940, p. 102). To the south and southeast the Summerville in part intertongues and intergrades with and in part is overlain by the Junction Creek (Bluff) Sandstone (Craig and Cadigan, 1958, p. 182-185; Shawe and others, 1968, p. A50).

Morrison Formation

Distribution and thickness

The Morrison Formation crops out widely in the Lisbon Valley area and generally forms a long, rough, partly landslide covered slope between the top of the cliff of the San Rafael Group and the ledges of the Burro Canyon Formation. Near the western edge of the area, where the Morrison has been partly stripped away, remnants of the lower part of the formation cap many small mesas.

The Morrison Formation in the Lisbon Valley area consists of two members of about equal thickness: the Salt Wash Member, below, and the Brushy Basin Member, above. The formation averages about 750 feet in thickness. Departures from this average are due to variations in placement of contacts and to a general eastward thinning of the formation.

Lithology

The Salt Wash Member, the lower part of the Morrison Formation, consists mainly of thick lenses of light-brown sandstone interbedded with red mudstone. The Brushy Basin Member, the upper part of the Morrison, is chiefly gray and grayish-red mudstone with some lenses of dark-brown conglomeratic sandstone at the base. Eash of these members of the Morrison has a characteristic topographic form, which permits recognition of the members even where they are mostly covered by landslide deposits. Owing to its interstratified sandstone lenses, the Salt Wash forms a steep ledgey slope interrupted by prominent benches; The Brushy Basin slopes are smoother and generally flatter.

The following section illustrates the general aspect of the Morrison Formation in the Lisbon Valley area. The section, measured with Abney level and tape by G. W. Weir and C. L. Dodson, 1953, was described from outcrops on the west side of East Canyon about 1.5 miles northwest of Iron Canyon Point.

Section of the Morrison Formation, measured in S1/2 sec. 25, NE1/4 sec. 35, NW1/4 sec. 36, T. 31 S., R. 24 E., San Juan County, Utah

	Thickness (feet)
Morrison Formation:	
Brushy Basin Member:	
14. Covered by landslide and talus. Rare outcrops suggest unit consists of gray, green, and red mudstone similar to mudstone of unit 12. Forms slope. Top approximate, placed at base of marked steepening of slope.................	375
13. Sandstone (95 percent) and conglomeratic sandstone (5 percent), very pale orange (1YR 8/2); weathers grayish orange (10YR 7/4) specked with light-brown limonite, fine to coarse grained with rare to abundant granules and pebbles as much as 3/8 in. across, well to poorly sorted in individual beds. Composed of rounded to subangular clear quartz and feldspar with rare to abundant grains, granules, and pebbles or orange, red, light- to dark-green, and gray chert and light-gray mudstone; well to poorly cemented, calcareous. In part in thin horizontal sets, in part in small- to medium-scale trough sets of low-angle cross laminae and in part structureless. Forms irregular cliff; weathered surface locally characterized by knobs 2 to 4 mm in diameter..	38
Total of Brush Basin Member........	413
Salt Wash Member:	
12. Mudstone (80 percent) and sandstone (20 percent). Mudstone, very dusky red (10R 2/2), pale-green (5G 7/2) and medium-dark-gray (N 4), silty and sandy but probably dominantly clayey. Sandstone, very pale orange (10Y 8/2), fine-grained, fair-sorted; composed of quartz and orange chert, and minor light-green chert with common black accessory minerals; firmly cemented, calcareous. Mostly covered by landslide and colluvium......	26.5
11. Sandstone, very pale orange (10YR 8/2); weathering grayish orange (10YR 7/4); very fine to fine grained, fair sorted; composed of subangular clear quartz and minor clear feldspar and white weathered feldspar or tuffaceous material with common red, black, and	

orange accessory minerals; firmly cemented, calcareous; in lensing sets of horizontally stratified thin beds and in small-scale trough sets of low-angle cross laminae. Forms minor cliff and broad bench.................38.5

10. Siltstone (60 percent) and sandstone (40 percent). Siltstone, pale-red (10R 6/2) and pale-greenish-yellow (10Y 8/2), clayey and very fine sandy, silty, firmly cemented, calcareous. Sandstone, pale-yellowish-orange (10YR 8/6), very fine grained, fair-sorted; composed of angular clear quartz, gray chert, and clear feldspar with common black and orange accessory accessory minerals; friable, calcareous. Unit forms bench or moderate slope. Poorly exposed......................10

9. Sandstone, very pale orange (10YR 8/2); weathering grayish orange (10YR 7/4); fine to medium grained; individual beds fair sorted; composed of subrounded to subangular clear quartz and feldspar with common orange and black accessory minerals and greenish mudstone flakes; firmly cemented, calcareous; mostly cross stratified in small- to medium-scale trough sets of low- to high-angle thin crossbeds, in part horizontally stratified and structureless; sets commonly separated by partings of green mudstone. Ripple marks and current lineation are rare to common. Forms irregular near-vertical cliff. Unit is main uranium-vanadium ore-bearing sandstone of East Canyon.................82

8. Covered. Float suggests interval dominantly made up of red mudstone and light-colored fine-grained sandstone similar to mudstone and sandstone of unit 2. Forms moderate slope.................................37

7. Sandstone, moderate-orange-pink (5YR 8/4) and very pale orange (10YR 8/2); weathers moderate reddish orange (10R 6/6); very fine grained, well sorted; composed of subangular to subrounded clear quartz and feldspar, white weathered feldspar or tuffaceous material and minor muscovite with common orange and black accessory minerals; firmly cemented, calcareous; structureless and horizontally stratified; very thin bedded and laminated. Forms minor irregular cliff..........14.5

6. Covered. Float suggests interval is mostly red mudstone and light-colored sandstone similar to mudstone and sandstone of unit 2. Forms moderate slope..............17.5

5. Sandstone, very pale orange (10YR 8/2); weathers grayish orange (10YR 7/4), fine to medium grained, individual beds fair sorted; composed of subangular to subrounded clear quartz and feldspar and white, weathered feldspar or tuffaceous material with rare- to common-colored accessory minerals and flakes and pebbles of green mud-

stone; well cemented, calcareous; dominantly cross stratified in small- to medium-scale trough sets of thin cross beds, common partings of red mudstone; rare ripple marks and current lineation; forms conspicuous irregular cliff....................................48

4. Mostly covered. Rare outcrops suggest unit is mainly red mudstone with minor light-colored sandstone, similar to mudstone and sandstone of unit 2. At top of unit about 0.5 ft exposure of pale-reddish-brown (10R 5/4) siltstone, top 1 in. altered to dark yellowish orange (10R 6/6) and very pale green (10G 8/2)................4

3. Sandstone, very pale orange (10YR 8/2); weathers grayish orange (10YR 7/4), medium grained with common coarse grains; poorly sorted; composed of subangular clear quartz and feldspar with abundant orange chert and common coarse grains and granules of red, green, black, and clear chert and light-greenish-gray claystone; firmly cemented, calcareous. Irregularly bedded; in part cross stratified. Forms minor ledge.................5.5

2. Mudstone (70 percent) and sandstone (30 percent). Mudstone, pale-red (10R 6/2), clayey and sandy but probably mostly silt; crudely laminated. Sandstone, grayish-orange-pink (10R 8/2); weathers moderate orange pink (10R 7/4); fine grained, fair sorted; composed of clear quartz and feldspar; well cemented, calcareous; in irregular lenses 1 to 4 ft thick. Forms moderate slope mostly covered by landslide and colluvium....................65

1. Sandstone, very pale orange (10YR 8/2); weathers moderate reddish orange (10R 6/6) and reddish orange (10YR 7/4); fine to medium grained, fair sorted; composed of subrounded clear quartz, feldspar, and white weathered feldspar or tuffaceous material with common black and orange accessory minerals; firmly cemented, calcareous; mainly cross stratified in small- to medium-scale trough sets of thin cross beds; in part horizontally bedded. Forms irregular ledge................16.5

Total Salt Wash Member................................365

Total Morrison Formation........778

Salt Wash member

The Salt Wash Member consists about equally of sandstone and mudstone. Limestone and conglomerate sandstone make up a small part of the member.

The sandstone is mostly very pale orange, weathering to grayish orange or very light brown. Typically, it is medium grained and fair sorted; however, it ranges from fine grained and silty to conglomeratic and from well sorted to poorly sorted. The chief detrital mineral is subangular to subrounded colorless quartz. About 10 to 20 percent of the grains are gray and colored chert, colorless feldspar, dull white tuffaceous(?) material, and green mudstone. Granules and small pebbles of black, gray, and reddish-brown chert and green mudstone occur sporadically in the sandstone, chiefly as thin stringers and irregular pockets. Conglomeratic sandstone is most common at the base of units near the top and bottom of the member. The sandstone is typically firmly cemented by calcite and interstitial clay. It is cross-stratified in medium-scale trough sets with high-angle crossbeds that for the most part dip easterly. Most of the sandstone is in ledge-forming lenses. The lenses vary in thickness within short distances but are commonly several tens of feet thick and hundreds of feet long. Sandstone lenses near the top and bottom of the member are most persistent; some of these lenses crop out continuously for many miles and are as much as 100 feet thick and more than a mile wide measured across the trend of the lens. Prominent scour surfaces are at the base of each lens and also frequently within thick lenses. These surfaces are diastems which commonly record the erosion of at least a few feet of the underlying beds; at the base of some channeling sandstones probably several tens of feet of the underlying rock have been cut out.

Mudstone in the Salt Wash Member is chiefly grayish red and reddish brown. Thin bands of grayish-green mudstone commonly underlie thick sandstone lenses, and mudstone seams in sandstone are frequently grayish green. The grayish green is, at least in part, an alteration from an originally reddish hue; as noted in the description of uranium deposits in the Salt Wash Member, this color alteration may be related to the ore-forming processes. Most of the mudstone is silty and much is very finely sandy. The clay minerals are chiefly hydromica with hydromica-montmorillonite mixtures and minor chloite (Craig and Cadigan, 1958, p. 189). The mudstone is generally calcareous and firmly cemented, but it is less resistant than the interstratified sandstone. It is horizontally stratified or structureless; some units are ripple-bedded, the result of superposed current ripple marks. The more silty and sandy mudstones are generally fissile; they split into paper-thin sheets.

Limestone, containing sparse fossil fresh-water algae, occurs as fairly continuous beds, only a few inches thick, near the base of the member and also as irregular nodules and thin discontinuous beds at the base of sandstone lenses. The limestone is bluish gray, more rarely pinkish gray, and aphanitic to very finely crystalline. It is locally converted to reddish-gray chert.

Brushy Basin member

The Brushy Basin member is chiefly made up of variegated mudstone. Sandstone and conglomeratic sandstone, and limestone are minor.

Mudstone in the Brushy Basin is grayish red, light to medium gray and, less commonly, greenish gray. Swelling clays make up a large part of the mudstone, which on weathered surfaces has a distinctive popcorn-like texture. This characteristic is an aid in identifying isolated outcrops of Brushy Basin, but the member also includes silty, sandy mudstone that lacks swelling clays and that resembles mudstone in the Salt Wash Member and in the Burro Canyon Formation. The clay minerals are chiefly montmorillonite and montmorillonite-hydromica mixtures (Craig and Cadigan, 1958, p. 191). The mudstone is obscurely horizontally stratified; ripple marks, common in the mudstones of the underlying Salt Wash, are rare in the Brushy Basin. Most of the mudstone lacks fissility.

Sandstone and conglomeratic sandstone occur in fairly continuous lenses near the base of the member and are sporadically interstratified in the upper part. They weather mostly dark brown or brownish red. The sandstone ranges from poorly sorted, conglomeratic and coarse grained to well sorted, very fine grained to silty. The conglomeratic and coarse-grained beds are characteristic of the basal part of the member. They occur in cross-stratified lenses that range from a few feet to about 50 feet in thickness. Coarse-grained sandstone grades both laterally and vertically to conglomeratic and fine-grained sandstone. The sandstone is similar in composition to sandstone in the Salt Wash Member but is distinguished by the presence of grains, granules, and small pebbles, generally a fraction of an inch in diameter, of red, orange, and light- to dark-green chert. Though generally firmly cemented and calcareous, many beds are friable. Most sandstone near the base of the member is cross-stratified in small-scale trough sets with high-angle, easterly dipping cross laminae. Fine-grained sandstone, especially in the upper part of the member, is commonly structureless or horizontally stratified.

Limestone makes up less than 1 percent of the Brushy Basin Member, but it is locally conspicuous. It is light brown to pinkish gray, extremely fine grained and occurs in thin beds, less than a foot thick, interbedded with mudstone.

The contact between the Salt Wash and Brushy Basin Members of the Morrison Formation is placed at the base of the lowest distinctive sandstone in the Brushy Basin. Between the top sandstone lens of the Salt Wash Member and the basal conglomeratic sandstone of the Brushy Basin Member is generally a poorly exposed transition zone, several tens of feet thick, consisting of frothy-weathering variegated mudstone and thin light-brown sandstone. In a few places, as a mile north of Pine Hollow, conglomeratic sandstone of the Brushy Basin cuts into the upper sandstone of the Salt Wash.

Contacts

In the Lisbon Valley area the Morrison Formation lies conformably on the Summerville Formation. The contact is somewhat arbitrarily placed at the top of thin but fairly persistent zone of thin lenses of bluish-gray limestone, which locally are converted to pinkish-gray chert. This contact generally separates the quiet-water deposits of the Summerville from the dominantly current-deposited beds of the Salt Wash Member of the Morrison. Near Browns Hole, however, the zone of lenses of limestone overlies small lenses of cross-bedded conglomeratic sandstone that are more characteristic of the Morrison than of the Summerville. In parts of the area where the basal limestone is discontinuous the contact is placed at the base of the lowest channeling sandstone of the Salt Wash; this horizon is approximately the same or a few feet higher than the top of the zone of limestone lenses.

The contact between the Brushy Basin Member of the Morrison Formation and the overlying Burro Canyon is conformable, gradational, and probably intertonguing.

Age

Since the review of the stratigraphic and fossil evidence by Baker and others (1936, p. 58-63), the Morrison Formation is generally assigned to the Upper Jurassic. The highest fossiliferous beds of the underlying San Rafael Group contain marine fossils of Middle Jurassic age; the overlying Burro Canyon and Cedar Mountain Formations contain a nonmarine flora and invertebrate fauna of Early Cretaceous age (Simmons, 1957, p. 2525-2528). The nonmarine reptiles, mammals, and molluscs of the Morrison indicate a Late Jurassic age, equivalent to the Kimmeridgian Stage and part of the Portlandian Stage (Imlay, 1952a, p. 958). Fossils are lacking in the upper 100 to 200 feet of the Morrison, and thus its upper age limit is not fixed (Stokes, 1952, p. 1770). The transitional contact between the Morrison Formation and the overlying Burro Canyon Formation suggests that deposition was virtually continuous from Late Jurassic into Early Cretaceous in the Lisbon Valley area and also in nearby areas (Simmons, 1957, p. 2523).

Few fossils were found in the Morrison Formation in the Lisbon Valley area. Dinosaur bones, generally broken and abraded, are very sparse in sandstone units, although Newberry's pioneer expedition found a nearly complete dinosaur skeleton in the Morrison above East Canyon (Newberry, 1876, p. 91). Silicified wood and macerated coalified debris are locally common in the middle part of the formation. Fossil charophytes, nonmarine aquatic plants, were found at two localities. Peck (1957, p. 12) reports *Latochara spherica* Peck in limestone and calcareous shale near the base of the Morrison near Church Rock, sec. 29, T. 31 S., R. 24 E., San Juan Co., Utah. We found rod-like striated spines in a limestone block, probably from the lower part of the Brushy Basin on the dump of the Silvertone prospect in NW1/4 sec. 25, T. 44 N., R. 20 W., San Miguel County, Colorado; these were identified in part as charophyte stems that may be referred to *Charaxis* sp. (R. E. Peck, written communication, 1959).

Regional stratigraphic relations

The regional stratigraphy and nomenclature of the Morrison Formation is discussed by Baker and others (1936), Reeside (1952), and Craig and others (1955). The Morrison Formation, named by Cross (1894, p. 2) for outcrops near Morrison, Colorado on the east side of the Rocky Mountains, is recognized over most of the Western Interior of the United States, including much of the Colorado Plateau. Gilluly and Reeside (1928, p. 82) extended the name Morrison Formation into the Plateau region to replace older names for the beds between the San Rafael Group and the Dakota Sandstone. Later, Stokes (1944; Stokes and Phoenix, 1948) assigned part of the upper Morrison to the Cedar Mountain and Burro Canyon Formations.

The Salt Wash Member, whose type locality is near Green River, Utah (Lupton, 1914, p. 127) extends over much of eastern Utah and western Colorado and parts of northeastern Arizona and northwestern New Mexico. The Salt Wash was deposited by aggrading braided streams to form a broad alluvial fan whose head was near the State line in south-central Utah. The member is divided regionally into three main lithologic facies by Craig and others (1955, p. 137, fig. 21). Near the head of the alluvial fan the Salt Wash is mainly conglomeratic sandstone containing pebbles as much as 4 inches in diameter. Northwest, north, and east of the conglomeratic sandstone facies is a facies consisting of scour-fill sandstone interstratified with impure claystone; the Lisbon Valley area lies entirely within this sandstone and mudstone facies. Along the northern edge of the fan is a facies consisting of claystone and sparse lenses of sandstone. Beyond the limits of the recognizable Salt Wash, the probable equivalent facies of the Morrison Formation consists of claystone and sandstone. The Salt Wash attains a maximum thickness of more than 600 feet near the head of the fan and thins irregularly away from this point. The source area of the Salt Wash Member was an older sedimentary terrance that lay southwest of south-central Utah.

In the Four Corners region the Salt Wash Member interfingers with the Recapture Member of the Morrison Formation. The Recapture is also a fluvial deposit but was derived from a sedimentary, metamorphic, and igneous terrane that probably lay in west-central New Mexico (Craig and others, 1955, p. 135-152).

The Brushy Basin Member, whose type locality is near Blanding, Utah (Gregory, 1938, p. 59), is recognized on the Colorado Plateau where the Salt Wash or Recapture Members are present. Southwest and south of the Four Corners region the Brushy Basin was removed by pre-Dakota erosion. The eastern and northeastern boundary of the Brushy Basin Member is an arbitrary line in western Colorado where the underlying Salt Wash Member loses its identity and cannot be distinguished from the upper part of the Morrison. The sandstone beds in the Brush Basin Member were deposited by steams probably flowing from the same general source area as the Salt Wash streams. The mudstone and limestone of the Brushy Basin record falls of volcanic ash and deposition in lakes (Craig and others, 1955, p. 152-157).

Cretaceous system

Burro Canyon Formation

Distribution and thickness

The Burro Canyon Formation rims the Sage Plain, forms the dip-slopes bordering East Coyote Wash, and forms hogbacks and dip-slopes around the La Sal Mountains.

The thickness of the formation averages about 125 feet over much of the area but ranges from about 80 to 300 feet. Wide divergences from the average are largely nonsystematic and are caused by channeling and possibly by intertonguing of the lower part of the Burro Canyon and by irregular pre-Late Cretaceous erosion of the upper part.

Lithology

The Burro Canyon Formation consists of sandstone and conglomerate, locally silicified to quartzite, and mudstone, locally containing nodules and thin beds of limestone. Sandstone and conglomerate are generally dominant and in places make up the whole formation. The following section illustrates the character of the Burro Canyon Formation in the southern part of the Lisbon Valley area. In the northern part of the area mudstone, silicified sandstone, and conglomerate are locally dominant. The section was measured with hand level and tape by G. W. Weir and V. C. Kennedy in 1955, along Wild Horse Draw on the east side of South Canyon Point.

Section of Burro Canyon Formation, measured in NE1/4SE1/4 sec. 2, T. 32 S., R. 24 E., San Juan County, Utah

Thickness (feet)

Dakota Sandstone (incomplete):

6. Sandstone and conglomerate, moderate-yellowish-brown (10YR 6/4), in part limonite-stained, fine- to medium-grained, fair-sorted; composed of subangular to subrounded clear quartz and minor yellowish-white weathered feldspar(?) with rare orange and black accessory minerals; firmly cemented, siliceous; crossbedded in small- to medium-scale trough and planar sets of cross laminae, in places thin seams of olive-gray mudstone are intercalated between groups of sets. Disconformity at base of Dakota marked by a distinctive conglomerate, a few inches to about 1 ft thick, composed of angular to subangular blocks of light-brown sandstone, light-grayish-brown silicified sandstone, gray and white- and gray-banded chert derived from Burro Canyon Formation. Blocks are as much as 12 in. across; most are between 2 and 5 in. across. Matrix is a conglomerate with rounded pebbles, as much as 2.5 in. across, and subangular pebbles, mostly 1/8 to 1/2 in. across, of very light gray quartz, gray, white, and black chert, green, and white claystone; interstices filled by medium-grained sand. Disconformity has irregular local relief of about 3 ft. Unit forms ledge; not measured; only lower 20 ft examined.................

Burro Canyon Formation:

5. Sandstone (60 percent) and conglomerate (40 percent), very pale orange (10YR 8/2) to grayish-orange (10YR 7/4); weathers grayish orange with streaks of moderate red (5R 4/6), fine to coarse grained, fair to poorly sorted; composed of subangular to subrounded clear and amber-stained quartz with common crystal overgrowths, with common accessory dark-gray, black and orange chert and white kaolinized feldspar(?). Conglomerate is in lens, 1 to 3 ft thick at base, and in stringers and pockets scattered through unit; consists of granules and pebbles, as much as 1-1/8 in. diameter, but generally less than 1/4 in. diameter, composed of very light gray and black chert, white kaolinized feldspar(?), and green mudstone. Unit irregularly cemented; cross stratified in thin rough sets with low-angle cross laminae; forms irregular cliff recessed below ledge

of unit 7. Thickness of unit differs along outcrop due to channeling disconformity above.........................7

4. Sandstone (80 percent) and mudstone (20 percent). Sandstone, pale-greenish-yellow (10Y 8/2); weathers same and grayish orange (10YR 7/4); silty, very fine to medium grained, with common scattered coarse grains, granules, and pebbles as much as 3/4 in. diameter, poorly sorted; composed of white quartz and feldspar(?) with abundant accessory black and reddish chert; granules and pebbles composed mainly of angular to subrounded black chert with minor light-gray chert; well cemented; structureless; grades upward to mudstone. Mudstone, light-greenish-gray (5GY 8/1), silty and with abundant very fine to fine sand grains; forms top of unit. Unit is lens only a few tens of feet long; forms ledge............................3

3. Sandstone (75 percent), conglomerate (20 percent), and mudstone (5 percent). Sandstone, mostly yellowish gray (5Y 8/1) to pale-yellowish-orange (10YR 8/6), in part white (N 9), very fine to medium grained, well- to fair-sorted yellowish sandstone composed of subrounded clear and amber-stained quartz with common crystal overgrowths and with accessory gray chert and white claystone (kaolinized feldspar?); white sandstone composed of subangular white quartz with abundant red, green, and black accessory minerals; firmly cemented; cross stratified in small-scale planar sets; small-scale planar sets; white sandstone occurs as thin lens at base of unit. Conglomerate, pale-yellowish-orange (10YR 8/6), matrix medium- to coarse-grained similar to yellowish sandstone described above; pebbles make up 10 to 60 percent of rock, are as much as 1-1/2 in. diameter, most commonly 1/8 to 1/2 in. diameter, larger pebbles are well rounded, smaller pebbles are subangular; composed of light-gray, black and red to orange chert, and white quartz; firmly cemented; cross stratified in trough sets with low-angle cross laminae. Mudstone, light-grayish-green (5GY 8/1), silty; in lenses a few inches thick near base of unit; poorly exposed. Unit forms irregular sloping bench partly covered by talus........3.5

2. Conglomerate (75 percent) and sandstone (25 percent). Conglomerate, very pale orange (10YR 8/2) and pale-yellowish-orange (10YR 8/6); pebbles make up 10 to 50 percent of rock, content ranges 10 to 50 percent in medium- to coarse-grained matrix similar to sandstone described below; largest pebbles about 1 in. across; most pebbles generally range between 1/16 and 3/8 in. diameter, and are composed of gray and black chert, brown sandstone, very light gray quartz, red silicified sandstone, white claystone, and green mudstone; matrix is medium- to coarse-grained sandstone similar to interbedded sand-

stone described below; firmly cemented; obscurely cross stratified. Sandstone, pale-yellowish-orange (10YR 8/6), medium-grained, fair-sorted; composed of subrounded to subangular clear quartz with minor angular white claystone and light-gray to black accessory minerals; firmly cemented; stratification obscure, in part horizontally bedded. Unit forms rough cliff continuous with cliff of unit 2. Face locally pocked with irregular pits, as much as 6 in. across, formed by weathering out of clasts of mudstone...41.5

1. Sandstone (90 percent) and conglomerate (10 percent). Sandstone, yellowish-gray (5Y 8/1); weathering pale yellowish orange (10YR 8/6), generally similar to sandstone in unit 3. Conglomerate, generally similar to conglomerate of unit 3, but weathers light brown (5YR 5/6) basal 1 ft, locally limonite stained; firmly to poorly cemented, calcareous and iron oxide cement; gypsum in veinlets and crusts near base; stratification obscure, in part in sets of high-angle crossbeds. Unit is interbedded conglomerate and conglomeratic sandstone near base; about 4 ft above base grades to sandstone; forms rough near-vertical cliff. Rests without apparent angular discordance on greenish-gray mudstone and shale of Brushy Basin Member of Morrison Formation; contact marked by limonite staining that commonly extends as much as 12 in. above base into conglomerate and 12 in. below contact into light-greenish-gray sandy mudstone of underlying Morrison Formation...37

Total Burro Canyon Formation........92

Sandstone and conglomerate of the Burro Canyon commonly weather yellowish-brown or gray; fresh surfaces are lighter colored. The sandstone shows great ranges in sorting, grain size, roundness, and cementation; most commonly it consists of medium-grained, fair-sorted, subrounded to subangular clear quartz, colored chert, and white feldspar, firmly cemented by silica. The conglomerate is made up of black, brown, red, and grayish-green, subangular to rounded pebbles, which are as much as 3 inches in diameter but average about 0.5 inch in diameter. Some chert pebbles derived from Paleozoic rocks contain fossil fragments of bryozoans and corals. The pebbles are mostly chert but include silicified fine-grained sedimentary rocks, white weathered feldspar, and green mudstone. The matrix consists of smaller pebbles and coarse- to medium-grained sand.

The sandstone and conglomerate commonly intergrade both laterally and vertically. In some sections the conglomerate occurs only as lenses at the base of thick sandstone units. Much of the sandstone and conglomerate is cross-stratified in thin, long sets of low-angle cross-laminae, which for the most part dip northeasterly. Current lineation, ranging generally from 30° to 110°, is common on many horizontal bedding planes.

The sandstone and conglomerate are locally silicified to form a glistening, very light gray quartzite. This extremely resistant rock fractures across the grains. Quartzite is a characteristic rock type of the Burro Canyon Formation north of the line of strike of Lisbon Valley; it is only sporadically present in the southern part of the area east of East Canyon, and is absent from the southwest part of the area. At some localities, as near the mouth of Brumley Creek, all the sandstone and conglomerate in the formation are converted to quartzite for thousands of feet along strike. More commonly only sandstone and conglomerate units at or near the top of the Burro Canyon are quartzite. The quartzite beds locally pass into normal sandstone and conglomerate with zones of irregular and contorted silica concretions. Near Pack Creek (sec. 16, T. 27 S., R. 23 E.) a red siltstone in the upper part of the Morrison Formation grades laterally within about 2,000 feet along strike into a fine- to medium-grained limy sandstone at the base of the Burro Canyon, and this sandstone grades laterally into a quartzite typical of the Burro Canyon.

The silicification of the sandstone and conglomerate of the Burro Canyon took place before the overlying Dakota Sandstone was laid down, for boulders of the quartzite are common in the basal conglomerate of the Dakota. As Carter (1957, p. 309) suggested, the quartzite probably formed during a time of extensive erosion and subaerial weathering between the deposition of the Burro Canyon and the Dakota.

Mudstone in the Burro Canyon Formation is mostly grayish green, grayish brown, and grayish to purplish red. Most typical is bright grayish-green mudstone, which is not found in the overlying Dakota. Mudstone in the Burro Canyon generally lacks carbonaceous fragments commonly found in mudstone in the Dakota. Though mudstone units in the Burro Canyon generally resemble mudstone in the underlying Morrison Formation, they lack the frothy weathering surfaces of some mudstone of the Morrison. Mudstone forms only a small part of the Burro Canyon in the southern part of the area, but its proportion increases irregularly northward and near Pack Creek locally makes up about half the formation.

Lenses of dull bluish-gray to brownish-gray, very finely crystalline limestone are interstratified with mudstone. These lenses are rarely more than a few inches thick but they persist for hundreds of feet. They commonly are veined by white, coarsely crystalline calcite and are apparently unfossiliferous. Limestone also occurs in mudstone, particularly in the northern part of the area, as irregular conceretions, commonly a few inches in diameter. The concretions have a dull- to bright-yellow surface and a grayish-yellow to medium-gray, very finely crystalline core. They are relatively resistant to weathering and they litter slopes underlain by mudstone of the Burro Canyon in the area north of Browns Hole.

Lower contact

The lower contact of the Burro Canyon Formation is placed at the base of the lowest bed of light-brown sandstone or conglomerate above the grayish-red, grayish-green, or variegated mudstone of the Brushy Basin Member of the Morrison Formation. Talus commonly covers this contact except for exposures a few hundred feet long at widely scattered localities. Where the contact is well exposed the Burro Canyon seems conformable on the underlying Morrison.

Although there is local and broad-scale channeling at the base of the Burro Canyon, this channeling is of the same type as found at the base of sandstone units in the Morrison and in the Burro Canyon and does not indicate a major disconformity.

In places the contact is not clear cut. South of McIntyre Canyon and along the north side of Pack Creek, we interpret poorly exposed, light-colored, fine-grained sandstone lenses at the base of the Burro Canyon as intertonguing with mudstone of the Brushy Basin Member of the Morrison Formation. These sandstone lenses are finer grained than sandstone characteristic of the Burro Canyon and much lighter colored than sandstone characteristic of the Brushy Basin.

Field studies lead us to agree with those workers who have described this contact to be locally indistinct, gradational, and marked by apparent interfingering with the Morrison (Cater, 1954; Simmons, 1957, p. 2523; Katich, 1958, p. 194; Ekren and Houser, 1959, p. 192). On the other hand, Young (1960, p. 191), who made a regional study of the basal Cretaceous deposits of the Coloado Plateau, argued that the basal contact is an unconformity which represents a large part of Early Cretaceous time. Young's argument rests largely on his interpretation of the fossil evidence and his confidence in differentiating mudstone units of the Morrison Formation from those of the basal Cretaceous formations.

Upper contact

The upper contact of the Burro Canyon Formation is a regional disconformity that in the Lisbon Valley area is characterized by channeling at the base of the overlying Dakota Sandstone.

Age

Fossils are sparse in the Burro Canyon Formation in the Lisbon Valley area. Fragments of poorly preserved fossil wood, mostly replaced by silica, occur near the base of the Burro Canyon near northwestern Lisbon Valley. Some sandstone beds near the Big Indian copper mine contain impressions suggestive of pine needles. Small fragments of abraded bone occur in sandstone on the cliffs bordering East Canyon. Vague markings, probably ascribable to worms and other animals, are found on the surfaces of fine-grained sandstone in many places. A specimen of Tempskya, a fossil fern collected by F. L. Hess from soil on the Morrison Formation near the head and on the northwest side of Pack Creek, was thought by Read and Brown, R. W., (1937) to be from the Dakota(?) Sandstone; the outcrop pattern in this part of the area, however, suggests that this fossil more likely came from the Burro Canyon Formation, a unit not recognized at the time of Read's and Brown's study.

Fossil plants and unioid pelecypods, diagnostic of an Early Cretaceous age, were collected in the Burro Canyon Foramtion by Stokes (1952) and by Simmons (1957) in the Slick Rock district in southwestern Colorado several miles east of the Lisbon Valley area. Earlier plant collections from Cretaceous rocks in this region were studied by Brown (1950), who found distinct differences between the flora of the Dakota and underlying Cretaceous rocks. Young (1960, p. 180-181) listed all the fossils reported from the Burro Canyon and its correlative the Cedar Mountain Formation. The fossils include conifers, ferns, cycads, charophytes, dinosaur bones, pelecypods, gastropods, ostracods, and fish scales. The pelecypods Protoelliptio douglassi and Unio (Lampasilis) farri, widespread Aptian species, and the conifer Frenelopsis varians, known only from Lower Cretaceous rocks, have led most workers to assign the Burro Canyon and the Cedar Mountain Formations to the Lower Cretaceous (Young, 1960, p. 188). However, as pointed out by Simmons (1957) and Young (1960), lack of fossils in the uppermost part of the Morrison and the basal beds of the Burro Canyon leads to uncertainty in the stratigraphic placement of the Jurassic-Cretaceous time boundary. As a matter of convenience, this boundary is presently placed at the basal contact of the Burro Canyon Formation, but, as previously noted, this contact is regarded by some geologists as gradational and intertonguing and by others as a regional unconformity.

Regional stratigraphic relations

In southwestern Colorado a post-Morrison, pre-Dakota lithologic unit, first recognized by Coffin (1921, p. 97), was named the Burro Canyon Formation by Stokes and Phoenix (1948). This formation near the type locality of the Burro Canyon, about 10 miles east of the Lisbon Valley area, consists chiefly of conglomerate and sandstone, and interbedded, noncarbonaceous mudstone (Stokes, 1952, p. 1773). In the northern part of the San Rafael Swell, Utah, an equivalent unit consisting chiefly of noncarbonaceous shale with a basal, discontinuous conglomerate unit, was earlier named by Stokes (1944, 1952) the Cedar Mountain Formation. Stokes (1952, p. 1774) recognized that the Burro Canyon and Cedar Mountain were probably equivalent, but he considered the lithologic differences warranted two formational names. He suggested the Colorado River as an arbitrary boundary between the Burro Canyon on the east and the Cedar Mountain on the west.

The Burro Canyon and the Cedar Mountain Formations are found on the Colorado Plateau throughout most of eastern Utah, western Colorado, and northwestern New Mexico. They pinch out partly due to pre-Dakota erosion and partly to nondeposition along a sinuous line that passes northwesterly through the Four Corners region to near Escalante, Utah (Young, 1960, fig. 7; p. 170). Young's correlations of individual sandstone lenses in the Lower Cretaceous formations led him to conclude that the Burro Canyon equivalents passed laterally into the Dakota in Colorado and east-central Utah (Young, 1960, fig. 6; p. 171). In the Lisbon Valley area, however, the Burro Canyon is everywhere separated from the Dakota by a distinct unconformity.

The fossil content and lenticular nature of the sandstone and conglomerate of the Burro Canyon suggest that they are stream deposits. The interbedded mudstone and thin limestone lenses were probably deposited in ponds and lakes in the interstream areas. Casual observations of dip-directions of cross-beds, and of thickness and coarseness of sandstone and conglomerate units suggest that the Burro Canyon of the Lisbo Valley area had a southwestern source. Young's regional study, however, suggests that most of the Cedar Mountain and Burro Canyon had a western source though southern and northwestern sources were locally important (Young, 1960, p. 170-171).

Dakota Sandstone

Distribution and thickness

The full thickness of the Dakota Sandstone is exposed only on a few high mesas in the northeastern part of the area and on hogbacks bordering the La Sal Mountains. The Dakota is preserved as scattered thin patches on high mesas in the central and southern parts of the area and is poorly exposed in downfolds adjacent to faults in Lisbon and Lower Lisbon Valleys. Commonly, the lower part of the Dakota caps cliffs formed by the Burro Canyon Formation.

Over much of the area the Dakota Sandstone is about 100 feet thick. An incomplete section measured on South Canyon Point indicates that the formation probably attains its greatest thickness in the southwestern part of the area. Local variations in thickness are caused by scouring into the underlying Burro Canyon Formation and, less clearly, by buildup of sand lenses that intertongue with the Mancos Shale.

Lithology

The Dakota Sandstone is made up of sandstone and conglomerate with interbedded carbonaceous mudstone and shale that locally grade to coal. The partial section given below shows the general character of the Dakota Sandstone in the Lisbon Valley area. The section, measured with hand level and tape by G. W. Weir and C. L. Dodson in 1954, was described from outcrops on the west side of East Canyon about 2 miles northwest of Iron Canyon Point.

Section of Dakota Sandstone measured in NW1/4NW1/4 sec. 28, T. 27 S., R. 23 E., San Juan County, Utah

	Thickness (feet)
Mancos Shale (incomplete):	
9. Shale olive-gray with dark-orange limonite stain at base; contains sparse rounded medium grains of quartz; poorly bedded; thin seams of gypsum; layer, 3 to 4 in. thick, of bentonitic clay about 3 ft above base; few fragments of gastropod and pelecypod shells. Not measured..................	
8. Shale (95 percent) and sandstone (5 percent). Shale, black to dark-gray; contains abundant plant fragments. Sandstone, brown, fine-grained, calcareous; contains carbonaceous fragments of fossil plants; occurs in thin discontinuous lenses a few inches thick. Lithology of unit is transitional between carbonaceous sandstone and minor shale of Dakota and marine-fossil-bearing gray shale characteristic of Mancos..........................	37
7. Sandstone (80 percent) and shale (20 percent). Sandstone, dark-orange-gray, common dark-orange limonite-stained, medium-grained, fair-sorted; composed of clear quartz with sparse feldspar and black accessory minerals; calcareous and white clayey cement; obscurely cross	

bedded in planar sets about 1 ft thick. Shale, dark-gray carbonaceous; occurs as partings in sandstone, and as coaly lens 6 to 12 in. thick near middle of unit..13.5

6. Mostly covered. Few exposures indicate unit is probably dark-gray, thin-bedded shale..............................29

5. Sandstone (65 percent) and shale (35 percent). Sandstone, dark-orange-gray, fine-grained, well-sorted; firmly cemented; horizontally bedded. Shale, black, carbonaceouos; occurs as layer about 5 in. thick at base of unit and as interbeds with sandstone................13.5

4. Sandstone, dark-yellowish-orange, commonly limonite stained, medium-grained to conglomeratic, fair to poorly sorted; composed of subrounded to subangular grains of quartz with sparse black accessory minerals; common thin films of white clay on grains; pebbles are chiefly subrounded to angular white and black chert and occur in discontinuous layers, a few inches thick, scattered through the sandstone; low-angle crossbeds 1 to 3 in. thick in planar sets 1 to 4 ft thick; forms prominent ledge.......................................43

Total Dakota Sandstone..................................99

Burro Canyon Formation (incomplete):

3. Sandstone, greenish-gray, silty to medium-grained, poorly sorted; composed chiefly of subangular grains of quartz; friable; thin bedded; forms minor recess............7

2. Silicified sandstone, light-gray, medium- to coarse-grained and conglomeratic in top 2 ft; contains abundant fragments of greenish-gray mudstone; forms ledge..5

1. Mudstone; greenish-gray; not measured..........................

Partial section of Dakota Sandstone, measured in NW1/4NE1/4 sec. 35, T. 31 S., R. 24 E., San Juan County, Utah

Thickness (feet)

Dakota Sandstone (incomplete):

7. Sandstone, conglomerate, and mudstone. Sandstone, grayish-orange (10YR 7/4); weathers same and moderate yellowish brown (10YR 5/2); very fine to coarse grained, fair to poorly sorted; composed of subrounded

to subangular clear quartz, gray chert, clear feldspar and white weathered feldspar(?) with abundant black and colored accessory minerals; firmly cemented, siliceous and calcareous cement. Conglomerate, similar to sandstone but contains granules and pebbles as much as 5/8 in. diameter of white weathered feldspar(?) and colorless, light-orange, and light-gray chert. Sandstone and conglomerate mainly in medium-scale trough sets of low-angle cross laminae; form ledges. Mudstone, pale-yellowish-brown (10YR 6/2) and medium-gray (N 5); brown mudstone is very fine sandy and probably dominantly silty; gray mudstone is silty and probably dominantly clayey, carbonaceous. Unit forms cliffs and benches. Top of local exposure, not top of formation................................44

6. Mudstone, medium-light-gray (N 6), silty but probably dominantly clayey; poorly cemented; abundant caliche veinlets. Forms gentle slope. Poorly exposed, may contain thin beds of sandstone similar to sandstone of unit 5..16.5

5. Sandstone, very pale orange (10YR 8/2) and grayish-orange (10YR 7/4), very fine to fine grained and silty, fair-sorted; composed of subangular clear quartz, white weathered feldspar(?), black chert, and clear feldspar; firmly cemented, calcareous; in small- to medium-scale sets of low-angle cross laminae. Contains sparse impressions of carbonaceous material. Forms irregular ledge..............................11

4. Mudstone and sandstone. Mudstone, medium-dark-gray (N 4), probably dominantly clayey but silty and very fine sandy, poorly sorted, carbonaceous. Sandstone, light-brown (5YR 6/4); weathers light brown (5YR 5/6) and moderate brown (5YR 4/4); very fine grained, fair sorted; composed of subangular grains of clear quartz, gray chert, and clear feldspar; firmly cemented, calcareous and limonitic; thinly splitting; common iron-stained impressions of carbonaceous material. Unit forms rubbly slope. Poorly exposed..27.5

3. Sandstone (75 percent), conglomeratic sandstone and conglomerate (20 percent), and mudstone (5 percent). Sandstone, moderate-yellowish-brown (10YR 5/4), medium- to coarse-grained; contains sparse pebbles about 1/8 to 1/2 in. across, fair sorted; composed of subangular to subrounded clear quartz with common yellowish-white weathered feldspar(?) and common black, orange, and gray accessory minerals; pebbles composed of dark-gray, light-tan and yellowish-white chert; firmly cemented, siliceous cement; cross laminated in thin planar sets. Conglomeratic sandstone and conglomerate, very pale

orange (10YR 8/2); weathering same and grayish orange (10YR 7/4); matrix is sandstone similar to that described above; pebbles, as much as 1 in. across, dominantly about 1/4 in. across, composed of subrounded to subangular gray chert, subrounded tan quartzite, poor- to fair-sorted; poorly to firmly cemented, cross stratified in trough sets; conglomerate occurs as lenses in conglomeratic sandstone. Mudstone, yellowish-gray (5 Y 7/2), in lenses, 1 to 4 in. thick along parting about 8 ft above base. Conglomeratic sandstone forms ledge at base with bench at mudstone horizon; above the mudstone the sandstone forms a rough, near-vertical cliff...47

2. Sandstone with basal conglomerate, and mudstone. Sandstone, moderate-yellowish-brown (10YR 6/4); weathering same and dark yellowish orange (10YR 6/6); fine to medium grained; generally similar to sandstone of unit 7. Disconformity at base is marked by thin conglomerate, less than 6 in. thick, contains irregular blocks, as much as 5 in. across, composed of gray silicified sandstone, brown sandstone, creamy-white chert and green mudstone in matrix of conglomerate with rounded gray chert pebbles commonly 2 to 3 in. across and well-rounded brown, gray and white chert and white weathered feldspar pebbles commonly 1/2 to 1 in. across. Mudstone, light-olive-gray (5Y 6/1), in seams a few inches thick intercalated near top of sandstone. Unit forms near-vertical cliff that except for recess along disconformity is continuous with cliff formed by underlying sandstone; minor bench at top.....................34

Total (incomplete) Dakota Sandstone........180

Burro Canyon(?) Formation (incomplete):

1. Conglomeratic sandstone (50 percent), sandstone (40 percent), conglomerate (10 percent). Conglomeratic sandstone, colors same as sandstone described below; matrix medium- to coarse-grained, poorly sorted, similar to sandstone described below; pebbles rounded to subrounded, about 1-1/8 in. maximum diameter. Sandstone, pale-yellowish-orange (10YR 8/6) grayish-orange (10YR 8/4) and dark-yellowish-orange (10YR 6/6), streaked with limonite stain, fine- to coarse-grained, mostly fair sorted; composed of subrounded quartz and minor yellowish-white weathered feldspar(?), pink and black chert, and rare very fine grains of a red accessory mineral similar to pebbles in conglomerate described below; pebbles as much as 1-1/8 in. diameter are scattered irregularly through most beds of sandstone and also occur as small lenses; firmly to poorly cemented, siliceous and calcareous cement; mostly in planar and trough sets

of low-angle crossbeds, in part in irregular horizontal beds; most sandstone is in lower part of unit. Conglomerate, grayish-orange (10YR 7/4), matrix is medium to very coarse grained sandstone similar to sandstone described above; pebbles as much as 2-5/8 in. across but dominantly 1/4 to 1 in. across, consist mainly of subrounded to rounded colorless to white quartz and light to dark-gray and yellowish-white chert; stratification similar to sandstone and conglomeratic sandstone; irregularly intercalated throughout unit. Forms basal part of cliffs that rim East Canyon. Underlain by slope-forming sandstone and mudstone. Thickness approximate..50

Sandstone and conglomerate make up most of the Dakota. Commonly they are grayish orange to dark yellow brown and in many places contrast strongly with the more grayish, lighter colored sandstone of the underlying Burro Canyon Formation. Most sandstone units in the Dakota are poorly sorted, composed chiefly of subrounded medium grains of clear quartz, and contain wispy partings of mudstone and irregular streaks and pockets of small pebbles. Pebbles in the sandstone and conglomerate are mostly dark-gray to black and light-gray to white chert. Grayish-red and grayish-green chert pebbles, common in the Burro Canyon, are sparse in the Dakota. Except in the basal conglomerate where large blocks several feet across are found, pebbles in the Dakota range from about 0.1 to 3 inches in diameter and commonly average about 0.4 inch in diameter. Most of the sandstone and conglomerate in the Dakota is cross stratified in small to medium planar and trough sets with low- to high-angle crossbeds. Fine-and very fine-grained units are commonly horizontally bedded. Current lineation, conspicuous on bedding planes in sandstone of the Burro Canyon, is sparse in the Dakota. Iron-stained impressions of plant fragments on sandstone surfaces are characteristic of the Dakota.

Mudstone in the Dakota is medium gray to black, and generally shaly splitting and carbonaceous. In places, as at the Blackbird copper mine in Lower Lisbon Valley, the carbonaceous shale grades into impure coal. Mudstone and carbonaceous shale occur as discontinuous seams in the sandstone and conglomerate and as thicker units, 10 to 30 feet thick, with thin lenses of fine-grained sandstone near the middle and top of the formation. The mudstone units form steep slope between ledge- and bench-forming units of sandstone and conglomerate.

Lower contact

The base of the Dakota Sandstone is a regional disconformity in southeastern Utah and in much of southwestern Colorado (Carter, 1957; Simmons, 1957). In the Lisbon Valley area the contact is characterized by small- and large-scale channeling of the overlying Dakota Sandstone into the Burro Canyon Formation. Near Pack Creek, in sec. 16, T. 26 S., R. 23 E., the Dakota rests with a small angular discordance on the Burro Canyon. Local relief is commonly only a few feet or a few tens of feet, but on West Summit near Sop Canyon, where the top of the Burro Canyon Formation is resistant silicified sandstone, the local relief is more than 100 feet. In many places sandstone of the Burro Canyon immediately beneath the disconformity is more friable and bleached for a thickness of a few feet, and forms a minor recess in the cliffs of Cretaceous rocks.

The contact is generally marked by a distinctive basal conglomerate in the Dakota Sandstone. This basal conglomerate differs from other conglomerates in the Dakota; it contains larger pebbles and angular clasts of sandstone, quartzite, conglomerate, white chert, and greenish-gray mudstone from the Burro Canyon Formation. In a few places the blocks of Burro Canyon sediments are as much as 3 feet across. The basal conglomerate is generally well cemented and commonly overhangs the less resistant Burro Canyon. It is a fairly persistent unit, commonly 1 to 3 feet thick, but it ranges from a few inches to several feet in thickness within a few hundred feet along strike.

In parts of the area, as on the east side of South Canyon Point because of parallelism of bedding, lithologic similarity of sandstone units in the Dakota and Burro Canyon and absence of a basal conglomerate, the contact is obscure. The two formations can be differentiated on the basis of lithologic criteria.

Upper contact

Surficial material generally covers the contact between the Dakota Sandstone and the Mancos Shale in the Lisbon Valley area. Scattered poor exposures of this contact suggest that sandstone units of the Dakota grade both vertically and laterally into the basal shale of the Mancos. The gradational and intertonguing nature of this contact has been demonstrated in regional studies (Fisher and others, 1960, p. 8; Young, 1960, p. 176).

Age

No significant fossils were found in the Dakota Sandstone in the Lisbon Valley area, although fossil plant debris is locally abundant in mudstone and coal and limonite-stained plant impressions and silicified pieces of coniferous wood are common in sandstone.

Most surveys of fossil collections made in the Dakota Sandstone of southeastern Utah and southwestern Colorado indicate that the Dakota of this region is early Late Cretaceous (Brown, R. W., 1950; Fisher and others, p. 25). The possibility that in some localities in Utah the lower part of the Dakota is Early Cretaceous cannot be denied nor proved until diagnostic fossils are found in the basal Dakota of this region. Fossil collections from the lower Mancos and upper Dakota near Montrose and Crawford in southwestern Colorado suggest that boundary between the Lower and Upper Cretaceous is there placed high in the Dakota (Young, 1960, p. 188). Westward from these localities the Dakota Sandstone is probably older so that at some point in southeastern Utah it is all Late Cretaceous (Young, 1960, fig. 2).

Regional stratigraphic relations

The regional relations of the Dakota Sandstone on the Colorado Plateau have long been obscure in large part because the name has been applied so as to include disparate sedimentary units. Even at the type locality, in Nebraska (Meek and Hayden, 1862, 419-421), there are uncertainties about the definition and age of the Dakota (Tester, 1931, 1952). Stratigraphic problems associated with the Dakota Sandstone of the Colorado Plateau have been reviewed by Katich (1958), Young (1960), and McGookey and others (1972).

The depositional environment of the Dakota ranged from fluvial to near-shore marine (Young, 1960, p. 178-180, 190-193). The sandstones and conglomerates in the lower part of the Dakota were deposited by eastward-flowing streams on a broad flood plain bordering a transgressing sea. Carbonaceous shale and coal were laid down in swamps and lagoons, and marine sandstones in the upper part of the formation were deposited in near-shore bar and beach environments.

Mancos shale

Distribution and thickness

Only poorly exposed remnants of the Mancos Shale are preserved in the Lisbon Valley area, chiefly on the high mesas bordering the La Sal Mountains. The formation probably attains a maximum thickness of about 2,500 feet along Pack Creek about 1.5 miles southeast of the M4 Ranch; most of this section is covered and possibly part of the Mancos is repeated by concealed faults. In the southern part of the area the Mancos Shale crops out in a few places along the Lisbon Valley fault and in the synclinal graben of Lower Lisbon Valley, where it probably attains a maximum thickness of about 500 feet.

Lithology

The Mancos Shale is mostly a fairly uniform, dark-olive-gray and brownish-gray marine shale. The shale is generally silty and locally is sandy and limy; near sandstone beds it is commonly carbonaceous. Fresh shale is thinly laminated and splits readily into paper thin pieces, but these properties are so obscured by weathering as to be inconspicuous in most outcrops. Plates of clear gypsum, as much as 4 inches across, litter shale slopes near pack Creek but were not found in place.

Thin lenses of fossiliferous dark-gray sandy limestone and brownish-gray, fine- to medium-grained limy sandstone occur in an interval about 10 feet thick at an estimated 300 feet above the base of the formation. The lenses are only a few inches thick and are interstratified with dark-gray carbonaceous shale.

Thin beds of fine-grained and silty sandstone probably occur sporadically throughout the Mancos, but most sandstone is concentrated in an interval 200 to 400 feet thick at an estimated 1,500 feet above the base of the formation. The variations in thickness are the result of pinching out of sandstone lenses at the base and top of the member and an eastward thinning. The section, measured near the M4 Ranch with Abney level and tape by the writers in 1958, was described from outcrops on the south side of Pack Creek. The following section shows the character of the sandstone member.

Section of sandstone member of Mancos Shale measured in E1/2SW1/4 sec. 23, T. 27 S., R. 23 E., San Juan County, Utah

Thickness (feet)

Mancos Shale (incomplete):

19. Shale, light-olive gray (5Y 5/2), carbonaceous; mostly covered by slope wash derived from overlying Pleistocene gravels. Not measured; probably only a few tens of feet present at this locality..

Unnamed sandstone member:

18. Sandstone, in part limy, and minor shale. Sandstone, pale-yellowish-brown (10YR 6/2); weathers moderate yellowish brown (10YR 5/4), fine grained, fair sorted; composed of subangular quartz and feldspar with common black accessory minerals; well cemented, calcareous. Differs from sandstone units below in weathering color and in high calcite content. The limy parts of the unit are pods several tens of feet long and 3 to 4 ft thick; generally weather darker brown than less limy parts of unit; locally separated from lower part of unit by 5 in. thick lens of dark-yellowish-brown shale. Megafossils occur near base of unit, include pelecypods and gastropods, mostly as casts and molds. Forms steep slope.........13.3

17. Sandstone (95 percent) and shale (5 percent). Sandstone, grayish-orange (10YR 7/4), fine-grained, fair-sorted; composed of subangular quartz and feldspar with common black accessory minerals; firmly cemented, calcareous, limonitic; float showing limonite-stained oscillation ripple marks probably from this unit; beds 1 to 3 ft thick in lower half of unit, bedding obscure in upper half. Shale, dusky-yellowish-brown (10YR 2/2), occurs as partings. Unit forms steep-sided ledge...........28.8

16. Sandstone (70 percent) and shale (30 percent). Sandstone, dark-yellowish-orange (10YR 6/6); weathers to moderate yellowish brown (10YR 5/4); fine-grained, fair-sorted; composed of subangular quartz and feldspar with common black accessory minerals; firmly cemented, calcareous, and limonitic; horizontally bedded. Shale, dusky-yellowish-brown (10YR 2/2), obscurely laminated; splits in paper thin sheets; sparse fossil plant material. Unit obscured by slope wash; appears to consist mainly of sandstone beds 1 to 2 ft thick separated by shale units 0.5 to 1 ft thick. Forms steep slope..........................56.9

15. Sandstone, similar to sandstone of unit 12; forms ledge. At base of unit was found a single pebble of dark-gray chert, subrounded, about 1 in. in maximum diameter...8.8

14. Sandstone (80 percent) and shale (20 percent). Sand stone and shale generally similar to those in lower part of section. Sandstone in beds 1 to 3 ft thick separated by thin sets of intercalated laminated sandstone and shale; sandstone in part cross laminated. Sparse fossil plant fragments in shale...............32.8

13. Shale (50 percent) and sandstone (50 percent). Shale olive-gray (5Y 4/1) and moderate-yellowish-brown (10YR 5/4); laminated and thin bedded, fissile; contains comminuted carbonaceous plant material. Sandstone, pale-dark-yellowish-orange (10YR 7/6), fine-grained fair-sorted; composed of subangular limonite-stained quartz and feldspar with rare black accessory minerals; firm to well cemented, calcareous. Unit characterized by alternating thin beds of sandstone and shale; common to abundant gypsum seams 1/8 to 1/4 in. thick, parallel to bedding; a few iron-stained worm-like concretions of sandy material. Unit forms a nearly vertical slope..........9.0

12. Sandstone, dark-yellowish-orange (10YR 6/6); weathers pale yellowish orange (10YR 7/4); fine grained, fair sorted; composed of subangular to subrounded limonite-stained quartz and feldspar with rare to common black accessory minerals; firmly to well cemented calcareous, limonitic; massive, stratification obscure; contains a few red clay pebbles like those described in unit 10; forms steep cliff...30.1

11. Shale (60 percent) and sandstone (40 percent). Shale, as in unit 9; sandstone as unit 10...........................5.6

10. Sandstone, grayish-orange (10YR 7/4), fine-grained to subangular quartz and feldspar with rare to common black accessory minerals; well cemented; contains spheroidal masses, as much as 1 in. across, and streaks of orange-red clay; bedding obscure; forms cliff............20.6

9. Sandstone (80 percent) and shale (20 percent); mostly covered. Sandstone generally similar to unit 8 but less well cemented and less resistant. Shale, dark-yellowish-brown (10YR 4/2) and dark-yellowish-orange (10YR 6/6), fissile; contains abundant minute fragments of carbonaceous plant remains; few flakes and thin plates of gypsum locally along bedding; in lenses as much as 1.5 ft thick near top of unit and probably intercalated in thin sets with sandstone in lower part of unit. Forms slope; minor bench on on shale near top...............16.0

8. Sandstone, grayish-orange (10YR 7/4) and dark-yellowish-orange (10YR 6/6); weathers pale yellowish orange (10YR 8/6); fine grained, well sorted; composed of subangular to subrounded yellow-brown-stained quartz and feldspar with common black accessory minerals; well cemented near bottom, less well cemented near top of unit; mostly horizontally stratified in thin beds but in low-angle crossbeds in basal 2 ft. Forms series of ledges, 1 to 8 ft. thick, that along strike merge to form a single ledge....................................18.8

7. Sandstone (85 percent) and shale (15 percent); poorly exposed. Lithology generally similar to unit 6 except sandstone is less firmly cemented, thinner bedded and in low-angle crossbeds at top of unit. Intercalated sets of shale, 1 to 2 in. thick, decrease in number and thickness upward; unit forms smooth, steep slope........35.0

6. Sandstone (70 percent) and shale (30 percent), in part poorly exposed. Sandstone, pale-yellowish-orange (10YR 8/6), fine-grained, well-sorted; composed of subrounded to subangular quartz and feldspar with common to abundant black accessory minerals, many grains coated with a yellowish-brown stain; near top of unit are a few flattened mudstone pellets; well cemented, calcitic; mostly in horizontal beds separated by thin seams of shale, but basal sandstone bed is as much as 1.5 ft thick and contains some low-angle cross-strata about 1/4 in. thick; shale, pale-yellowish-brown (10YR 6/2) and dark-yellowish-brown (10YR 4/2) and dark-yellowish-orange (10YR 6/6), weathering to lighter shades; clayey; weathers to paper-thin flakes. Unit appears transitional between shale units lower on slope and thicker more resistant sandstone units higher on slope; forms steep slope.................................31.9

5. Sandstone, grayish-orange (10YR 7/4), weathering moderate yellowish brown (10YR 5/4); fine- to very fine-grained, well-sorted; composed of subangular quartz and feldspar and common black accessory minerals; well cemented, calcareous; basal 0.5 ft thin bedded, bedding obscure above. Base of this unit mapped as base of unnamed sandstone member of Mancos Shale, but note that massive cliff-forming ledge does not begin till unit 8.............................4.0

Total unnamed sandstone member of Mancos Shale..........311.6

Mancos Shale (incomplete)

4. Covered; probably shale and siltstone as in unit 1..........14.8

3. Sandstone, pale-yellowish brown (10YR 6/2), very

fine grained, well-sorted; composed of subangular quartz and feldspar with common black accessory mcalcareous; unevenly bedded, inerals; well cemented, 1/4-1/2 in. thick; causes slight steepening in slope; probably a lens..6

2. Covered; probably shale and siltstone as in unit 1..........34.4

1. Shale (70 percent) and siltstone (30 percent). Shale, light-olive-gray (5Y 5/2); clayey; firmly cemented, in laminae and very thin beds. Siltstone, dark-yellowish-orange (10YR 6/6), well-sorted, well-cemented, calcareous; beds about 1 in. thick; conspicuous because of color and cementation. Unit forms smooth steep slope mostly covered with sandstone fragments from above. Exposures suggest that this unit is 100 or more feet thick; not measured. Bottom of section, not bottom of exposure. An estimated 2,000± ft of Mancos Shale lies stratigraphically below this level, but practically all of this part of the Mancos is hidden by valley fill along Pack Creek..........................

Above this sandstone member is more shale, generally very poorly exposed but all apparently like that below the sandstone member. There are only a few exposures of this upper shale unit, but in sec. 25, T. 27 S., R. 23 E., it probably reaches a maximum thickness of about 1,000 feet.

Contacts

The base of the Mancos Shale is mostly covered by slope wash and Pleistocene deposits in the Lisbon Valley area. Carbonaceous shale and sandstone of the Dakota wherever exposed, appear to intergrade and possibly intertongue with the marine shale of the Mancos.

The Mancos Shale is unconformably overlain by Quaternary alluvial, eolian and glacial deposits.

Age and stratigraphic relations

Fossils were collected in the Mancos Shale at two localities in the Lisbon Valley area. The lower horizon was in sandy limestone about 300 feet above the Dakota in Pole Creek Canyon a few hundred feet east of the point where a poor dirt road crosses the wash in the NW1/4NW1/4 sec. 36, T. 27 S., R. 23 E., San Juan County, Utah (U.S.G.S. Mesozoic locality D2403):

Pelecypods:

Inoceramus cf. *I. dimidius* White
Ostrea lugubris Conrad

Cephalopod (Ammonite):

Prionocyclus wyomingensis Meek

W. A.Cobban (U.S. Geological Survey, written communication, 1960), who identified these fossils, remarked that this collection represents the Prionocyclus wyomingensis Zone and should be the same as Baker's lot (U.S.G.S. lot 13755).

A. A. Baker in 1926 made a small collection from the Mancos Shale which is described on the field label as "top of the Ferron sandstone on Pack Creek in SW1/4 sec. 23, T. 27 S., R. 23 E." It was on the basis of this collection that Baker (1933, p. 55 and pl. 1) correlated the unnamed sandstone member of the present report with the Ferron Sandstone Member of the Mancos Shale of the San Rafael Swell region. However, our fossil collection from the unnamed sandstone member at apparently the same locality disclosed a much younger fauna and our estimate of the stratigraphic distance from the base of the formation to the base of the member is about twice that given by Baker. Although unrecognized faults may exist in this part of the area, we think that most likely Baker's collection was made in a different unit in the north half of sec. 23 or 24.

J. B. Reeside, Jr., who originally identified Baker's 1926 collection (U.S.G.S. lot 13755) reexamined it in 1953. In 1958 Reeside said (written commun.):

> "There are two flat, weathered pieces of rock, dark gray, entirely composed of Inoceramus prisms and about two inches in maximum dimension. On the surfaces are fragments of Inoceramus and six specimens of Ostrea lugubris Conrad. The collection wyomingensis zone of the Carlile equivalent all over the western interior region. In New Mexico it is the Juana Lopez Sandstone Member of the Mancos Shale; in central Utah it is part of the Ferron Sandstone; in eastern Utah and western Colorado it is a sandy zone low in the Mancos Shale, sometimes called Ferron but mostly left unnamed. So far as the collection goes, I cannot question the assignment made in 1926--it is still good. On the other hand, it is at least possible that the lot is float, entirely out of place where found and not valid evidence of the age of the beds at the locality. The field man will have to be the judge."

Our collection from the unnamed sandstone member (USGS lot 26983) was made on the south side of the Pack Creek road about one-half mile east of the M4 Ranch in the SW1/4 sec. 23, T. 27 S., R. 23 E., San Juan County, Utah. The fossils came from near the top of a conspicuous ridge from the upper part of a sequence of yellow, fine-grained sandstone and shale, unit 18 of the measured section described on page 226. The following fossils were identified by J. B. Reeside, Jr.:

Ostrea sp.
Syncyclonema sp.
Cymella montanensis Henderson
Veniella aff. V. mortoni Meek and Hayden
Cardium pauperculum Meek
"Tellina" aff. "T." isonema Meek
"Cancellaria" malachitensis Stanton?
Cinulia? sp.

Baculites sp., fragment
Stantonoceras ("*Placenticeras*") sp., fragment
Trails and borings, undetermined
Clay "pellets"

Concerning this collection Reeside (written communication, 1958) remarked:

> "The new lot, now given the number 26983 and assigned to the same land-line location as lot 13755, is an entirely different matrix. It is of Colorado age and considerably older than any fossil assemblage known in the Mesaverde of the Book Cliffs or in southwestern Colorado * * *. I would now call the horizon an equivalent of the upper part of the Niobrara, which is considerably younger than the level represented by Baker's collection 13755."

The sandstone member of the Mancos Shale exposed in Pack Creek and Pole Canyon may correlate with the Emery Sandstone Member of the Mancos Shale in the Wasatch Plateau about 100 miles northwest of the Pack Creek locality. The Mancos Shale of eastern Utah generally contains few sandstone units in the part of the Mancos equivalent to the upper Niobrara (Fisher and others, 1960, pls. 11, 12). Katich (1956, p. 117, 18) however, in a note on the Cretaceous of the Book Cliffs, which lie about 50 miles north of Pack Creek, correlated a sandy concretionary shale zone that lies about 800 feet below the Mesaverde Formation in Mancos of upper Niobrara age with the Emergy Sandstone Member of the Mancos Shale in the Wasatch Plateau. The Emery is also well developed in the Henry Mountains about 75 miles southwest of the Pack Creek locality (Hunt and others, 1953, p. 84), but this part of the Mancos Shale is not preserved in other nearby areas. Although the fossil evidence suggests a correlation of the unnamed sandstone member of the Mancos Shale of the Lisbon Valley area with the Emery, physical continuity with the Emery Sandstone Member is impossible to prove and the isolated sandstone unit of Pack Creek and Pole Canyon seems best left unnamed.

Quaternary system

Surficial deposits of Quaternary age are widespread in the Lisbon Valley area, but they are minimized on the geologic map (fig. 3). Many small outcrops of bedrock are shown at this map scale at the expense of the Quaternary mantle. Where the surficial deposits are thin and discontinuous only bedrock formations are shown. For example, much of the Navajo Sandstone that forms the rock plateau in the western part of the area is veneered by locally derived sand, but this sandy material was not mapped, because it did not obscure the underlying geology.

The surficial deposits are thickest, most extensive, and most varied in and near the La Sal Mountains. Here, to show the character of the bedrock geology, some fairly broad and thick surficial deposits were ignored. For example, most outcrops shown as igneous rock are actually frost rubble deposits. Much of this type of surficial material lies directly above its parent rock, and commonly it is mapped only where it masks important contacts in the bedrock.

The Quaternary deposits as studied were divided into 10 formations based on age and facies. The two age groups are: early (pre-Wisconsin) and late Pleistocene (Wisconsin) and Holocene. The facies are the result of deposition by alluvial and eolian, mass-wasting, and glacial processes. The formations are older gravel, older till, older rubble and landslide deposits, eolian and alluvial sand, younger gravel, younger till, rock glacier deposits, landslide, talus and block rubble deposits. These formations are briefly described below.

The division of the Quaternary deposits is based in large part on the detailed study by Richmond (1955, 1962) of the Quaternary stratigraphy of the La Sal Mountains. Richmond's map includes the La Sal Junction 15-minute quadrangle, the northwestern one-third of the Lisbon Valley area. he grouped the Quaternary deposits into four formations whose upper surface" . . . is marked by a widespread distinctive soil that is locally truncated or cut out by a disconformity which also separates the formations" (Richmond, 1962, p. 1). He subdivided the formations into members, representing minor cycles of deposition, and commonly showed several genetically distinct lithofacies of each member. In all, Richmond used 55 map units where we used but 10.

Lower Pleistocene deposits

Older gravel

Alluvial gravels of early Pleistocene age lie on the high mesas around the La Sal Mountains. These deposits are older than the present canyons. For example, the older gravel perched on the narrow mesa about 1.5 miles northeast of the Grand County airport was probably deposited by an ancestral Mill Creek that flowed westward into an ancestal Spanish Valley. This gravel deposit now lies about 500 feet above the north-flowing Mill Creek and about 750 feet above the floor of modern Spanish Valley.

The older gravels consist mainly of rounded cobbles and pebbles derived from diorite porphyry of Tertiary age and resistant sandstone of late Mesozoic age. Some of the cobbles and pebbles--particularly those derived from igneous rocks--are deeply weathered and partly disintegrated, but most of them are fresh-looking and firm. The matrix consists of small pebbles, coarse- to fine-grained sand, sand, and silt. Lenses of cross-stratified sand and structureless silt are locally interstratified with the conglomerate. Such lenses, at least in part, represent a lithofacies similar to the upper Pleistocene and Holocene units of eolian and alluvial sand and silt. Structureless gray silt, derived from the Mancos Shale and strongly resembling that formation, forms a basal unit, locally more than 100 feet thick, on the west end of the mesa between Pole Canyon and Pack Creek.

Consolidation of the gravels differs from place to place. Commonly, the matrix is firmly cemented with caliche, and between Pole Canyon and Pack Creek the gravel forms near vertical cliffs more than 100 feet high. Northwest of the Grand County airport the base of the older gravel is tightly cemented with several feet of light-gray caliche. On mesa tops, however, the cobbles and pebbles lie loose; matrix and cement have been removed, and older gravels on the mesas tops closely resemble more recent alluvial gravels in the canyons.

The older gravels range in thickness from a feather edge to about 200 feet. The estimate of maximum thickness is perhaps too low, for base of the older gravels is rarely exposed where the deposit is thick. Both the bottom and top surfaces of the gravel deposits are regional unconformities and other unconformities lie within the deposits. The present outcrops of older gravels are thus only a small sample of the tremendous thickness of gravels deposited in the area in the early Pleistocene.

The alluvial gravels were thought by Baker (1933) to be of Tertiary(?) age, but they commonly grade near the mountain front into older till deposits, which according to Richmond (1955) correlate with the pre-Wisconsin glacial deposits of the central and eastern United States. Tertiary deposits do occur in other parts of the La Sal Mountains: folded conglomerates of Pliocene(?) age were mapped by Hunt, C. B., (1958) in Castle Valley on the north side of the mountains and by Carter and Gualtieri (1958; 1965, p. 19-22) on the east side of the mountains. With the possible exception of the siltstone unit locally found at the base of the gravels, all of the older surficial deposits on the west slopes of the mountains seem to form a single complicated group, the result of repeated glaciation, alluvial deposition, and erosion in the early Pleistocene.

A small collection of invertebrate fossils was made in the siltstone forming the base of the older gravels on the west end of the mesa between Pole Canyon and Pack Creek. (Because this siltstone unit is separated from the overlying gravels by a local unconformity, it possibly correlates with Pliocene(?) conglomerates on the north side and on the eastern slopes of the mountains, but the upper part of this siltstone unit contains a few thin conglomerate lenses indistinguishable from the older gravels, and the siltstone unit seems best grouped with the older gravel deposits. Probably the siltstone unit is the result of local ponding of the early Pleistocene streams.) The following fossils from the siltstone were identified by D. W. Taylor of the U.S. Geological Survey.

USGS Cenozoic locality 19909, NW1/4 sec. 28, T. 27 S., R. 23 E., San Juan County, Utah:

Freshwater clam:

Pisidium casertanum (Poli)

Freshwater snails:

Lymnaea parva Lea
Gyraulus parvus (Say)

Land snails:

Vallenia
sf. *Succinea*
Discus

Taylor (written commun., 1956) comments on this collection as follows:

"These species are all both living today and fairly long-ranging, and cannot indicate a Pliocene rather than Pleistocene age in the present state of our knowledge. The collection is very small, however (*Discus* and *Vallonia* are each represented by one broken specimen), and it is possible that more material would help give the answer to your question of Pliocene or Pleistocene age. The local habitat of the species was probably a shallow intermittent stream or temporary pond bordered by some trees or shrubs. The *Pisidium*, *Lymnaea*, and *Gyraulus* require water for several months of the year, but not necessarily perennial water bodies. It is the absence of species requiring permanent water which suggests the pond or stream was only intermittent. *Vallonia* and *Discus* require some moisture and shelter, such as leaf litter or humus beneath trees. The cf. *Succinea* is of no significance."

Older till

Deposits of older till are found only on high mesas above 6,800 feet near the mountains in the northeast quarter of the La Sal Junction quadrangle. The composition of these tills is much like the older gravels except that rotted boulders are more common. The boulders and cobbles in the till are more angular than in the gravels and the clasts attain a larger maximum size. A few subangular boulders in the tills near Pack Creek are more than 5 feet in diameter. Morainal topography is generally lacking in these older tills, but is discernible in a few places, as on the mesa between Pole Canyon and Pack Creek and on Boren mesa. The tills rest on an old erosion surface, chiefly cut on the nonresistant Mancos Shale and on surfaces cut in the older gravels. The older tills grade laterally downslope into the older alluvial gravels; this contact is commonly indefinite and difficult to pick within 1,000 feet. The till ranges from a feather edge to an estimated 200 feet in thickness on the mesa between Pole Canyon and Pack Creek and on Boren Mesa. Richmond (1962, pl. 1; table 11, p. 87) mapped three generations of the older tills and tentatively correlated them with the pre-Wisconsin glaciations of the midcontinent region.

Older rubble and older landslide

Older rubble is found in small patches on the rock plateau that characterizes the mapped area west of U.S 160. The genetically related older landslide deposits are confined to a small outcrop on top of Rone Bailey Mesa and a larger outcrop on the northwest cliffs of this mesa. And a small outcrop on a hill about 1.5 miles southwest of the Rattlesnake mine, east of U.S. 160. Most of the older rubble and older landslide deposits occur in the southwest part of the mapped area.

The deposits consist of angular to subangular blocks that are as much as 7 feet across in the rubble deposits and 30 feet across in the landslide deposits. The blocks, for the most part, are resistant, crossbedded, gray silicified sandstone derived from the Burro Canyon formation (Lower Cretaceous) and very light gray to light-reddish-gray chert derived from the summerville Formation (Middle Jurassic). Some fragments of light-brown sandstone and medium-gray limestone were derived from the Salt Wash Member of the Morrison Formation (Upper Jurassic), and some blocks of dark-brown conglomeratic sandstone were probably derived from the Dakota Sandstone (Upper Cretaceous) and the Brushy Basin Member of the Morrison Formation. The matrix of the older rubble and landslide deposits consists chiefly of small angular fragments of resistant sandstone and chert and small pebbles weathered out of conglomeratic sandstone. Locally, the deposits are very firmly cemented with caliche.

The older rubble deposits mostly rest on an irregular ancient erosion surface that commonly lies a few tens of feet above the top of the Navajo Sandstone. Crudely bedded, moderate-orange-pink, sandy caliche as much as 3 feet thick characterizes the basal contact of most of the rubble deposits.

The outcrop of older landslide near VABM Bailey (6,657 feet) on Rone Bailey Mesa rests on a sandstone bed of the Salt Wash Member about 100 feet above the base of the Morrison Formation. Here large blocks of silicified sandstone from the Burro Canyon Formation are mixed with plastic red and greenish-blue mudstone probably derived from the Brushy Basin Member of the Morrison Formation. The outcrop of older landslide flanking the cliffs on the northwest point of Rone Bailey Mesa rests on a steep (30°) slope that is cut on the lower part of the Entrada Sandstone. Locally, caliche marks the base of this outcrop. The outcrop of older landslide near the Rattlesnake mine at VABM Rattlesnake (6,793 feet) rests on a sandstone bed about 200 feet above the base of the Morrison, and in part is cemented with caliche.

Most of these deposits are thin. The older rubble deposits average less than 20 feet in thickness and probably have a maximum thickness of about 50 feet. The older landslide deposit on top of Rone Bailey Mesa is 33 feet thick and the heap on the northwest cliffs may locally be about 60 feet; the outcrop at VABM Rattlesnake is only about 10 feet thick. A litter of blocks derived from the older rubble deposits characterizes the rock plateau in the western part of the area, and this indicates that these deposits were once much thicker and more extensive than is suggested by their present patchy distribution.

The distinction between older rubble and older landslide is based mainly on differences in elevation and to a lesser extent on differences in form. The older rubble deposits lie at a generally lower elevation and form minor ridges and low mounds on a rock plateau whose surface is close to the top of the Navajo Sandstone. The older landslide deposits form knolls on isolated mesas and rest on beds of the lower part of the Morrison Formation. The older landslide on the northwest side of Rone Bailey Mesa is obviously transitional between these two types for it is a roughly cone-shaped deposit resting on a steep slope about midway between the two common elevations. The older landslide deposits differ little in composition from the older rubble, but they contain a significantly larger average and maximum size of blocks.

Both the older rubble and older landslide are mass-moved deposits. Transitions between the two types suggest that most if not all of the deposits were produced during one period of vigorous erosion. The scattered outcrops of rubble suggest that this material once covered much of the rock plateau west of U.S. 160 and north of Rone Bailey Mesa. The large size of some blocks of Cretaceous rocks in the deposits as on and near Rone Bailey Mesa imply a local source, but the nearest present-day outcrops of Cretaceous rocks are about 12 miles distant at the south end of Dry Valley. At the time these older deposits were formed, mesas covered with Cretaceous rocks must have extended much farther out on the rock plateau than they do today. The chain of irregular mesas extending north from Peters Point and South Canyon Point may be remnants of a high mesa that once extended to Hatch Rock.

All these deposits probably originated as landslides, perhaps locally grading into mudflows, from mesas capped with Cretaceous rock. They probably resembled the younger landslide deposits along the southern border of Dry Valley that now mantle most of the slopes and locally extend onto the floor of the rock plateau.

The older rubble and landslide deposits are probably early Pleistocene in age, but they may be older. They are perhaps the rock-plateau equivalents of the older gravel and older till deposits found in and near the La Sal Mountains. They are obviously much older than the present cycle of erosion, not only because their source rocks have been eroded away, but also because many of the deposits as on Hatch Point are separated by shallow canyons about 100 feet deep. The evidence for their assignment to the early Pleistocene, however, is indirect and only permissive. About one-half of a mile south of La Sal Junction, two patches of younger gravel, of probable Wisconsin age (incorrectly shown as older gravel by Weir and Kennedy, 1958) contain fragments that apparently were derived by reworking of the older rubble deposits. This occurrence indicates that the older rubble deposits are pre-Wisconsin. The lone deposit of older rubble on Bridger Jack Mesa rests on an ancient erosion surface that may be the same surface on which rest the older gravels north of Pole Canyon. Baker (1933, p. 57) mentioned a patch of grayish-pink caliche on Hatch Point west of the Lisbon Valley area that probably is a remnant of the basal caliche of old rubble. He noted that similar caliche deposits are found at widely separated localities in the rock plateau country of southeastern Utah. He interpreted these outcrops as probably marking an ancient Tertiary(?) surface below which the Colorado River near the junction with the Green has cut nearly 2,500 feet.

Assignment of the older rubble and landslide deposits to the Pleistocene implies great erosion of the rock-plateau country during the early glaciations of the mountains. Mesas from which the older rubble deposits were derived have been greatly reduced in size and their tops have been lowered hundreds of feet. None of the remnants of the ancient mesas are now capped by rocks higher in the section than the middle of the Salt Wash Member of the Morrison Formation; when they were capped by Cretaceous formations they stood at least 500 feet higher. Further study of the history of the rock plateau country may show that the older rubble deposits are Tertiary in age and contemporary with the Pliocene(?) conglomerates of Castle Valley and the east slopes of the La Sal Mountains.

Upper Pleistocene and Holocene depoists

Eolian and alluvial sand and silt

Eolian and alluvial sands and silt form the most widespread lithologic unit of the Lisbon Valley area, even though its extent is minimized to show the character of the bedrock. It covers most flat or gently sloping terrains and occurs as scattered patches elsewhere in the area.

The lithology of this unit varies locally depending on its origin. The greatest contrast is between the reddish-brown homogeneous mantle on the high mesas along the southern edge of the area and the light-colored diverse mantle of the country north of these high mesas.

Much of the mantle north of these mesas consists of yellowish-gray to light-brown, fairly well sorted, very fine grained sand with minor silt. Generally, it is only crudely stratified and unconsolidated. Most of it was probably derived from sandstones of the San Rafael and Glen Canyon Groups. Near some present stream courses the material is less well sorted, includes lenses of silt and pebble conglomerate, and is partly consolidated so as to form cliffs more than 20 feet high. Eolian mantle in much of the area cannot be sharply differentiated from sheetwash and stream deposits, but in the southwestern part of the area and on the east side of Spanish Valley, partly stabilized dunes more than 20 feet high are locally piled up against mesa fronts and partly fill long reentrants in the cliffs. The thickness of the eolian and alluvial sand and silt ranges generally from a few feet on mesa tops to several tens of feet near stream courses. The greatest thickness is undoubtedly in Spanish Valley in which a drill hole, 4 miles north of the area, passed through more than 200 feet of alluvial fill (Baker, 1933, p. 57).

Dark-reddish silt with very fine grained sand forms most of the mantle on the high mesas along the southern edge of the area. These high mesas, all above 7,000 feet, form the northern edge of the Sage Plain, a gently southward sloping tableland; the dark reddish silt and sand cover much of this plain (Cross, 1908). The farms of South Canyon Point, West Summit, and East Summit are based on outcrops of this material; elsewhere barren resistant Cretaceous sandstone crops out. Most of this reddish material appears structureless but near some gullies it is stratified in thin beds. Its thickness varies for it fills irregular basins in the rock plain. Generally, it is thin; even beneath the tilled fields of West Summit, it probably averages less than 10 feet in thickness. Near the heads of major canyons, such as East Canyon, are thicker accumulations. Canyon streams such as East Canyon Wash, have carried some of the red silt and sand into the southern part of Dry Valley. Cross (1908) and Huff and Lesure (1965, p. 44) attributed the wide distribution of this uniform, red, very fine grained surficial material to wind erosion and transport from the desert country west of the Sage Plain. Deposition of this material probably accompanied the later glaciations of the nearby mountain areas, for Richmond (1962, p. 102) noted evidence of extensive eolian activity in the La Sal Mountains in the Holocene. Most of the deposits of red silt and sand on the high mesas within the mapped area, however, have been partly reworked by sheetwash and intermittent streams.

Younger gravel

Upper Pleistocene and Holocene gravels are found in the northern and southwestern parts of the Lisbon Valley area. In the northern part of the area younger gravels are found in Spanish Valley, on the alluvial fan south of Lackey Basin and along major streams flowing from the La Sal Mountains. In the southern part of the area younger gravel is found along East Canyon, in Peters Canyon and near the head of Hart Draw.

The younger gravels in the northern part of the area were derived mainly by reworking of older gravel and older till. They resemble the older deposits in composition--cobbles and pebbles of diorite porphyry and resistant sandstone--but lack the rotted cobbles that occur in the older deposits. The matrix of the younger gravels commonly consists of alluvial sand and silt, which also irregularly mantles the gravels. Most of the younger gravels are unconsolidated or only weakly cemented, but some exceptional outcrops, such as the younger gravel near Utah 46, about one mile east of La Sal Junction, are firmly cemented by caliche. Where the younger gravels are fully exposed in the La Sal Junction quadrangle they are generally less than 40 feet thick, but partial exposures in upper Pack Creek suggest that here the younger gravel is more than 50 feet thick and in the compound fill of Spanish Valley, gravel interstratified with alluvial silt and sand, the younger gravel is perhaps more than 100 feet thick.

The younger gravels in the southern part of the area consist mainly of cobbles and pebbles of resistant sandstone and chert derived from Upper Jurassic and Cretaceous formations. Diorite porphyry derived from the Abajo Mountains commonly makes up less than 10 percent of the pebbles. Pebbles of igneous rock are most common in the gravel deposits near the head of Peters Canyon and Hart Draw; they are absent from the gravels in East Canyon. Some of the deposits near South Canyon Point contain blocks of mudstone as much as 4 feet across that apparently were derived from the Morrison Formation, probably by reworking of nearby landslide deposits. Most of the deposits in the southern part of the area are partly consolidated by the clay binding of interstitial fines and by caliche which locally forms a layer a few inches thick at the basal contact. Some caliche fragments and caliche-coated pebbles in these gravels appear detrital and probably represent reworking of older rubble and gravel. The younger gravels in this part of the area range in thickness from a feather edge to about 40 feet. They locally overlap landslide deposits in Peters Canyon and are commonly overlain by thin sheets of eolian and alluvial silt and sand. Most of the gravel deposits are perched 20 to 100 feet above modern stream courses, and, in contrast to the northern part of the area, little gravel is now being deposited. The younger gravels in the southern part of the area were probably deposited during the early part of the late Pleistocene, perhaps at the same time as the last glaciation of the Abajo Mountains.

Younger till

Deposits of younger till are found mostly above 9,000 feet in canyons that head in cirques carved in the high peaks of the La Sal Mountains. The till is made up chiefly of subangular blocks of diorite porphyry and resistant sandstone. The matrix consists of small fragments of these rocks and arkosic sand and clayey silt. Rotted boulders are uncommon and probably were derived from older till. Fresh-looking morainal topography is characteristic of these deposits; in places, as in upper Brumley Creek, several distinct sets of end moraines are evident. The till grades downslope locally into outwash gravel as in upper Pack Creek. Small patches of younger gravel and rubble are included with the younger till on the geologic map (fig. 3). Judging by the height of some end moraines, the younger tills must reach a maximum thickness of about 200 feet, but the average thickness is probably only about half this amount. Richmond (1955, 1962) discriminated seven generations of these younger tills, which he correlated with the Wisconsinan Stage of the Pleistocene and with the Holocene.

Rock glacier deposits

Rock glaciers occur mostly above 10,000 feet in cirques marking canyon heads on the north- and east-facing slopes of the La Sal Mountains. They are composed mainly of loose angular blocks of diorite porphyry, commonly several feet in diameter. Richmond (1962, p. 60, 78) inferred that these deposits have a till-like core of blocks set in a matrix of unsorted sand, silt, and clay. The rock glaciers are lobate masses about 0.1 to 0.6 miles long and a few hundred yards wide. Generally, their tops are ridged and furrowed and they end in steep snouts about 50 feet high. Their maximum thickness is probably about 100 feet. The rock glacier deposits overlap younger till and are overlain at their upstream ends by talus. Richmond (1962) distinguished four generations of rock glaciers, which he correlated with late Wisconsinan and Holocene times. Most of the rock glacier units are made up of more than one rock glacier. The units include talus of the cirque heads, and locally small patches of younger moraine and block rubble.

Landslide deposits

In the Lisbon Valley area landslide is practically coextensive with the outcrop of the Brushy Basin Member of the Morrison Formation. The landslide forms hummocky deposits and thin patchy sheets that cover much of the slopes that are underlain by the Morrison Formation, and locally extend over cliffs of the San Rafael Group. The deposits are largely made up of small to large blocks of sandstone and conglomerate derived from the Burro Canyon Formation and Dakota Sandstone and large masses of mudstone from the Brushy Basin Member. As mapped, landslide includes talus below cliffs near heads and small patches of rubble near toes of landslide. In and near the La Sal Mountains it includes thick solifluction mantle--typical of slopes on the Mancos Shale, and sheets of slopewash from older gravel and till. The landslide deposits range in thickness from a feather edge to more than 100 feet; over most of the area mapped landslide deposits probably average 10 to 20 feet in thickness.

Although some landslides appear fresh and are locally active--especially on north-facing slopes, most of the landslide deposits belong to an older cycle of erosion than the present. They are much eroded, particularly near their toes, so that locally the original mudstone matrix is removed and only a litter of large foreign sandstone blocks remains. In Peters Canyon younger gravel, not now being deposited, overlaps some landslide. Probably most of these landslide deposits were formed during the last Pleistocene glaciation of the mountains.

The open pit at the Rattlesnake mine in 1959 provided an exceptional view of an ancient landslide, for it cut the landslide so as to expose its basal contact nearly from head to toe. The basal contact is very steep near the head--about 65^{o} but flattens in a few hundred feet and locally dips gently back toward the head. The base of the landslide for the most part rests on a resistant siltstone bed in the lower part of the Brushy Basin Member of the Morrison Formation. The upper surface of this landslide lacks the hummocky topography of most landslide deposits in the area. It was eroded to a smooth slope and mantled with talus of silicified sandstone derived from cliffs of the Burro Canyon Formation. The talus is filled with eolian silt and sand and is locally well cemented by caliche. These relations suggest that this landslide is older than most landslide deposits in the area and possibly is correlative with some older gravels and older tills.

Talus

Talus was mapped separately only in the rock-plateau country in the western part of the area. Elsewhere talus was included with associated landslide or block rubble. Most of the talus lies below the high cliffs of the Glen Canyon Group on the west side of Spanish Valley. Here it consists of heaps of angular blocks derived from the Navajo Sandsotne, Kayenta Formation and Wingate Sandstone. The heaps of blocks are partly filled with sand derived from weathering of the blocks. The sliderock is unconsolidated and locally is unstable. The fresh appearance of the heaps of sliderock and of some scars on the cliff face suggest that most of the talus was formed in the present cycle of erosion. The talus deposits on the west side of Spanish Valley are not generally more than a few tens of feet thick, but these deposits obscure details of a complex fault system at the base of the cliffs.

Frost rubble deposits

Frost rubble deposits resemble talus but lack cliffs at their heads and are primarily the product of frost action. They are the characteristic surficial deposit of the higher parts of the La Sal Mountains. Frost rubble mantles most all the area shown as igneous rock on the geological map and extends beyond the igneous outcrops chiefly as broad sheets on gentle to steep slopes. In canyon frost rubble grades into till and rock glacier deposits. Their true estent is not indicated on the generalized geological map.

Most of the frost rubble is made up of irregular angular blocks and slabs of diorite porphyry with relatively few blocks of resistant sedimentary rock. Some small patches, however, are composed only of resistant sandstone; the rubble-strewn slopes along Pack Creek Canyon are derived entirely from the Glen Canyon Group. The blocks commonly average about 1 or 2 feet in diameter and are randomly oriented in a loose mass. Interstitial material is rare. The surfaces of the rubble deposits are commonly marked by irregular ridges and furrows subparallel to the edges of the deposits, though some are virtually featureless. The average thickness of frost rubble deposits ranges from a few feet over most areas of igneous rock to an estimated 100 feet in some fields at the foot of the igneous masses. Among the thickest deposits are those at the west base of Haystack Mountain and those at the wet base of Mount Tukinikivatz.

IGNEOUS ROCKS

Igneous rocks crop out only in the northeastern corner of the Lisbon Valley area, in the South Mountain and Middle Mountain groups of the La Sal Mountains. Frost rubble deposits generally cover the igneous rocks, but good outcrops are common along stream courses and in the walls of cirques near mountain summits. The following brief descriptions of the igneous rocks in the Lisbon Valley area are drawn largely from C. B. Hunt's (1958) discussion of the petrology and the structural setting of the igneous rocks of the La Sal Mountains.

Diorite porphyry

Diorite porphyry in stocks and laccoliths and, less commonly, in sills and dikes make up more than 90 percent of the igneous outcrops in the Lisbon Valley area.

In hand specimen the rock is very light gray to medium light gray flecked with white and black of phenocrysts. Phenocrysts make up about half the rock. About two-thirds of them are subangular to angular, white to colorless plagioclase feldspar, which are as much as 10 mm in diameter and averge about 4 mm in diameter. The cores of the plagioclase are sodic andesine or calcic oligoclase, but the outer zones are oligoclase or even albite. About one-third of the phenocrysts are angular hornblende crystals, which are generally about half the size of the feldspar phenocrysts. Biotite and magnetite locally make up a minor part of the visible crystals. The aphanitic groundmass is a microcrystalline aggregate of orthoclase, plagioclase, quartz, hornblende, and magnetite.

Phenocrysts commonly persist with only slight lessening in size to contacts with the sedimentary rock. The constancy in phenocryst size suggests that the magma was partly crystallized before it intruded the sedimentary rock. The porphyry commonly shows some flow banding and platy structure, especially near contacts.

Locally, as on the south slopes of South Mountain and the north wall of Gold Basin, the diorite porphyry has been hydrothermally altered. It is brecciated, argillized, and silicified and contains large irregular phenocrysts of quartz. Hornblende has been removed; the rock is stained by iron oxide and in Gold Basin contains small pyrite cubes. Veinlets and coatings of grayish-green epidote and of radial crystalling aggregates of black specular hematite are locally common in and near altered diorite porphyry; they also occur sporadically in the unaltered igneous rock and in sandstone of the country rock.

Monzonite porphyry

Two small, stubby, dike-like intrusions of monzonite porphyry crop out along the upper part of Lackey Creek on the south side of South Mountain. The intrusion near the head of the creek is about 500 feet long and 150 feet wide and lies near the center of the diorite porphyry mass that makes up most of South Mountain; the other intrusion, about a mile and a quarter downstream, is slightly larger and lies on the edge of the diorite porphyry mass.

The monzonite porphyry is commonly a darker gray than the surrounding diorite porphyry, because of the numerous dark-gray phenocrysts. The phenocrysts, chiefly oligoclase, make up about half the rock, and are as much as 15 mm long and average larger than in the diorite porphyry. Most of the phenocrysts have notably rounded corners. Mafic minerals, chiefly common hornblende, are sparse and make up less than 5 percent of the rock. The contacts of the monzonite porphyry with the diorite porphyry are fairly sharp, but there is little decrease in phenocryst size toward the contacts.

Noselite (sodalite?) syenite porphyry

Noselite (or sodalite) syenite porphyry forms a large cross-cutting tabular mass on the eastern part of Brumley Ridge. About 35 percent of this porphyry consists of large round and subround phenocrysts of perthite as much as 25 mm long but more commonly about 5 mm long. The perthite phenocrysts are surrounded by a lineated felt consisting of about 50 percent orthoclase, 12 percent noselite or sodalite, 3 percent aegirine-augite and traces of magnetite, apatite, and sphene. The rock is platy, and most of its outcrop is covered by block rubble formed more or less in place. The noselite syenite porphyry is petrographically unlike other intrusive rocks of Middle and South Mountains and probably is allied to feldspathoidal rocks that form part of the igneous complex of North Mountain.

Alteration of intruded rocks

Sedimentary rocks near the boundary of the igneous masses are little altered. The contacts between the sedimentary and igneous rocks are invariable sharp and the porphyry shows no evidence of assimilation of the intruded sediments. Such minor alteration as is present is most conspicuous along discordant contacts. Shaly units are generally baked for several tens of feet from the contact with the igneous rock. Coarser sediments are slightly silicified near the intrusives and generally are more firmly cemented in the mountain region than in the mesa lands. Yellowish-green coatings of epidote and shiny black coatings and irregular aggregates of specular hematite occur sporadically and are locally abundant in both the intrusive and intruded rocks.

Origin of the igneous rocks

The sequence of igneous rocks in the Lisbon Valley area is diorite porphyry, monzonite porphyry, and finally, by analogy with the sequence in North Mountain a few miles north of the Lisbon Valley area, syenite porphyry. The sequence in North Mountain is much more complex (Hunt, 1958, p. 318-339). It consists of stocks and laccoliths of diorite porphyry followed successively by dikes and sills of monzonite porphyry, a dike swarm of dominantly syenitic rocks, feldspathoidal dikes, an irregular mass of soda syenite, and finally pipelike masses of explosion breccias (marking the roots of volcanoes) with associated intrusions of aegirine granite porphyry and soda rhyolite porphyry. Hydrothermal activity began with the intrusion of the syenitic dikes and persisted slightly beyond the volcanic phase.

Waters and Hunt, C. B., (1958) set forth a hypothesis for the origin of the La Sal magmas based largely on the relations in North Mountain. They suggested that the igneous processes began with fusion of amphibolite or similar rocks producing a diorite melt with hornblende-rich remnants of the parent rocks. This melt was injected upward and formed stocks and laccoliths. Further melting of hornblende-rich remnants in the substratum yielded a more alkalic and femic liquid which, differentiating as it rose in the stock, produced injections of monzonite and then of syenite and finally of feldspathoidal rocks. Crystallization progressed until only a small part of the magma was fluid, when the rise in gas pressure blasted diatremes through the roof of the stock. In this volcanic phase the stock became a gaseous diffusion column, and the residual syenitic liquid was transformed into a silica-rich melt that is represented by aegirine granite in the volcanic vents and by soda rhyolite porphyry dikes. Gases continued to rise after the crystallization of the magmas; they altered the igneous rocks and deposited some sulphide minerals.

Age of the igneous rocks

Stratigraphic evidence

The igneous rocks of the La Sal Mountains were dated by Hunt (1958, p. 39) as Middle(?) Tertiary. They intrude rocks as young as the Mancos Shale (approximately middle Late Cretaceous in age) and are overlain by Pleistocene glacial deposits. Fragments of the igneous rocks make up a conglomerate in Castle Valley on the north side of the mountains (Hunt, 1958, p. 314) and a fanglomerate on the east side of the mountains (Carter and Gualtieri, 1957c, p. 88; 1958). These alluvial deposits are unfossiliferous, but because they have been folded and are older than the Pleistocene glacio-fluvial deposits of the mountains, they are assumed to be of late Pliocene age. Hunt noted, however, that the conglomerate of Castle Valley could be earliest Pleistocene, and Carter and Gualtieri believed that the fanglomerate on the east flank of the mountains may have been deposited much earlier in the Tertiary when the youngest extrusions of North Mountain breached the surface.

In summary, the local stratigraphic evidence indicates only that the La Sal intrusions are latest Cretaceous to Pliocene in age. The finding of fossils in the preglacial conglomerates of the area might fix the intrusions as pre-Pliocene or even earlier, but the chance of finding fossils in these coarse alluvial deposits seems small. The volcanic phase in the igneous history of the La Sal Mountains (Hunt, C. B., 1958, p. 331) is not recorded in deposits near the mountains. If the volcanics were of early Tertiary age, some of their pyroclastic material may be identified in the early Tertiary continental sediments preserved in the Uinta Basin, whose southern edge lies about 40 miles north of the La Sals.

Lead-alpha apparent ages

Lead-alpha age determinations of zircons from the igneous rocks of the La Sal Mountains are not definitive. Lead-alpha ages of five samples of the porphyries of North Mountain, collected by D. R. Shawe, show wide discrepancies (Jaffe and others, 1959, p. 72). Three different samples of diorite porphyry gave lead-alpha ages of 490, 419, and 386 million years. These dates indicate an early Paleozoic age in the geologic time scale of Kulp (1960), but as the diorite porphyry intrudes Cretaceous rocks, it must be latest Cretaceous or Cenozoic in age. The discrepancy between the apparent and true age of the diorite porphyry is probably due to contamination of the porphyry by zircon from Precambrian rocks (Gottfried and others, 1959, p. 27). The diorite locally contains abundant xenoliths, and Waters and Hunt, C. B., (1958) inferred that the diorite melt was derived from fusion of Precambrian amphibolite.

Lead-alpha ages of 55 and 51 million years were obtained on zircon from different fractions of a sample of monzonite porphyry; these dates correspond with an early Eocene age in the time scale of Kulp. A sample of syenite porphyry yielded a lead-alpha age of 25 million years, late Oligocene on the time-scale of Kulp. Inclusions in the monzonite porphyry are fewer and smaller than in the diorite porphyry, but the syenite porphyry contains abundant huge masses of xenolithic schist, gneiss, and amphibolite (Hunt, C. B., 1958, p. 324, 330). Gottfried and others (1959, p. 27) suggested that zircon in the monzonite and syenite porphyries is dominantly magmatic or recrystallized whereas relict zircon is present in the diorite porphyry. The porphyry sequence--diorite to monzonite to syenite--determined by Hunt in the field, is correctly reproduced by the sequence of the lead-alpha ages. The monzonite porphyry and syenite prophyry, however, are unlikely to differ in true age by 25-30 million years, for the field evidence indicates that the differentiation was a virtually continuous process (Waters and Hunt, C. B. 1958). The syenite prophyry, the youngest of these igneous rocks, possibly has the most completely recrystallized zircon, but its lead-alpha age cannot be accepted as dating the La Sal intrusions without assumptions as great as those involved in broad geologic considerations of the age of the laccolithic intrusions of the Colorado plateau.

Regional geologic evidence

Witking (1958, p. 64), in summarizing the regional geologic evidence, noted that the assumption that the laccolithic mountains of the Colorado Plateau are all of the same age, rests on their similarity in composition, igneous history, and stratigraphic level of emplacement. The dating of the laccolithic centers has been based largely on (1) analogies with the igneous history of the San Juan Mountains in southwestern Colorado, the San Francisco volcanic field in Arizona, and the Mount Taylor volcanic field in New Mexico; (2) interpretations of the igneous detritus in Upper Cretaceous and Tertiary sedimentary rocks, especially in the San Juan Basin; and (3) reconstructions of the geomorphic history of the Colorado Plateau. Widely differing results come from these various approaches to the problem. For example, Shoemaker (1956c, p. 162) favored a Late Cretaceous age for the laccolithic intrusions, whereas Hunt, C. B., (1956, p. 82) assigned them to the Miocene. Kelley (1955, p. 56) on the other hand, suggested that the laccolithic centers are of different ages, some as old as Late Cretaceous and others as young as Oligocene. The only certain conclusion to be drawn from these arguments is that the age of the La Sal and other laccolithic centers on the Colorado Plateau is as yet uncertain. Detailed stratigraphic studies of Upper Cretaceous and Tertiary sedimentary rocks and isotopic age analyses of carefully selected samples of the igneous rocks may yield a firmer answer to this problem.

STRUCTURAL GEOLOGY

TECTONIC SETTING

The Lisbon Valley area lies near the center of the Paradox fold and fault belt. This major tectonic division of the Colorado Plateau is characterized by northwest-trending folds and faults (Kelley, 1955, 1958). The principal anticlines are underlain by thickened rolls of salt of the Paradox Member of the Hermosa Formation of Pennsylvanian age. The tectonic division occupies roughly the north half of the Paradox basin, a depression of Pennsylvanian age, now defined by the area underlain by the saline and penesaline facies of the Paradox Member. The main features controlling the structure of this division are the thick uncompetent Paradox strata and the buttress-like

Uncompahgre uplift that borders the division on the northwest. Minor influences were the igneous intrusions of the Abajo and La Sal centers. Some anomalous northeast-trending folds and faults may be related to shear zones in the Precambrian basement.

GENERAL FEATURES

The major structures of the Lisbon Valley area are the Lisbon Valley, Moab, and Pack Creek salt-cored anticlines and associated faults, and the igneous domes of the southern part of the La Sal Mountains. Away from the salt anticlines and the mountains most of the area is characterized by gentle warps. Synclines bordering the salt anticlines are generally much broader than the anticlines and are not broken by faults.

Faults in the area are steeply dipping, normal, and generally have displacements of less than 300 feet. As indicated by slickensides on exposed fault planes most faults have displacements that are directly down the dip, though some minor faults near Kane Springs may have a small component of strike slip.

The major fault in the area is the northwest-trending Lisbon Valley fault, which, extends about 40 miles as a series of connected segments. In the southern part of Lisbon Valley this fault attains a maximum stratigraphic separation in the post-Paradox beds of about 5,000 feet. A set of northeast-trending faults near Kane Springs links the Lisbon Valley fault with northwest-trending faults associated with the Moab salt anticline. A concealed fault in the Moab anticline set is inferred to have a maximum stratigraphic separation of more than 2,000 feet.

The geologic structure of the area is interpreted by contour lines on the base of the Morrison Formation. This is the most widely exposed and readily determined horizon in the area. Near the salt anticlines, however, where the base of the Morrison must be projected upward from older beds, the contours are conjectural because of probable thinning of the lower Mesozoic formations and because of the indeterminate amount of truncation of Paleozoic beds by the pre-Chinle unconformity.

The chief structural elements of the Lisbon Valley area are shown on figure 3. The principal folds and faults are described in the subsequent pages in a roughly north to south order. The intrusive structures of the La Sal Mountains are treated separately. Final attention is given to the probable subsurface structure of the area.

FOLDS AND FAULTS

Spanish Valley syncline

The surface structure of Spanish Valley is a northwest-trending, faulted asymmetric syncline, bounded on the southwest by the Hunter anticline and by the Moab fault zone. Only formations of the Glen Canyon Group crop out on the southwestern limb of the syncline; they dip from about 5° to 30° toward the valley and probably flatten near the center of the valley.

At the south end of the valley the northwest-plunging Spanish Valley syncline is separated by an inferred fault from a poorly defined smaller syncline that plunges southeasterly into a complexly faulted structural low in sec. 20, T. 27 S., R. 23 E. At the southwest end of the valley the Spanish Valley syncline is separated by projected fault from the similar but more westerly trending Pack Creek synclinal graben.

On the northeast the Spanish Valley syncline is bounded by a narrow anticlinal flexure. Its axis and associated fault lie along the top of a prominent northwest-trending ridge on the west side of Mill Creek and Brumley Ridge. The axial fault of this flexure commonly has a displacement of less than 50 feet down toward the valley; it dies out before reaching the north end of the area and to the south merges with a more westerly trending fault that borders the Pack Creek synclinal graben. Except near this faulted anticlinal flexure, the northeast limb of the Spanish Valley syncline is generally more gently dipping than the southwest limb. Formations of the Glen Canyon and San Rafael Groups form the principal outcrops on the northeast side of the valley. The formations commonly dip about 5^{o} to 15^{o} toward the valley, but close to the alluvial cover of the valley several changes in dip and strike suggest that the floor of the syncline has minor warps.

The northern end of the Spanish Valley syncline lies north of the Lisbon Valley area in the northwestern part of T. 27 S., R. 23 E. (Baker, 1933, p. 66). Northwest of this point and on the same trend the surface structure is the Moab anticline (Baker, 1933, p. 64).

An inferred major fault lies concealed beneath the middle of the valley, probably near the axis of the Spanish Valley syncline. The chief evidence for this fault in Spanish Valley is the presence of two isolated outcrops of steeply west-dipping beds of the Burro Canyon Formation (Lower Cretaceous) near the middle of the valley southeast of the Grand County airport. These outcrops suggest that the Burro Canyon abuts Triassic beds that dip into the valley from the southwest. The inferred displacement is thus downward on the northeast side; it probably averages about 1,000 feet and decreases to the northwest. The greatest displacement on this fault is probably in sec. 18, T. 27 S., R. 23 E. where minor buckling and faulting in the Glen Canyon Group suggest a possible throw of about 2,500 feet. This fault probably connects southward with a fault exposed in sec. 20, T. 27 S., R. 23 E. that drops the Mancos Shale (Upper Cretaceous) against the Morrison Formation (Upper Jurassic). To the north in the area near Moab mapped by Baker (1933), the fault either dies out or possibly branches out into the faults bordering Moab Valley.

Moab fault zone

The Moab fault zone on the southwest side of Spanish Valley is the southerly expression of the Moab fault, which attains a displacement of about 2,600 feet on a single break a few miles northwest of Moab (Baker, 1933, p. 64). This fault system has a total length of more than 30 miles (McKnight, 1940, p. 120). In the Lisbon Valley area this system is a network of hinge-type normal faults that offset rocks of the Glen Canyon Group down toward Spanish Valley. The most prominent and continuous fault lies at the west edge of the zone at the base of the sheer cliffs formed by the Glen Canyon Group. This fault has a relatively straight trace and near the north edge of the area attains a displacement of about 400 feet; at the south end of the fault zone this fault passes into a small monocline. Other faults in this system are commonly discontinuous, have curving traces, and have displacements of less than 300 feet. The number of faults and average displacements increase northwestward. Formations of the Glen Canyon Group are locally difficult to identify in the shattered outcrops and the traces of faults are lost in a welter of joints. The width of the fault zone is unknown, for along the western edge of Spanish Valley the zone is covered by alluvium. However, the faults near the valley have smaller displacements than those at the west edge of the zone.

Hunters Canyon monocline

Hunters Canyon monocline is a prominent fold in the Glen Canyon Group on the southwest side of Spanish Valley. The axis of the anticlinal bend of the monocline (Kelly, 1955, p. 791-792) lies along the crest of the ridge bordering the valley. This axis near the south end of the fold curves slightly southward and plunges about 3° south-southeast. Farther southeast on the nose of the monocline the approximate position of the anticlinal bend axis is marked by a small graben. Dips on the west side of the monocline are gentle; the drop on this flank averages only about 600 feet in the first mile. A small westerly bulge on this flank lies along the south rim of Hunters Canyon. Northwest of the bulge the rocks slope into the Kings Bottom syncline, a major northwest-trending fold centered on the Colorado River near Moab (Baker, 1933, p. 67). To the south of this bulge the rocks slope into a shallow east-plunging syncline on southeastern Bridger Jack Mesa. Most of the steep eastern flank and synclinal bend of the Hunters Canyon monocline is cut by the Moab fault zone; the faulting and folding effect a drop on this flank of about 1,500 feet in a mile. The axis of the synclinal bend is probably near the covered east edge of the fault zone. At the south tip of the monocline the east flank is cut by only a few small faults, and the rocks slope gently into a southeast-plunging syncline at the south end of Spanish Valley.

Pack Creek syncline

The surface structural depression of Spanish Valley at its southern end swings easterly up the canyon of Pack Creek. The axis of this downfold, the Pack Creek syncline, lies south of the creek near the middle of a conspicuous long, sloping, drift- and gravel-covered mesa. This structural depression was referred to by Baker (1933, p. 66) as the Pack Creek synclinal graben, because it is bounded by faults, but displacements on these faults are trivial compared with the total structural relief of the downfold of about 3,000 feet. The low point in the syncline lies about one mile southeast of the M4 Ranch. From this point the axis rises eastward toward south Mountain and rises westward to the reentrant in the west face of a long mesa in sec. 21, T. 27 S., R. 23 E. Outcrops in the syncline are mainly of Cretaceous rocks and an estimated 2,500 feet of Mancos Shale is infolded southeast of the M4 Ranch, the thickest section of the Lisbon Valley area.

The north flank of the Pack Creek syncline involves Jurassic and Cretaceous formations that are separated from the homoclinal area of Brumley Ridge along an east-trending system of normal faults that offset the rocks toward Pack Creek generally less than 100 feet. North of these faults dips average about 5°; immediately south of the faults, dips average more than 20°. The fault system is a continuation of the fault on the ridge on the east side of Spanish Valley. Near the mouth of Hell Canyon the fault system bends sharply to the south and the junction of the South Mountain uplift and the Pack Creek syncline is in part marked by several small south-trending faults.

The south flank of the Pack Creek syncline is also bounded by normal faults, but this system of faults is more poorly exposed and perhaps more complex than the system along the northern flank. Displacements along these faults are commonly less than 500 feet with the younger rocks dropped toward Pack Creek. On the west these faults separate the syncline from the adjacent Pole Canyon dome; to the east they separate it from the structural slope between the South Mountain dome and the Browns Hole syncline. The system apparently coalesces to a single fault with a displacement of about 1,000 feet near the head of Pole Canyon and continues to the edge of the South Mountain intrusion. Only a narrow band of Jurassic and Cretaceous rocks is exposed on the north side of the faults. In general these rocks dip more steeply (as much as 60^{o}) than on the northern flank of the syncline.

On the west the Pack Creek syncline abuts the complex of faults in the northeastern part of the Cane Springs fault block, though on the northwest it is continuous with the Spanish Valley syncline. On the east the syncline is partly bounded by minor south-trending faults, but the main structural feature that separates the syncline from the South Mountain dome appears to be a short, steep south-trending monocline.

A fault that has an inferred displacement of about 500 feet (down on the north) probably lies slightly north of the synclinal axis. Evidence for this fault includes the offsets of the sandstone member in the Mancos Shale near the M4 Ranch and near the head of Pack Creek. The apparent offsets may, however, be due to undetected thinning in the Mancos Shale over the buried salt structure or to several concealed faults.

Brumley Ridge fault zone

North of the Pack Creek syncline between the Spanish Valley syncline and the La Sal Mountains domes is a structural slop with a few minor warps. Over much of this homoclinal area, dips are less than 5^{o}. The chief interruption in the structural slope is the Brumley Ridge fault zone which cuts across the middle of the area. This fault zone extends northwesterly for about 8 miles from Hells Canyon to the west rim of South Mesa. Commonly the fault zone is less than 0.5 mile wide. Most of the faults in this zone are steep, have fairly straight traces, and offset the rocks less than 50 feet. Maximum displacement is on a fault about a mile north of Hells Canyon that drops the Mancos Shale against the Brushy Basin Member of the Morrison Formation--a stratigraphic throw of about 200 feet.

Pole Canyon anticline

Immediately south of the Pack Creek syncline and nearly parallel to it is a small faulted upfold, the Pole Canyon anticline. This anticline is about 4 miles long and trends about N. 70^{o} W. The west nose of the anticline is narrow and well defined. The east nose is broad and poorly defined, because much of this fold merges eastward into the broad structural slope between the South Mountain dome and the Browns Hole syncline. Rocks of Jurassic age form most of the outcrops of the Pole Canyon anticline. On the north flank these rocks commonly dip about 20^{o} and are cut by many small normal faults that trend about parallel with the strike of the beds and in general offset the rocks down to the north. On the south flank of the anticline the rocks dip more gently, and except on the east nose, the rocks are not broken by faults.

Collapse structures of Spanish Valley and environs

The collapse structures of Spanish Valley and environs are roughly oval in plan, a few hundred feet in diameter, and contain a mass of broken rock that has been dropped several hundreds of feet (Weir and others, 1961). They are found in all exposed formations from the Navajo Sandstone through a sandstone member of the Mancos Shale--a stratigraphic section more than 3,000 feet thick. Although the vertical exposure of any of these collapse structures is only about 200 feet, they are inferred to be breccia pipes that extend several thousand feet below the surface into Paleozoic rocks.

Seventy-seven collapse structures were identified in the area between Pole Canyon and the North Fork of Mill Creek near Moab--mostly on the east side of Spanish Valley. Thirty-three of these structures lie north of the Lisbon Valley area. All but a few of the collapse structures lie within a northwest-trending belt about three-quarters of a mile wide and 10 miles long that parallels Spanish Valley. The few collapse structures lying south of Pack Creek probably lie in a conjected, more westerly trending belt.

Most of the collapse structures are partly obscured by surficial deposits and form inconspicuous mounds or swales. The sharp boundaries of these structures are fault contacts that in plan consist of many short straight segments enclosing a core of broken rocks. The bounding faults frequently dip steeply inward, but several exposures of wavy fault planes suggest that they average about vertical. Downward displacements along these faults range from a few hundred feet to about 1,500 feet and frequently differ greatly in adjacent collapse structures.

The large downward displacements (about 1,500 feet) of some breccia cores surrounded by Navajo Sandstone indicate that the collapse structures penetrate the Mesozoic rocks in the area and probably bottom in inclined Paleozoic limestone beds that flank the thick salt core of the Moab anticline and related upfolds beneath Spanish Valley and the canyon of Pack Creek. Connate water, perhaps admixed with hydrothermal solutions, probably moved downslope from the La Sal Mountain domes during the Teritary and dissolved limestone and salt beds of the Hermosa Formation in the subsurface near Spanish Valley and thus created space for breccia from the overlying formations. The solutions were discharged upward from the tilted Paleozoic formations, and as they moved along fracture channelways in the younger formations dissolved carbonate cement so that the younger rocks caved into the open spaces. If these inferences and hypothesis are approximately correct, the collapse structures are the outcrops of breccia pipes that are as much as 5,000 feet high. The collapse structures of Spanish Valley are not known to be mineralized, but they resemble in part other pipe-like bodies of brecciated sedimentary rock that contain uranium ore, such as the Temple Mountain collapse structure in the San Rafael Swell (Kerr and others, 1957; Keys and White, 1956).

Kane Springs graben

The Kane Springs graben is a complexly folded and faulted down-dropped block that trends northeasterly, almost at right angles to the trends of folds and faults in the surrounding area. The northwest side of the graben is bounded by several long, somewhat sinuous normal faults that on Bridger Jack Mesa have maximum throws of more than 400 feet. This northwestern fault system extends from Hatch Wash to Spanish Valley and is about 2 miles longer than the faults on the southeast side of the graben. On the northeast the block is bounded by a northwest-trending fault that is probably continuous with the medial fault of the Spanish Valley syncline. On the southwest end of the block are two small faults representing the northermost extension of the Lisbon Valley fault system. The southeast side of the block is bounded by a fairly straight and simple fault that a mile northeast of Kane Springs attains a displacement of about 300 feet. This southeastermost fault is roughly paralleled by several lesser faults that have displacements of only a few tens of feet. Most of the block is warped and dips gently eastward, but the northeastern edge of the block is structurally lower, and is squeezed into a complex of minor folds and faults. The most conspicuous of these folds are synclinal. The southermost of the downfolds may be considered as a continuation of the northwest-trending Browns Hole syncline whose axis bends abruptly to the northeast within the Kane Springs graben.

Browns Hole syncline

The Browns Hole syncline is a northwest-trending downfold that extends about 12 miles from south of La Sal to Kane Springs Canyon. The syncline occupies the center of a broader depression between the South Mountain dome and the West Coyote and Looking Glass anticlinal noses. The formations, which are mainly of Late Jurassic and Cretaceous age, dip gently on both flanks of the syncline near the trough, though higher on the structural slope off South Mountain they dip on average about 10°. The western side of the depression is cut by many small faults of the Lisbon Valley fault system. The syncline plunges gently to the northwest and is truncated by the southeasternmost fault of the Kane Springs graben. Near Browns Hole a minor low in the synclinal trough interrupts this northern plunge of the axis.

East Coyote syncline

The East Coyote syncline is a northwest-trending downwarp about 16 miles long. The axis plunges gently towards the low point of the trough on Middle Mesa. The axis is virtually continuous with the axis of the Browns Hole syncline but the two downfolds are divided by a vaguely defined high at the head of East Coyote Wash. On the southeast the axis veers slightly and lies south of the northwest tip of the Disappointment syncline mapped by Cater (1955c, 1955e) in the adjacent Anderson Mesa and Horse Range Mesa quadrangles. Dips are commonly less than 3° in this syncline but they increase near the Lisbon Canyon anticline on the southwest. On the north in the Mount Peale 1 SW quadrangle (Carter and Gualtieri, 1957b) the dips remain low to the faulted center of the pine Ridge anticline.

Near the edge of the area the structure contours bulge northeastward and outline a small downwarp, the Greasewood synclinal nose. This minor fold has no closure and merges on the southwest into the northeast flank of the East Coyote syncline.

Lisbon Canyon anticline

Northeast of Lisbon Valley is a narrow asymmetric upfold that extends from near Lisbon Canyon to near the Big Indian copper mine. This upfold, the Lisbon Canyon anticline, may be regarded as the faulted northeast flank of the Lisbon Valley anticline, but although they undoubtedly share a common genesis and both folds are underlain by the same thickened roll of salt, their present surface expressions are different and each fold has a separate closure.

The two folds are separated by the Lisbon Valley fault that in this part of the area has a displacement measurable in thousands of feet. The northeast flank of the Lisbon Canyon anticline is characterized by gentle dips, commonly less than 5°. A single small fault cuts the northeast flank; it drops the rocks towards Lisbon Valley about 150 feet at Lisbon Spring.

The southwest flank is characterized by steep dips, commonly ranging from between 20° to 35°. Many discontinuous faults, subparallel to the major Lisbon Valley fault, cut the southwest flank and part of the crestal area. Most of the faults displace the rocks downward towards Lisbon Valley and have maximum displacements from about 100 to 300 feet.

On the north the axis of the Lisbon Canyon anticline plunges gently toward a small syncline lying alongside the Lisbon Valley fault southeast of the Rattlesnake open pit mine. On the south, between Lisbon Canyon and Snyder Water Canyon, the southeast nose of the anticline fades out against the northeastern bounding fault of the McIntyre graben. The high point of the fold lies near the center of the SW1/4 sec. 5, T. 30 S., R. 25 E. and near this point the Lisbon Canyon anticline has its maximum closure of about 300 feet.

Lisbon Valley anticline

The Lisbon Valley anticline, the dominant fold of the area, extends about 20 miles northwest from near Little Indian Canyon to the Rattlesnake Ranch. Only a small part of the northeast flank of the fold crops out, for most of the northeast flank is cut off by the Lisbon Valley fault and is now represented at the surface in large part by the neighboring Lisbon Canyon anticline. The projected surface trace of the axis of the Lisbon Valley anticline thus lies close to, perhaps in part north of, the outcrop of the fault. Near the middle of Lisbon Valley, sec. 16 and environs, T. 30 S., R. 25 E., the surface trace of the axis lies south of the fault for a distance of several miles. This crestal region of the anticline is complicated by many small northwest-trending folds and faults. Northeasterly dips in and near this crestal region commonly exceed 10° and near the major fault are commonly more than 30°.

The surface expression of the Lisbon Valley anticline is mostly a broad, dip slope formed on the southwestern half of the fold. Dips on this flank are as much as 20° in Paleozoic rocks along the northeastern edge of Big Indian Valley. Above the post-Paleozoic unconformity the Mesozoic rocks dip 2° to 5° less steeply than the underlying rocks, but strikes above and below the unconformity do not differ noticeably. Strikes are almost due west near Woods

Ranch, but the principal strike is to the northwest. The southwestern flank, for the most part, grades into the gentle downwarps of Dry Valley and the Sage Plain, but near the northwest end of the anticline a fairly prominent narrow bulge, the Looking Glass anticlinal nose, swings westerly off the main fold. A somewhat similar but much less conspicuous bulge is near the southeast end of the anticline on top of Three Step Hill.

The southwestern flank of the anticline is virtually unfaulted except for the Lisbon Valley fault and related subsidiary faults in the crestal region. A small fault, nearly perpendicular to the Lisbon Valley fault system, cuts the Paleozoic limestone about 2 miles northeast of Big Indian Rock. This fault is less than a mile long and has a displacement of only a few feet, but contains copper minerals and is further described in connection with the Philadelphia copper prospects.

Lisbon Valley fault system

The Lisbon Valley fault system extends northwestward across the area for a distance of more than 30 miles. The system is divisible into three parts of roughly equal length. The approximate boundary between the northwestern and central parts of the system is in sec. 12, T. 29 S., R. 23 E. about 4.5 miles east-southeast of La Sal Junction. The approximate boundary between the central and southeastern segment of the system is in sec. 26, T. 30 S., R. 25 E. near the mouth of Lisbon Canyon.

The northwestern part of the system extends to Kane Springs Canyon where the northernmost faults form the southwestern boundary of the Kane Springs graben. Displacements on faults in this part of the system reach a maximum of about 400 feet near the Rattlesnake pit and Utah highway 46. Maximum offsets decrease northwestward and on the faults near Kane Springs Canyon average less than 20 feet. All the faults are steeply dipping and most are nearly vertical. North of the road to Browns Hole the system consists of many small faults arranged roughly en echelon. Many of these faults are conspicuous because they contain small amounts of purplish-black manganese minerals which contrast with the light-colored country rock.

The central part of the system consists chiefly of a single major fault with relatively few branch faults. Near Lisbon Valley, however, many subsidiary faults, more or less parallel to the major fault, cut the rocks near the crests of the Lisbon Valley and Lisbon Canyon anticlines. These subsidiary faults have maximum displacements ranging from a few tens of feet to a few hundreds of feet and, for the most part, dip steeply toward the major fault, which lies between the anticlines near the main drainage of the Lisbon Valley. The greatest displacement in the system is in the southern part of this central segment in and near the SW1/4 sec. 23, T. 30 S., R. 25 E. about 1.5 miles northwest of Woods Ranch. Here, Mancos Shale of Late Cretaceous age has been faulted down against the upper member of the Hermosa Formation of Pennsylvanian age. If the formations are as thick at this locality as in the closest measured sections, the stratigraphic separation at this point is about 5,000 feet.

The major fault at the surface dips generally 50° to 60° to the northwest. The major fault plane dips about 55° where exposed north of the Far West mine, at the Big Indian copper mine, and on the hill one mile southeast of the Big Indian mine; southeast of this hill the fault is mostly covered by alluvium and the few outcrops are poor, but the closest exposed fault in the southeastern part of the system, near Woods Ranch, also dips about 55° northeast.

Rocks on either side of the main fault, for the most part, are not strongly deformed. Competent units on the northeast side of the fault, such as the sandstone beds in the Burro Canyon Formation and Dakota Sandstone, contain many northwest-trending fractures as much as several hundred feet from the fault, but brecciated rock is limited to within a foot or so of the fault. Drag is also limited to within a few feet of the fault and is most apparent in incompetent units such as the Mancos Shale. On the southwest side of the fault, the competent beds of the Cutler and Hermosa Forrmations are much less fractured than similar beds in formations on the northeast side. Fractures are abundant in the Glen Canyon Group, but for the most part, they seem to be tensional joints related to the Lisbon Valley anticline rather than to the fault.

South of Lisbon Canyon the main fault splits into several smaller faults that in part form the McIntyre graben. The southeastern part of the Lisbon Valley fault system is described in the following section on this graben.

Age of the Lisbon Valley fault system

The Lisbon Valley fault system cuts folded Upper Cretaceous rocks and is undoubtedly, in the main, a Tertiary structure. The last fault movements however, may obscure the more ancient history of the system. Three geologic features suggest that faulting began early in the Mesozoic:

(1) Near a fault in the system west of the Rattlesnake pit in the SW1/4 sec. 12, T. 29 S., R. 23 E., the Salt Wash Member of the Morrison Formation (Upper Jurassic) contains beds of brecciated sandstone that may have been formed by faulting in Jurassic time. The breccia has been recemented into units that are conformable to the bedding of the formation. The breccia units extend only a few feet away from the fault plane and have been slickensided by more recent movements on the same fault.

(2) In the Pioneer Uranium Corp. drill hole no. 1 on the north side of the Lisbon Valley fault, in the NW1/4 sec. 6, T. 30 S., R. 25 E., the electric and gamma-ray logs indicate that the Navajo Sandstone (Late Triassic? and Jurassic) attains an anomalous thickness of about 500 feet (P. L. Grubaugh, U.S. Atomic Energy Commission, written commun., 1956). The Navajo is generally only about 300 feet thick in the nearest sections on the south side of the fault. This difference in thickness may be the result of differential uplift on the Lisbon Valley fault during Navajo deposition. On the other hand, it may be related to an exceptional heaping up of dunes in Navajo time and to extreme irregularity of pre-Entrada erosion.

(3) The Far West fault, best exposed in the Far West mine, displaces the contact between the Cutler and Chinle Formations about 60 feet. The fault dies out upward and is reflected in the surface in the Wingate Sandstone (Late Triassic) only by northwest-trending joints. Apparently the displacement is taken up within the upper part of the Chinle Formation (late Triassic). The Far West fault and the Radon fault probably are branchs of the main fault and

seem to record movement on the Lisbon Valley fault system in Triassic time.

Possibly the Lisbon Valley fault system is as old as the late Paleozoic folding of the anticline evidenced by the pre-Late Triassic unconformity. The fault may die out downward within the crumpled thick salt sequence of the Paradox Member of the Hermosa Formation (Pennsylvanian). The aeromagnetic map of the Lisbon Valley area by Byerly and Joesting (1959), which mainly reflects the magnetization and structural alignments of the basement, shows no discordance along the line of the major fault.

Neff (1960, p. 60-61; fig. 9), however, implied that the fault system may date from pre-Paradox time. He reported that differences in thickness and in units present indicates a high was present on the northeast side of the fault in Mississippian time. His section between the Skelly Oil Co. no. 1 Summit Point well in sec. 21, T. 31, S., R. 25 E., Utah, northeast 11 miles to the Pure Oil Co. no. 1 Southeast Lisbon well in sec. 5, T. 44 N., R. 19 W., Colorado, shows a probable fault separating the dissimilar Mississippian sections. This probable fault is within the Lisbon Valley fault system on the north side of the McIntyre graben.

McIntyre graben

The McIntyre graben is a downfolded and downdropped block that lies immediately southeast of and on the same northwest trend as the Lisbon Valley anticline. The graben is about 11 miles long and from about 1.2 to 3 miles wide. It includes most of Lower Lisbon Valley and the uppermost part of McIntyre Canyon and dies out on Horse Range Mesa about a mile east of the map boundary (Cater, 1955c). The graben is dominantly synclinal with many minor folds. Details of the folding are mostly obscured by the alluvial cover of Lower Lisbon Valley.

The best exposed minor structure is a fault-bounded, tightly folded syncline in Lower Lisbon Valley near the Woods Ranch. The axis of this syncline is nearly aligned with the axis of the Lisbon Valley anticline. Exposed formations ranging in age from Permian to Cretaceous wrap sharply around the trough and dip 20^{o} to 35^{o} toward the axis which plunges about 30^{o} to the southeast. Two short faults with displacements of less than 50 feet cut the rocks near the axis on the northwesternmost exposures of the fold; otherwise the syncline is not faulted except at its margins. Dips in scattered outcrops in Mancos Shale indicate that the syncline closes around a low point about 0.5 mile east of the Patterson Ranch. The southern part of this syncline is obscured by the alluvial cover. Probably the fold merges with a more general depression whose low is near the southeast corner of sec. 5, T. 31 S., R. 26 E. The fold ends in the irregular upwarp near the head of McIntyre Canyon about a mile west of the State line.

In the northeastern part of the graben, north of the minor syncline described above, the beds generally strike west to northwest and dip 5^{o} to 15^{o} to the southwest. The southeastern part of the graben contains several fault blocks that for the most part are tilted to the northwest.

The faults bounding and cutting the McIntyre graben are the southeastern part of the Lisbon Valley fault system and are roughly divisible into three sets--northern, central, and southern. The faults on the north side of the graben are apparently a continuation of the faults cutting the crestal region of the Lisbon Canyon anticline. Displacements on these northern faults generally are less than 100 feet, but a maximum displacement of about 600 feet is attained near the State line where the northern set has merged into a single fault that drops Dakota Sandstone in the graben against beds of the Salt Wash Member of the Morrison Formation. East of the State line the northern fault arcs southward and dies out near McIntyre Canyon just north of a shorter, but otherwise similar fault, which also arcs southward and at the edge of the area practically joins the southern set of faults bounding the graben.

The central and southern sets of faults of the McIntyre graben branch off the main Lisbon Valley fault north of the Woods Ranch. The principal fault of the central set in the SW1/4 sec. 25, T. 30 S., R. 25 E. separates northwest-striking Cretaceous beds from northeast-striking Triassic and Jurassic beds and has a maximum offset of about 2,000 feet. Southeast of this locality mine the displacement on this fault decreases rapidly to less than 100 feet and, like other persistent faults in this set, probably joins the northern faults about one mile southeast of Lisbon Gap.

The greatest displacement on the southern set of faults is on the graben-bounding fault between the Woods Ranch and the Patterson Ranch. North of the Patterson Ranch beneath alluvium, Cretaceous rocks abut Triassic rocks, an offset of about 2,500 feet. Southeast of the Patterson Ranch the southern set consists of several branching, subparallel faults, which are irregularly sinuous in plan and commonly have offsets of several hundred feet. To the southeast displacements generally decrease and the number of faults increase. This southern set of faults persists more than 10 miles beyond the limits of the McIntyre graben and in adjacent quadrangles in Colorado is represented by a southeast-trending zone of small normal faults on the northeast flank of the Dolores anticline (Cater, 1955d). These faults die out near the Dolores River Canyon in the Joe Davis Hill quadrangle, Colorado.

Folds and faults of Dry Valley and vicinity

The southwestern part of the Lisbon Valley area is characterized by low dips and broad folds. This subarea of gentle warping includes all of Day Valley and extends north to Iron Mesa and southeast to West Summit.

West of La Sal Junction is an ill-defined uplift here referred to as the West Coyote anticlinal nose. The nose plunges gently to the east, but the trend of the western part of the axis is uncertain. It may swing northwest into a very flat area and trend approximately parallel to Hatch Wash, marking the crest of a fold approximately the same as that figured by Joesting and Case (1960, fig. 114.2) as the "West Coyote anticline."

The Hatch Rock syncline is centered on Hatch Wash between Hatch Rock and U.S. Highway 160. The axis of the syncline trends northwest, curving somewhat more westerly near the edge of the area. Dips around this downfold average about 1°. Total closure of the syncline in an area about 6 miles long and 2 to 3 miles wide is about 100 feet.

At the southern edge of the Lisbon Valley area is a south-trending broad depression, the East Canyon syncline. Dips around this syncline average less than 1°. Most of this downfold lies south of the mapped area.

A small upwarp suggestive of an anticlinal nose lies in the southeastern part of this region of gentle warping, near the southeast corner of the Lisbon Valley area. This is probably the northwesternmost expression of the northwest-trending Dolores anticline, which has been mapped in adjacent quadrangles in Colorado by Cater (1955a-f).

The subarea of gentle warping is virtually unbroken by faults, except near the Lisbon Valley fault system and near the faults of Shay graben. Both the North and South Shay faults dip about 70° toward the narrow graben. Offset on these northeast-trending faults is about 100 feet near the south edge of the mapped area and decreases rapidly to the northeast. The North Shay fault dies out northeastward near Peters Point, but the South Shay fault persists to the rim of South Canyon Point. Northeastward beyond South Canyon Point the influence of the graben is reflected by a prominent, narrow zone of closely spaced joints, trending about N. 60° E., that persists to near the southern part of the Lisbon Valley anticline (Kelley and Clinton, 1960, p. 62, fig. 2). Witking (1964) presented evidence from the Abajo Mountains area, showing that the faults of the Shay graben and similar faults are younger than the Mancos Shale of Late Cretaceous age and older than the igneous intrusions of probable Miocene and Pliocene age.

INTRUSIVE STRUCTURES OF THE LA SAL MOUNTAINS

The Lisbon Valley area includes roughly the southeastern quarter of the intrusive structures of the La Sal Mountains. The following discussion is based in part on the work of Hunt (1958), who studied the geology of the mountain region with particular attention to the igneous rocks. C. B. Hunt's discussion of the structure and history of the La Sals rests largely on his detailed studies of the complex and varied intrusions of the North Mountain group, which lied several miles northeast of the Lisbon Valley area. Our studies of the southern La Sals were focused on the sedimentary rocks, and we did not find it practicable to map some igenous contacts as, for example, the contacts between the diorite porphyry of the stocks and the diorite porphyry of the adjoining laccoliths.

The intrusive bodies within the Lisbon Valley area can be conveniently divided into three groups: (1) those associated with South Mountain, (2) those associated with Middle Mountain, and (3) the more or less isolated intrusions lying north of Middle Mountain. The structural setting of the South Mountain intrusions differ from that of the other groups, but most of the intrusions are much alike.

South Mountain group

The South Mountain group was intruded along the line of a thickened roll of salt in the underlying Paradox Member of the Hermosa Formation. This thickened roll of salt extends from Moab and Spanish Valleys along the upper course of Pack Creek to Pine Ridge, east of La Sal, and is aligned with the Gypsum Valley salt anticline in Colorado (Carter and Gualtieri, 1957a; Shoemaker and others, 1958, p. 45). Byerly and Joesting (1959, p. 49) suggested that "* * * the location of the South Mountain group of igneous intrusions was determined by the old zone of weakness within the basement which was responsible for the initiation of the Gypsum Valley piercement structure and the Pine Ridge salt plug in late Paleozoic time."

The South Mountain intrusions are elongated northwesterly, parallel to the trend of a preexisting sal-cored fold of this locality. The intrusions seem to have been emplaced in a small faulted anticline similar to the Pine Ridge fold. Hunt (1958, p. 318), on the other hand, believed that the host structure for the South Mountain intrusions was a faulted syncline. Along the northwest side of the intrusions the igneous rocks in part crosscut northwesterly and northeasterly dipping beds; along the southwest side they abut southwesterly and southerly dipping beds. A large component of the steep dip (50^o to 70^o), characteristic of the contacts along the south side of the igneous mass, is probably inherited from the earlier salt anticline at this locality. The faults associated with Pack Creek syncline, which lies northwest of South Mountain, for the most part curve across the southwest nose of the syncline and die out west of the mountain front. The southernmost fault bounding the Pack Creek syncline, however, continues to the mountains and is probably older than the igneous intrusions, for at the Pole Canyon the diorite porphyry locally abuts the fault plane.

South Mountain stock

According to Hunt (1958, p. 345), near the center of the South Mountain cluster of intrusions is a stock, roughly circular in plan and about 1 mile in diameter. The eastern margin of the stock cuts almost perpendicular to the strike across northerly dipping rocks, which range in age from Triassic to Cretaceous.

The southern and western margins of the stock are much less clear. Hornfelsed gray shale, assigned questionably to the Cutler Formation, crops out poorly east of Lackey Basin. This shale is probably on the northeastern flank of the pre-intrusive anticline, although the scattered poor exposures do not exclude the possibility that it is an isolated roof pendant. The shale separates diorite porphyry bodies of similar appearance; the porphyry body on the north side was considered the stock of South Mountain by Hunt (1958, pl. 39).

The edge of the stock west of the gray shale outcrops, according to Hunt (1958, p. 346, pl. 39), is partly marked by small masses of hematite-stained, argillized, brecciated porphyry, veined on a small scale by quartz and calcite. Some of this altered porphyry is the host rock for the copper ores of Lackey Basin. The brecciated masses are in part similar to the explosion breccias of volcanic vents in North Mountain, and perhaps are analogous features, though aegirine granite associated with most of the vent breccias, is not present in South Mountain. Hunt considered the breccia masses as marking a shatter zone just within the southern margin of the stock, but he noted that between the brecciated masses the porphyry of the stock is apparently continuous with that of the intrusions to the south and west.

The southwestern margin of the stock is indefinite, although outcrops of the porphyry in this part of the area are fairly good. The northwestern margin crosscuts sedimentary rocks of Jurassic age which are obscured by surficial deposits. Discordances in strike in the poorly exposed sedimentary rocks suggest that they are cut by concealed faults. Hunt, C. B., (1958, pl. 39) noted that the contact between the intrusion and sedimentary rocks on the northwest side of the mountain dips about 65^o inward toward the intrusion. Some protrusions of igneous rock on this side of the mountain, however, appear conformable with steeply north-dipping beds of the Salt Wash Member of the Morrison Formation.

On the north and northeast side of South Mountain no petrographic differences are apparent between the porphyry of the stock and the porphyry of the laccoliths and sills that extend to near La Sal Pass. A conspicuous zone of near-vertical sheeting in the igneous rock just north of the boundary of T. 27 S. and T. 28 S. probably marks the boundary of the South Mountain stock.

Intrusions around the stock of South Mountain

Southwest and south of the stock of South Mountain as outlined by Hunt is a large mass of diorite porphyry that extends from the head of Pole Canyon to several miles east of the boundary of the Lisbon Valley area. This mass of porphyry is bordered for the most part by steeply dipping red beds and yellowish gray limestone assigned with question to the Cutler Formation. Exposures of the border are poor but the porphyry mass is apparently concordant with the country rock. This porphyry body is probably a thick laccolithic intrusion or possibly several closely spaced laccolithic intrusions. Case and others (1963, p. 111-112) on the basis of their aeromagnetic profile estimated that the thickness of the porphyry body near the east edge of the map ranges between about 4,000 and about 5,000 feet. At the northwest end of this body, near the head of Pole Canyon, the porphyry cuts across or abuts a fault in rocks of Triassic age. The porphyry mass on the southwest and south side of the peak of South Mountain largely occupies the axial region of the preexisting salt fold, and the intrusions probably lie mostly within the Paradox Member of the Hermosa Formation.

The Pack Creek laccolith (Hunt, C. B., 1958, p. 345) exposed mostly in sec. 32, T. 27 S., R. 24 E., is composed of diorite porphyry, which crops out poorly in an area only about 0.7 mile long and less than 0.3 mile wide. It forms a prominent ridge on the south side of Pack Creek. The laccolith is in the nose of an anticline and intrudes the upper part of the Chinle Formation. This laccolith may be an offshoot of the intrusions on the southwest side of the mountain, but the intervening area is mostly covered by rubble.

North of the peak of South Mountain at the head of Pack Creek is another small laccolith, which is about 0.5 mile in diameter and about 700 feet thick. The laccolith intrudes the mudstones of the Brushy Basin Member of the Morrison Formation (Late Jurassic) and is capped by silicified sandstone of the Burro Canyon Formation (Early Cretaceous). The north edge of the intrusive abuts Mancos Shale (Late Cretaceous), probably along the line of a preporphyry fault that dropped the Mancos against the Morrison Formation. North of this laccolith is a poorly exposed sill of diorite porphyry. The sill is emplaced near the base of the Mancos Shale and is probably about 200 feet thick.

Middle Mountain group

The intrusions of Middle Mountain were described by Hunt, C. B., (1958, p. 339) as consisting of a central stock in Gold Basin surrounded by laccoliths that radiate from this stock. Within the Lisbon Valley area the principal exposures consist of the partly discordant, partly concordant intrusion of Mounta Tukuhnikivatz, and the Brumley Ridge and Dorry Canyon laccoliths.

Parts of several smaller intrusions are exposed along the east edge of the area.

The sedimentary formations are bowed up around the Middle Mountain group. Dips in the sedimentary rocks commonly range between 10^{o} and 15^{o} on the flanks of the dome but locally are much steeper near the intrusions. The pre-intrusive structure of the area of Middle Mountain is obscure but probably was a shallow broad syncline similar to the downwarp between the Pine Ridge and Lisbon Valley anticlines.

Mount Tukuhnikivatz intrusion

The intrusion of Mount Tukuhnikivatz was described by Hunt, C. B., (1958, p. 341) as a discordant laccolith about 1 to 1.5 miles in diameter and at least 2,500 feet in maximum thickness. The east contact of the intrusion is nearly vertical and cuts across steeply south-dipping Jurassic and Cretaceous rocks. Where exposed on the north the contact is also nearly vertical and cuts across moderately southwest-dipping Jurassic(?) and Jurassic beds. On the west and south the contact is mostly covered but apparently dips somewhat more steeply than the surrounding sediments. The cross-cutting contacts of part of the intrusion and its relations to some of the surrounding laccoliths suggest that the northeastern plart of the Mount Tukuhnikivatz intrusion may be a stock, similar to the stock on the north side of the South Mountain group of intrusions.

Hell Canyon laccolith

A small laccolithic body, less than 0.5 mile in diameter, is partly exposed on a minor ridge north of Hell Canyon in the SW1/4 sec. 21, T. 27 S., R. 24 E. The floor of the laccolith is in the basal 100 feet of the Mancos Shale and its top probably lay about 300 feet higher in the same formation. The Hell Canyon laccolith is a western extension of the Mount Tukuhnikivatz intrusive.

Dorry Canyon laccolith

A partly discordant laccolithic intrusion crops out over an area of about one-quarter of a square mile on the south side of Dorry Canyon. At the east end of the outcrop the contact dips steeply to the southeast and cuts across the lower part of the Entrada Sandstone and the upper part of the Navajo Sandstone. South of this point the east edge of the intrusive apparently passes conformably beneath middle of the Entrada Sandstone and perhaps connects the southeasterly with the Mount Tukuhnikivatz intrusion. The floor of the Dorry Canyon laccolith is not exposed, but by analogy with better known laccoliths of the Colorado Plateau, is probably near the base of the Kayenta Formation, the closest subjacent incompetent unit. Under this hypothesis the laccolith is as much as 750 feet thick.

Brumley Creek laccolith

The Brumley Creek laccolith crops out mostly along the ridge between Dorry Canyon and Gold Basin. The eastern end of this intrusion lies within the Chinle Formation of the southwest edge of Gold Basin. The base of the laccolith is not exposed but probably rests on competent sandstone of the lower Chinle or of the underlying Cutler Formation. To the northwest the base of the laccolith rises stratigraphically through the Wingate Sandstone and Kayenta Formation. The northwestern end of the laccolith probably lies within the San Rafael Group. In the NE1/4 sec. 16, T. 27 S., R. 24 E., the intrusion is roofed by south-dipping beds of the Wingate and Kayenta. Here the laccolith is about 500 feet thick. It thins southeastward; to the northwest it seems to have a bulbous nose that attains about 1,000 feet in thickness. The Brumley Creek laccolith lies stratigraphically lower than the neighboring Dorry Canyon laccolith and probably lower than any other exposed laccolithic body in the Middle Mountain group of intrusions.

Middle Mountain stock and minor intrusions around Gold Basin

According to Hung, C. B., (1958, p. 344) the center of igneous activity and structural doming of the Middle Mountain group is in Gold Basin in W1/2 sec. 14 and E1/2 sec. 15, T. 27 S., R. 24 E. Most of the floor and part of the enclosing walls of Gold Basin are covered by morainal, rock glacier and rubble deposits. Of the igneous rock outcrops in Gold Basin within the Lisbon Valley area only the northern tip of the Mount Tukuhnikivatz intrusion and a smaller body along the east margin of the mapped area and some parts of the igneous bodies on the northeast wall of the basin were included by Hunt, C. B., (1958, pl. 39) as parts of the Middle Mountain stock. In our mapping, however, we did not distinguish a contact between the stock and adjacent intrusions.

Several small but conspicuous dikes but sedimentary rocks on the west side of Gold Basin between the Mount Tukuhnikivatz intrusion and the Brumley Creek laccolith. The southernmost of these dikes is about 1,000 feet long and 100 feet wide at the outcrop; it cuts across the Kayenta and Navajo Formations, and ends within the Entrada Sandstone only 100 feet from the edge of the Mount Tukuhnikivatz intrusion. About 500 feet north of this southernmost dike is a smaller dike that cuts the Wingate Sandstone and ends in the Kayenta Formation; about 100 feet higher on the slope in the Navajo Sandstone is a small diorite porphyry outcrop which may be a continuation of this same dike. Hunt, C. B., (1958, p. 341) noted a horizontal lineation parallel to the walls of these dikes and he considered them to be probably feeders from the Middle Mountain stock to the Dorry Canyon laccolith.

About 1,000 feet west of the above-mentioned dikes is a similar thin dike that cuts across the Kayenta and Navajo and branches into two sills in the lower part of the Entrada Sandstone. The distal end of the dike is covered by rock glacier deposits but probably crosscuts or branches off the Brumley Creek laccolith. The sills branching off the dike may connect beneath a thin rock cover with the Dorry Canyon and Mount Tukuhnikivatz intrusion.

East of Mount Tukuhnikivatz, in SE1/4 sec. 22, T. 27 S., R. 24 E., are several outcrops of steeply dipping sills in the Brushy Basin Member of the Morrison Formation. These outcrops are probably of a single irregularly tabular body more than 0.5 mile wide and 100 feet thick. Carter and Gualtieri (1958) showed that the northern part of this sill has a thin lower split that cuts beds of the Salt Wash Member of the Morrison at a small angle. This sill may be linked directly with the adjacent Mount Tukuhnikivatz intrusion, but more likely it is connected with a subjacent crosscutting igneous body in the northeast quarter of section 22. This latter body is considered a stock by

Carter and Gualtieri (1958). It cuts across the San Rafael Group and most of the Morrison Formation. The map relations suggest that in its distal portion it may be tabular. Its probable contact within the Lisbon Valley area with the Mount Tukuhnikivatz intrusion is obscured by a rock glacier that is composed chiefly of sandstone.

On the northeast side of Gold Basin, in the E1/2 sec. 15, T. 27 S., R. 24 E., is a small complex of crosscutting intrusions that in part are probably bounded by pre-intrusion faults. The southern boundary of the largest of these bodies is anomalously straight. This intrusion extends more than one-half mile northeasterly from Gold Basin and averages about a quarter of a mile wide. It cuts across the Jurassic and Cretaceous rocks and is considered a stock by Carter and Gualtieri (1958). On the north side of the intrusion is a sill that is emplaced near the base of the Entrada Sandstone and a dike that follows the line of an inferred fault in the Morrison Formation. Near Gold Basin these intrusions are locally altered and brecciated. The diorite porphyry is argillized, limonite stained, and contains limonite remnants of pyrite.

Intrusions north of Middle Mountain

North of Brumley Creek are several isolated intrusions that are probably allied with the intrusions of North Mountain rather than Middle Mountain. These intrusions include the syenite porphyry body of Brumley Ridge, the diorite porphyry sill of Boren Mesa and the diorite porphyry intrusion of Haystack Mountain. All these intrusions were apparently emplaced in moderately west- or southwest-dipping sediments.

Brumley Ridge intrusion

The noselite syenite porphyry intrusion of Brumley Ridge is apparently a tabular body about 1.2 miles long, about 0.5 mile wide, and locally at least 200 feet thick. The floor of the intrusion is well exposed along its southeastern edge where it is conformable with the underlying northwest-dipping sandstone beds of the Salt Wash Member of the Morrison Formation. Elsewhere the contacts are covered or poorly exposed, but the northwestern edge of the intrusion lies within the Brush Basin Member of the Morrison Formation. The syenite porphyry has a platy structure and its outcrop chiefly consists of a jumble of loose tabular blocks. Hunt, C. B., (1958, p. 344) considered that the entire mass might be out of position because of sliding on underlying fine-grained rocks. Although this possibility cannot be denied, the southeastern edge of the body shows an apparently normal igneous contact and the contact on the northwest edge of the body, though poorly exposed, can be located by float within a few tens of feet. The Brumley Ridge syenite porphyry intrusion is geographically closest to the Middle Mountain group of intrusions, but petrographically it is out of place among the Middle Mountain intrusions, which are entirely diorite porphyry; probably it is related to feldspathoidal dikes of the North Mountain group (Hunt, C. B., 1958, p. 328).

Mill Creek sill

The southwestern tip of the Mill Creek sill is exposed on Boren Mesa in sec. 31, T. 26 S., R. 24 E. Here the sill is locally more than 50 feet thick. It rests on Dakota Sandstone and is overlain by Mancos Shale. According to

Hunt, C. B., (1958, p. 322) the sill is about 2 miles long, 1,000 feet wide and 50 to 100 feet thick. Its northwestern outcrops are in the Morrison Formation near the Warner Ranger station.

Haystack Mountain intrusion

A small part of the Haystack Mountain intrusion is exposed in the northeastern corner of the Lisbon Valley area. Here the intrusion is bordered by extremely steep-dipping (50^{o} to 85^{o}) beds of Dakota Sandstone and the Burro Canyon and Morrison Formations. Within a quarter of a mile of the igneous boundary the sedimentary rocks are only moderately dipping (10^{o} to 20^{o}). Hunt, C. B., (1958, p. 322) has described Haystack Mountain as a laccolith, but Carter and Gualtieri (1965, p. 30) inferred from exposures along the southeast side of Haystack Mountain that the intrusion may be a vertical plug.

STRUCTURAL HISTORY

The Lisbon Valley area was part of a stable region during the early Paleozoic. Cambrian formations are shallow marine sediments deposited on a shelf that bordered the Cordilleran geosyncline of western Utah. The absence of Ordovician and Silurian rocks suggests that for a time the shelf was elevated to a lowland. Subsidence in the Devonian led to a renewal of marine shelf conditions which persisted into the Mississippian. Near the end of the Mississippian or in the earliest Pennsylvanian the shelf was again uplifted; a karst surface was developed on the exposed Mississippian limestone and on this karst surface were deposited the marginal marine sediments of the Molas Formation.

Tectonic activity on the Colorado Plateau during the Pennsylvanian affected the later structural history of the Lisbon Valley area. Northeast and east of the area, the Uncompahgre highland and its southern extension the San Luis highland were uplifted. These highlands and contemporaneous uplifts to the south and northwest of the Lisbon Valley area defined a narrow northwest-trending seaway. Subsidence was greatest in the northern part of the seaway, and owing to restriction of the sea by the uplifts and by sedimentary barriers, an evaporite basin was formed (Fetzner, 1960). This Pennsylvanian structural feature is now represented by the evaporite lithofacies of the Paradox Member of the Hermosa Formation and is termed the Paradox basin, or perhaps more commonly the Paradox salt basin, defined by the salt-bearing lithofacies of the Paradox Member (Kelley, 1958, p. 31).

The floor of the northeastern half of the Paradox basin was also deformed, but the details of this Early Pennsylvanian deformation in the basin are poorly known, for the floor is buried under thousands of feet of sediments. Geophysical studies in the northeastern part of the basin, the region whose surface structures characterize the Paradox fold and fault belt, indicate that locally the basement has been differentially uplifted as much as several thousand feet (Joesting and Byerly, 1958, p. 10; Joesting and Plouff, 1958, p. 89; Joesting and Case, 1960). The trend of these basement uplifts are mostly northwesterly, about parallel to the front of the Uncompahgre highland, but there is also a secondary northeasterly trend.

This Early Pennsylvanian faulting or warping of the basement in the Paradox basin affected the details of the sedimentation of the Paradox Member of the Hermosa Formation and controlled the location of many of the salt anticlines that now characterize the region (Case and others, 1963, p. 114-115). Kelley (1958, p. 35), who integrated drill-hole and geophysical data, suggested that the salt anticlines were underlain by synclines or grabens and that the cores of the salt anticlines were deformed downward as well as upward. Kelley's suggestions are supported by Hite's (1960, p. 88) analysis of the stratigraphy of the saline facies of the Paradox Member:

> "These structures [the salt anticlines] were in fact depositional troughs throughout most of the time of salt deposition. Many of the basal salt beds and intervening shale-anhydrite marker beds are found only in these troughs and wedge out against adjacent subsurface presalt highs. Each new bed added to the trough was downfolded making room for succeeding beds. Original thickness of salt beds deposited in these troughs range from 15 to 990 feet. Further evidence that structurally formed topography along the sea floor influenced deposition in the salt basin is found in certain potash-bearing units. These units show a change of mineralogy or disappear entirely as the enveloping salt bed thins over the underlying positive structure."

The form of the pre-Paradox structural framework is imperfectly known because of the sparsity of drill holes in the area. Neff (1960, p. 62, fig. 8) hypothesized that all the salt anticlines are bounded on one or both sides by northwest-trending highs of Mississippian age. The structural configuration of the Mississippian rocks in the Lisbon Valley area is completely masked by the younter Paleozoic and Mesozoic formations.

The Lisbon Valley area lies near the center of the Paradox basin, a few tens of miles southwest of the area of greatest subsidence and sedimentation, which lay close to and paralleled the front of the Uncompahgre highland in Colorado. The original thickness of the Pennsylvanian evaporite sequence in the Lisbon Valley area totaled several thousands of feet and was greatest along the lines of the subsequent salt anticlines. The evaporites were succeeded by a few thousand feet of marine limestone and terrigenous rocks of Pennsylvanian age. Throughout the Pennsylvanian and Permian the Uncompahgre highland was a continually active tectonic element and supplied clastic material for the Upper Pennsylvanian and Permain rocks in the Lisbon Valley area (Elston and Shoemaker, 1960). Toward the end of the Paleozoic the Paradox basin was uplifted and filled with continental sediments.

Uplifts of the Uncompahgre highland were reflected in the growth of the salt anticlines in the Paradox basin. The salt-cored folds began to form in Middle Pennsylvanian time as shown by local unconformities within and at the top of the Hermosa Formation along salt anticlines east and northeast of the Lisbon Valley area (Elston and Landes, 1960; Elston and Shoemaker, 1960, p. 54). The major growth of the salt anticlines accompanied the Permian uplift of the Uncompahgre and the concomitant deposition of the Cutler Formation. The Paradox Member of the Hermosa Formation was exposed along many of the salt anticlines during deposition of the Cutler Formation (Shoemaker and others, 1958, p. 50). In outcrops near Moab most of the Cutler and all of the Moenkopi and Chinle Formations are locally missing on the east flank of the Moab anticline owing to Permian and possibly to early Mesozoic movements of the salt core (Baker, 1933, p. 77). The southwesterly extension of the Moab salt roll from Spanish Valley to Pine Ridge and the Lisbon-Dolores salt roll probably never breached the surface. By the end of the Paleozoic era the anticlines formed over the rolls of thickened salt were well-developed structural features that were only slightly modified by later tectonic activity and sedimentation.

An unconformity separates the Moenkopi Formation of Early and Middle(?) Triassic age from the underlying Cutler Formation over most of the Colorado Plateau and records a general uplift of the region. Near Moab and along other salt anticlines north and east of the Lisbon Valley area, this unconformity is markedly angular, attesting the continued growth of the salt anticlines. Further evidence of the movement of the salt cores and renewed uplifts of the Uncompahgre highland is recorded by intermember unconformities and arkosic facies of the Moenkopi in the northeastern part of the Paradox fold and fault belt (Elston and Shoemaker, 1960, p. 54). The Moenkopi Formation is absent from the central part of the Lisbon Valley area. The stratigraphic record of other salt anticlines suggests that the Moenkopi wedged out against the topographic high of the Lisbon Valley anticline.

The unconformity at the base of the Chinle Formation of Late Triassic age is of regional extent and records a general uplift with a change of environment and source areas. The discordance at the unconformity is greatest near the salt anticlines and indicates further movement of the salt cores in Triassic time. Minor internal thinning within the Chinle Formation, as near Little Valley, and truncations of contortions at the top of the Chinle by the Wingate Sandstone of Late Triassic age, as along Big Indian Wash, probably attest minor adjustments of the salt core of the Lisbon Valley anticline. In response to these adjustments the basal contact of the Wingate Sandstone is locally disconformable and generally sharper near the Lisbon Valley anticline than elsewhere in the area. Variations in thickness of the Navajo Sandstone and the Kayenta Formation west of Spanish Valley suggest that a topographic high over the southern part of the Moab anticline affected the deposition of these formations in the Late Triassic.

The Jurassic and Early Cretaceous were relatively tectonically quiescent times during which more than 1,000 feet of continental sediments were accumulated in the Lisbon Valley area. The disconformity at the base of the San Rafael Group apparently marks a minor tilting of the region. The preservation of the lower member of the Entrada Sandstone chiefly in synclinal areas may reflect the influence of topographic highs over the Moab and Lisbon Valley anticlines. Along salt anticlines northeast and east of the Lisbon Valley area, pinchouts and thinning of stratigraphic units show that local movements of the salt cores influenced sedimentation throughout most of the Jurassic (Stokes and Phoenix, 1948; Stokes, 1948). Similar thinning of pre-Morrison Mesozoic units has been postulated in the structural contouring of the base of the Morrison Formation near the crests of the Lisbon Valley and Moab anticlines.

The channeled unconformity at the base of the Dakota Sandstone of Late Cretaceous age records a time of vigorous erosion and an eastward tilting of the region. The unconformity has much local relief; but with the following exception, it was not influenced by the salt anticlines. Along Pack Creek the base of the Dakota has a local discordance of several degrees with the beds of the underlying Burro Canyon Formation of Early Cretaceous age; this discordance probably resulted from local movement of the salt core underlying Pack Creek.

The post-Dakota structural history of the Lisbon Valley area is obscure because the Upper Cretaceous formations are not fully preserved and Tertiary sediments are absent. A period of regional uplift, folding and faulting that intensified the salt anticlines and associated structural elements probably began in the Late Cretaceous and extended into the early Tertiary. The igneous intrusions of the La Sal Mountains, the collapse structures of Spanish Valley and the Shay graben perhaps date from the latter part of this period of uplift and folding. Many of the laccoliths of South Mountain are intruded at the top of the salt facies of the Paradox Member of the Hermosa Formation of Pennsylvanian age (Hunt, C. B., 1958, p. 347; Carter and Gualtieri, 1957). The intrusions cut rocks of Late Cretaceous age, but the general configuration of the South Mountain group of intrusions is controlled by the preexisting salt-cored fold that extends from Pine Ridge to Spanish Valley and which is mainly a late Paleozoic structure. The ultimate structural control of the La Sal Mountains intrusives may be much older, for Case and Joesting (1961) pointed out that the intrusions of North Mountain are emplaced near the intersection of northeast- and northwest-trending structural zones, probably faults, in the Precambrian basement.

The Tertiary period was a time of regional uplift, rejuvenation of streams, and vigorous erosion on the Colorado Plateau (Cater, 1955f). The formation of the Spanish Valley syncline probably dates from the Late Cretaceous-early Tertiary regional deformation, but this syncline undoubtedly was intensified by collapse of the underlying Moab anticline in middle and late Tertiary time. Collapse of the anticline probably commenced near Moab, where the Colorado River crosses the fold, and extended gradually towards southern Spanish Valley. The conspicuous joints in the Navajo Sandstone rimming Spanish Valley were probably developed or emphasized at this time in connection with the collapse. The folding of conglomerate beds of probable Pliocene age in Castle Valley (Hunt, C. B., 1958, p. 314) and on the east side of the La Sal Mountains (Carter and Gualtieri, 1965, p. 27) indiates late Tertiary or early Quaternary adjustments of the salt-cored folds northeast of the Lisbon Valley area.

Isolated remnants of early Pleistocene fluvial gravels perched on mesas about 800 feet above the floor of Spanish Valley near Mill Creek show that subsidence and erosion of the valley continued into the Quaternary. Folds and faults have not been detected in the Quaternary deposits in the Lisbon Valley area, but such recent structural features are common in some collapsed salt anticlines of Colorado (Cater, 1955, p. 131).

NATURAL RESOURCES

The Lisbon Valley area has a long and fairly continuous record of mineral production. Copper deposits were discovered in the central part of the area in the early 1880's and since then have been worked sporadically. Some uranium-vanadium deposits were mined on a small scale for their radium content beginning about World War I and into the early 1920's; in the 1930;s and 1940's these deposits were mined chiefly for their vanadium content. After World War II, many new uranium-vanadium deposits were discovered and developed so that the area has become an important uranium-vanadium mining district. Manganese and gold have been found in noncommercial quantities.

Several decades of exploration for petroleum were rewarded by a major discovery in the central part of the area in 1960. The new field has been extended by several offset wells.

Nonmetallic resources, except for petroleum, have been little exploited in the Lisbon Valley area. Deeply buried potash deposits, however, are known in the central part of the area and are a significant potential mineral resource.

No mention of the natural resources of the Lisbon Valley area is complete without a brief tribute to its magnificent scenery. Most of the region is a flat-lying desert cut by narrow, steep-walled canyons and studded with buttes and mesas, which are rimmed by milticolored rock cliffs. The desert lands are at their best in the windless days of late spring and early fall, but the great relief of almost 8,000 feet within the area offers a variety of environments. Especially in midsummer the forests, streams, and lakes of the La Sal Mountains form a pleasing contrast with the surrounding desert lands.

URANIUM AND VANADIUM

Uranium and vanadium deposits in the Cutler Formation

The uranium-vanadium deposits in the Cutler Formation of the Lisbon Valley area are all on the southwest edge of Big Indian Valley northwest of Big Indian Rock. Most of the deposits lie within about 100 feet of the unconformity separating the Culter from the overlying Chinle Formation. The deposits in the Cutler are in a part of the Big Indian mining district also characterized by large uranium deposits in the Chinle, but the spatial correspondence is not exact. As presently known, none of the deposits in the Cutler are immediately overlain by ore bodies in the Chinle.

The deposits in the Cutler consist of oxidized uranium and vanadium minerals irregularly disseminated through arkosic sandstone. These deposits were found by surface prospecting and are developed by short adits or inclines, rim cuts and trenches. The average grade of ore is low, and for this reason, no full-scale mining of these deposits has been done since 1954. Most of the deposits are small, but a few suggest sizeable reserves of low-grade ore that may be of future economic interest.

Character of the host rock

The uranium-vanadium deposits in the Cutler Formation are in lenses, commonly several hundred feet long and less than 20 feet thick, of light-colored sandstone near the top of the formation. The upper and lower boundaries of the lenses of sandstone are sharp, but edges of the lenses are commonly gradational into surrounding mudstone.

The mudstone is dominantly dark grayish red and consists of various proportions, but lighter shades of red and gray also occur. It is micaceous, poorly indurated, obscurely bedded, and tends to part along micaceous laminae. Only in a few places is mudstone visibly mineralized or anomalously radioactive.

The sandstone lenses are channel deposits; the surrounding mudstones are flood plain deposits.

The lenses appear to be elongated southwesterly and probably were deposited by streams flowing from part of the ancestral Uncompahgre highland northeast of the Lisbon Valley area.

The sandstone of the mineralized lenses is poorly sorted, conglomeratic, and very coarse to fine grained, grading in places to mudstone. Feldspar is the dominant detrital mineral, commonly making up about 30 to 65 percent of the grains. About one-third of the feldspar is microcline; the rest plagioclase, most of which is altered to sericite. Quartz constitutes about 15 to 35 percent of the sandstone. Much of the quartz occurs as particles of fine-grained quartzite. Mica, chiefly biotite but including chlorite and muscovite, generally accounts for about 4 to 20 percent of the detrital sands grains. Clay mineral aggregates make up 10 to 30 percent of the grains. Pebbles in conglomeratic sandstone range from about one-eighth of an inch to one inch in diameter; most are about one-eighth to one-fourth of an inch in diameter. The pebbles consist mainly of chert, feldspar, fine-grained granite, schist and quartzite, derived from Precambrian rocks exposed in the ancestral Uncompahgre highland. Sparse to common pebbles of dark-red mudstone are as much as several inches across and were derived from the Cutler itself.

The ore-bearing sandstone is generally friable, but induration differs from place to place within a lens without apparent system. The principal cement is calcite; clay binding and iron oxides cement are also important. Most lenses are made up of obscure horizontally bedded units and a few small sets of crossbeds.

Color

Mineralized sandstone is of a lighter shade than barren sandstone and is mottled with darker colors in contrast to the more uniform coloring of barren sandstone. The prevailing color is light brown, more precisely very pale orange (10YR8/2), with mottles of purplish gray, ranging from pale red purple (5RP6/2) to grayish red purple (5RP4/2), and of dark red ranging from dark reddish brown (10R3/4) to very dusky red (10R2/2). The mottles range from irregular small spots a fraction of an inch across to blotches several feet in diameter. The boundaries of the mottles are sharp and frequently crosscut individual grains. The spots and patches of purplish gray and dark red are, for the most part, distributed randomly without apparent control through the light-brown sandstone. Some spots and blotches are strung out parallel to a bedding plane and some are centered on mudstone pebbles.

Iron as the ferric oxide hematite is the chief coloring agent. In the light-brown sandstone hematite occurs very sparsely as minute particules, that rarely coat grains. In the purplish-gray sandstone the hematite occurs as minute particules that form microcrystalline coatings on each clastic grain. In dark-red sandstone the hematite occurs as fine to medium flakes mixed with clay minerals, which together form an interstitial filling. Ore minerals are most abundant in the light-brown sandstone and are least abundant in the dark-red sandstone. Dark red or dark purplish gray probably was the original color of the mineralized sandstone lenses. Many specimens suggest that the purplish gray is an alteration of the dark red and that the light brown is an alteration of the purplish gray. The association of mottled sandstone with ore suggests that the color changes were coincident with the deposition or oxidation of the uranium and vanadium minerals.

The amount of sandstone altered to light brown seems to be a rough index of the intensity of mineralization. Thus, light-brown sandstone is dominant at the Big Buck and Big Indian deposits which are judged to be substantially larger and of higher average uranium content than the Calico Dike deposit where purplish gray is dominant.

Mudstone within and around the mineralized lenses in the Cutler Formation rarely shows color alterations. Mudstone adjacent to the mineralized sandstone lenses is dominantly dark red. Some pebbles of mudstone in mineralized sandstone, especially those impreganted with ore minerals, are latered to greenish gray.

Mineralogy

The chief ore minerals of the uranium-vanadium deposits in the Cutler Formation along Big Indian Valley are carnotite, bequerellite, vanadium hydromica, and volborthite or calciovolborthite. Probably present are pascoite or hummerite, tyuyamunite, uranophane, and uraninite. Copper oxides and, less commonly, copper sulfates are locally present.

Many of these minerals can be identified positively only by their X-ray powder pattern, but unless otherwise credited, the identifications are based on the more obvious physical and optical properties supplemented by a few simple chemical tests suggested by Weeks and Thompson (1954). The formulas given in the text for the uranium and vanadium minerals are also from Weeks and Thompson (1954).

Uranium minerals

Carnotite ($K_2(UO_2)2(VO_4)2.1\text{-}3H_2O$) occurs as bright-yellow powdery material loosely attached to sand grains and commonly intermixed with equally abundant uranium hydromica. These two minerals generally make up more than 90 percent of the ore minerals.

Tyuyamunite ($Ca(UO_2)_2(VO_2)_2.7\text{-}10\text{-}1/2H_2O$), the calcium analog of carnotite, has not been positively identified from these deposits, but because it is common in similar oxidized uranium-vanadium ores in other formations it is probably a component of some of fine-grained yellow uraniferous material in calcareous parts of the mineralized sandstone.

Becquerelite ($2UO_3.3H_2O$) according to Dix (1953a, p. 11) is disseminated with carnotite in the sandstone and also occurs with carnotite in mineral bands in "concretions" (selectively impregnated mudstone pebbles). The becquerelite occurs in the sandstone in small amounts as yellowish-orange aggregates of microcrystalline plates surrounded by powdery yellow carnotite.

Uranophane ($Ca(UO_2)_2Si_2O_7.6H\ O$), commonly a very finely fibrous yellowish mineral, is listed tentatively as a constituent of the Cutler ores by Dix (1953a).

Uraninite (UO_2) was tentatively identified by Abraham Rosenzweig some radioactive particles in fine-grained sandstone as "sooty uranite(?)" (Dix, 1953a, fig. 6). The uraninite(?) was associated with particles of carnotite and bequerellite. Uraninite is also reported to occur in sandstone about 40 feet below the top of the Cutler Formation near the face of the haulage drift of the Little Beaver mine (N.E. Salo, U.S. Atomic Energy Commission, oral communication).

Vanadium minerals

A dark-gray, very finely flaky vanadium mineral is a chief constituent of the Cutler ores. It fills interstices between grains, is mixed with clay minerals, and is closely associated with carnotite. In this report the dark-gray vanadium mineral is referred to as vanadium hydromica though it may be roscoelite or a mixture of the two minerals and perhaps includes some vanadium oxides. Vanadium hydromica is closely allied to roscoelite $(Al, V)_2(AlSi_3)(K, Na)\ O_{10}(OH, F)_2$; hydromica contains less potassium and is more hydrated than roscoelite (Weeks and Thompson, 1954, p. 55).

Rare, bright-orange efflorescences on some mine exposure of sandstone impregnated with vanadium hydromica are probably pascoite ($Ca_2V_6O_{17}.11H_2O$) or hummerite ($K_2Mg_2V_{10}O_{28}.16H\ O$). Both of these vanadates are soluble in water.

Copper minerals

Malachite ($Cu_2CO_3(OH_2)$), the green copper carbonate, is very sparse in most of the Cutler ore deposits but in a few, such as the Lackey No. 4, it is locally dominant. Malachite occurs chiefly as coatings of sand grains and less commonly as isolated grains. Commonly it is closely associated with vanadium hydromica, but carnotite is generally sparse in the malachite-rich rock.

Azurite ($Cu_3(CO_3)_2(OH)_2$), the blue copper carbonate, occurs as sparse minute isolated grains.

Volborthite ($Cu_3(VO_4)_2.3H_2O$(?) or calciovolborthite ($(CuCa]_2(VO_4)\ (OH)$) is sparse to common as yellowish-green crusts on sand grains in rocks with abundant malachite and vanadium hydromica.

Gangue minerals

The common rock-forming minerals, such as feldspar, quartz, mica, and clay minerals, and rock fragments of granite, quartzite, and schist make up the bulk of the host sandstone in the Cutler. Except for sericitization of the feldspar, which preceded the uranium-vanadium mineralization, these grains appear unaltered.

Most of the minor gangue minerals--hematite, calcite, barite, limonite, and magnetite--were originally detrital but have been partly redistributed during mineralization or oxidation. Hematite (Fe_2O_3) is very sparse in mineralized light-brown sandstone where it occurs chiefly as microscopic particles on a few sand grains. Calcite ($CaCO_3$), the common cement, is irregularly distributed in ore-bearing sandstone. Typically it occurs as interstitial fillings and grain coatings and small particles in clayey material between sand grains. Barite ($BaSO_4$) occurs in small amounts in the sandstone, and according to Dix (1953a, fig. 6) in concretionary centers of mineralized mudstone pebbles. Limonite, a mixture of iron hydroxides, occurs sparingly in the light-brown sandstone as a stain on sand grains. Frequently it is most abundant in or around small aggregates of vanadium hydromica.

Interrelations of minerals

Vanadium hydromica and most carnotite occupies the position of the cementing material. Commonly the boundary between vanadium hydromica and the clay binding is not sharp as if only part of the clay minerals were converted to vanadium hydromica. Some vanadium hydromica and carnotite invade altered feldspar of the host sandstone and partly replace the sericitized portion of the grain. Most feldspar and quartz grains adjacent to ore minerals have smooth borders or show only minor corrosion. Carnotite surrounded by hematite occurs sparsely in red sandstone, but vanadium hydromica is apparently absent in the red rock. Carnotite also commonly occurs adjacent to shreds of magnetite without vanadium hydromica. The copper minerals, particularly malachite and volborthite or calciovolborthite, are more frequently mixed with vanadium hydromica than with carnotite.

Age relations of the ore minerals are ambiguous and are perhaps of little significance in these oxidized deposits, because the oxidation probably proceeded at different rates in different parts of the same deposit. Furthermore, assuming that the minerals were deposited in their unoxidized state, the original relations may be completely masked by the subsequent oxidation. The general impression gained from study of thin sections of the ore is that for the most part the vanadium mica and the carnotite were contemporaneous but that the deposition of carnotite persisted longer.

Geologic habits of ore

[1]Ore occurs in the Cutler Formation as irregular dark-gray and yellow spots, streaks, patches, and disseminated grains of uranium and vanadium minerals in sandstone. Some mudstone pebbles are impregnated with ore minerals, but most mudstone layers are barren.

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[1]"Ore" in the uranium-vanadium sandstone-type deposits of the Colorado Plateau at the time of mapping was commonly arbitrarily defined as mineralized rock at least 1.0 foot thick with a minimum average grade of 0.10 percent U_3O_8 or 1.0 percent V_2O_5. Mining practice, in most mines in the Lisbon Valley area in the 1950's, was to keep the minimum grade of ore at 0.20 percent U_3O_8, because the base price per pound of U_3O_8 contained in the ore decreases below 0.20 percent according to U.S. Atomic Energy Comm. domestic Uranium Circular 6, amended Oct. 9, 1953.

As a matter of convenience, in this report no thickness cutoff of ore is implied. In the absence of other analytical data, rock whose radioactivity exceeds 0.1 milliroentgen per hour is assumed to be of ore grade.

The dark-gray spots of ore minerals are dominant and generally range from a fraction of an inch to about an inch in diameter and consist of dark-gray vanadium hydromica with cores of admixed yellow uranium minerals, chiefly carnotite and becquerelite. Locally the spots of ore minerals are aligned but only rarely along a distinct bedding plane. Aggregates of dark spots grade insensibly into uneven streaks and thin layers, as much as 1 inch thick and a foot long. The dark spots, streaks, and layers are commonly scattered through the mineralized sandstone, but in places they are clustered in patches, a few feet across, which generally contain abundant yellow uranium minerals and a few grains of green copper minerals. Carnotite and becquerelite also irregularly impregnate patches of sandstone with little or no vanadium mica and form yellow spots irregularly around the dark-gray spots. Some isolated grains of carnotite occur randomly in the sandstone. In the cupriferous deposits the copper minerals, chiefly malachite, tend to be mixed with vanadium hydromica in thin layers parallel to bedding.

Mudstone pebbles impregnated with ore minerals are conspicuous where present. They are more abundant in the Big Buck and Big Indian incline than in other deposits in the Cutler. The mineralized pebbles generally are flattened and range from about 0.5 to 4 inches in diameter. The pebbles occur mostly in conglomeratic coarse-grained sandstone, but they occur sporadically in medium- to fine-grained sandstone. The mineralized pebbles and some barren pebbles in mineralized sandstone are altered to light gray or light grayish green; a few such pebbles have traces of the original red coloration near their centers. The mineralized mudstone pebbles typically have a concentric dark-gray band rich in vanadium hydromica that parallels the edge of the pebbles. Yellow uranium minerals impregnate the outer skin of the pebble and the surrounding sandstone; they are sparsely disseminated in the dark-gray band and also form minute yellow bands which divide the dark-gray band in several parts. The vanadium hydromica grades out toward the center of the pebble, but the yellow uranium minerals persist irregularly to near the center. The centers of the pebbles are generally practically barren of ore minerals, but a few, as noted by Dix (1953a, p. 13), contain abundant barite. The uranium-vanadium content of the mineralized mudstone pebbles is much higher than the average mineralized rock in the Cutler, but except in some hand-sorted ore shipped from the Big Buck and Small Fry deposits, they, are too sparse to be of economic importance.

The appearance of the ore--spots, streaks, and patches of dark-gray and yellow ore minerals in the mottled light-brown host sandstone--possesses great irregularity in detail, but overall homogeneity. Variations in the metal content of ore, shipped from the same deposit, seem to be mainly the result of variations in selectivity of stockpiling.

Distinct ore bodies with well-defined boundaries within the deposits are lacking. Edges of ore are hard to define visually and the average radioactivity of the mineralized rock, as measured with a Geiger counter, rarely shows sharp cutoffs. Most lenses of mineralized sandstone are anomalously radioactive throughout the limits of ore must be defined by arbitrary grade and thickness cutoffs.

The shape of ore deposits conform to the shape of the lens of the host sandstone. Indeed, the whole lens is commonly anomalously radioactive, and in this sense the deposits can be said to be practically coextensive with the host sandstone. Considering only rock at least 1 foot thick with a grade cutoff of 0.1 percent U_3O_8, the deposits are broadly tabular or lenslike, and occupy only a small part of the host lens of sandstone. Radioactivity surveys and observation of visible ore minerals suggest that most of the ore deposits consist of many vaguely defined irregular clusters, a few feet across, of spots and patches of uranium and vanadium minerals. The edges of the ore deposit are marked by a diminution in size and frequency of these clusters.

The irregular distribution of uranium and vanadium minerals in the host sandstone lenses and the consequent arbitrary nature of the boundaries of the ore deposits in the Cutler makes estimation of the size and grade of ore bodies difficult. Using the definition of ore given previously, the following estimates can be made based on production records, samples collected by us and by C. A. Rasor (U.S. Atomic Energy Comm., written communication, 1949), and measurements of radioactivity with a Geiger counter and scintillometer in and around the mine workings: The maximum thickness of ore is about 8 feet (Big Buck miner and Big Indian incline). The maximum width of ore is probably exposed at the Big Buck workings, where it is about 400 feet. The longest mine working in ore perpendicular to the outcrop is an incline only 260 feet long on the Big Buck property; it seems reasonable to infer that this ore body is elongated along the trend of the host sandstone and may attain 1,000 feet in length. The size of the deposit is partly a function of the size of the lens of host sandstone. The three largest deposits in the Cutler Formation of the Lisbon Valley area are probably the Big Buck, Big Indian, and Small Fry deposits, all of which are in relatively thick and continuous lenses as compared with other mineralized sandstones in the Cutler.

The grade of mineralized rock differs greatly in hand samples, but in bulk differences of grade are small. The maximum grade of shipments of 10 tons or more from the Cutler deposits was 0.34 percent U_3O_8 and 0.64 percent vanadium. The average grade of all ore-grade rock shipped from the Cutler, amounting to less than 1,000 tons, is about 0.2 percent U_3O_8 and 0.3 percent V_2O_5. Calcium carbonate content of the Cutler ores differs greatly from shipment to shipment and perhaps on a small scale from mine to mine, but calculations by C. A. Rasor (U.S. Atomic Energy Comm., written communication, 1949) on the 1948 production from the Big Buck mine suggests that the average $CaCO_3$ of the Cutler ores content is about 5 percent.

The vanadium content of the mineralized rock is generally too low to qualify as vanadium ore. Only a few small, probably hand-sorted, shipments of ore have assayed above 1.0 percent V_2O_5. The vanadium-uranium ratio (V_2O_5:U_3O_8) of the ore is fairly constant, ranging from about 5:1 to 1:1. Radioactivity surveys of the deposits that have little or no recorded production suggest, however, that some of the smaller deposits probably have a higher vanadium-uranium ratio and significantly lower uranium content than those with recorded production.

Surveys of the radioactivity of mine walls show a general increase in radioactivity with depth, but this increase in radioactivity is not related to increase in uranium content of the host rock. Away from the mine portals the inclines are progressively less well ventilated; accumulated radon, a radioactive gas, causes the Geiger counter to give higher readings than the same grade rock at the outcrop. In the Big Buck and Small Fry inclines samples from near the face have the same range of radioactivity as samples from near the portal when both were measured outside the mine. No general increase in grade or thickness of ore with increasing depth has been detected in these deposits.

Localization

The most obvious factor affecting the localization of the uranium-vanadium ore deposits in the Cutler Formation is the host lenses of fluvial sandstone in the upper part of the formation. Ore has not been found in mudstone units in any part of the formation, in sandstone lenses in the middle or the lower part of the formation, or in fine-grained eolian sandstone near the top of the formation.

The uranium-vanadium deposits tend to be in the thicker parts of the host lenses of sandstone. This tendency is especially well marked at the Calico Dike prospect, where the deposit is restricted to a part of the lens five or six times thicker than the part of the lens marginal to the ore deposit. In most of the ore-bearing lenses, the lateral thinning is gradual, and there is no abrupt thinning at the margins of the ore deposit.

The internal variation of lithology in a host lens of sandstone has little influence on the distribution of radioactive rock of probable ore grade. Mudstone layers and lenses are mostly barren, though some mudstone pebbles and seams are well mineralized. Differences in grain size in the host sandstone do not generally delimit differences in radioactivity. Marked local differences in induration of the host sandstone are common but have no consistent relation to ore. Although some streaks of ore minerals follow horizontal or crossbedding planes, most ore shows no relation to sedimentary structures except to the contact of the host sandstone with the underlying and overlying mudstone units.

The host lenses of sandstone and the Cutler Formation, as a whole, are characterized by a lack of visible carbonaceous material. In this characteristic the Cutler differs significantly from most important ore-bearing parts of the Morrison and Chinle Formations (Wright, R. J., 1955). A single small piece of limonite-stained coalified wood, about 3 inches long and 1 inch wide, was found in the back of the 1,400-foot adit on the School Section 2 property; this was the only carbonaceous material seen in any of the uranium-vanadium deposits in the Cutler Formation. Thus, carbonaceous material is not a significant factor in the localization of the ore deposits in the Cutler.

Joints are common in the host rock but rarely influence the distribution of ore. Most joints are about parallel to the northwest strike of the beds and dip very steeply northeast. Joints are less conspicuous and probably less common in the deeper parts of the workings. In general, the joints show no influence on the distribution of radioactive rock, and the joints are evidently younger than the ore. A few fracture surfaces are partly coated with ore minerals, but perhaps no more than any random plane through a deposit. Minor post-ore movement has been detected on several of the joints in the Big Indian incline. In this same mine one joint about 70 feet from the portal has apparently served as a conduit for solutions which removed radioactive minerals; possibly the effect is due more to better aeration of the wall than leaching along this joint. Isachsen (1954, p. 101) noted that in the Small Fry mine, mineralization had been more intense adjacent to joints. A radioactivity survey of this mine shows that one irregular patch of radioactive rock about 100 feet from the portal has one boundary roughly paralleling a nearby joint. Such associations and correspondences are infrequent, and in general, no genetic relation can be demonstrated between joints and ore.

Proximity of uranium-vanadium deposits in the Cutler to the ore deposits in the overlying Chinle Formation has been an important factor in the localization of the Cutler deposits, but this factor is difficult to evaluate. The full extent of the deposits in the Cutler is not known, but the Big Buck, the Small Fry, and the mines and prospects between these two deposits are not more than several hundred feet from mineralized rock in the lower Chinle. Deposits southeast of the Big Buck, such as the Lackey No. 4 and Carrot, are far from any known ore-grade material in the Chinle; but it is impossible to determine whether they were once near Chinle ore deposits now eroded away. All that can be said definitely is that all the Cutler ore deposits lie within a part of the Big Indian mining district characterized by large uranium deposits in the Chinle Formation.

Suggestion for prospecting

The uranium-vanadium deposits in the Cutler Formation in the Lisbon Valley area are presently of little economic interest. Since 1954 these deposits have mostly lain idle because the ore is low grade and difficult to mine selectively. These deposits in the Cutler are dwarfed by nearby large medium- to high-grade uranium deposits in the Chinle Formation and also by some deposits in the Morrison Formation.

If economic conditions ever warrant further exploration of the uranium-vanadium deposits in the Cutler Formation, first efforts should be directed to developing the known deposits. Exploratory drilling, perhaps by deepening some preexisting holes that tested the basal Chinle, might be the next logical step. Surface prospecting of mottled sandstone lenses between Big Indian Rock and the Wood Ranch in the southeast part of the Big Indian mining district, may also be merited, because the geology permits ore deposits in this part of the area. The wide stratigraphic distribution of uranium deposits within the Cutler Formation 20 to 30 miles west and northwest of the Lisbon Valley area (Dix, 1953b; Hinrichs, 1958) suggests that sandstone units in the lower part of the formation should also be examined. The Cutler Formation around South Mountain is mostly covered by superficial debris, and though this part of the Lisbon Valley area is characterized by a general paucity of ore deposits, it is relatively little prospected and merits further attention.

Mines and prospects

The mines and prospects in the Cutler Formation of the Lisbon Valley area were mostly studied in 1957. Developments after this date are not described.

Each lens of uranium-bearing sandstone is here considered a mineral deposit, though material of ore grade and thickness may make up only small portions of the lens. All the mines and prospects described separately below are in separate lenses with the possible exception of the Lackey No. 4 and GCGV No. 1 prospects.

Mineralized rock is easily recognized in the Cutler uranium deposits, but ore-grade material is not readily discriminated by eye. Rock with a radioactivity of 0.2 or more mr/hr at the outcrop is probably of ore grade, but rock with a similar radioactivity underground may be nearly barren. In all these small workings the radioactivity increases away from the portal, probably chiefly as the result of accumulated radon gas in the less well ventilated parts of the workings and to the mass effect of the mineralized rock. The Geiger counter is thus a useful and necessary tool in outlining local differences in radioactivity that indicate local differences in uranium content. Differences in uranium content between one part of a mine and another or between mines, however, are obscured by factors that determine the general local level or "background" of radioactivity. Differences in grade of ore between different parts of the same deposit or between different deposits must be estimated on the basis of abundance of visible ore minerals, analyses of samples, and production data.

Carrot prospect

The Carrot claims are in rocky flats about a quarter of a mile north of Big Indian Rock. Development consists mainly of short trenches that are inclined about 12°, paralleling the dip of the beds. In several small areas the overburden has been stripped off the mineralized bed. Several tons of low-grade uranium-vanadium-bearing rock are piled near the workings, but there is no recorded production from these claims.

The mineralized bed is a sandstone lens lying an estimated 100 feet below the Chinle-Cutler contact. The sandstone is medium grained, yellowish gray, and crossbedded. The ore minerals, dark-gray vanadium mica and a bright-yellow uranium mineral (probably carnotite), are generally sparse and occur mostly as small irregular spots and as isolated grains scattered through the sandstone. In a few places they are concentrated near exposed surfaces as if they had been concentrated by recent leaching. Azurite and malachite are present in trace amounts.

Lackey No. 6 prospect

The Lackey No. 6 and nearby claims, which include the Lackey No. 5, GCGV, GCGV No. 1, GCGV No. 2 and others, are in rocky flats and cliffs along the southwest side of Big Indian Valley northwest of Spiller Canyon. Two trenches about 40 feet long and 4 to 8 feet deep and wide have been dug into the uranium-bearing sandstone on the Lackey No. 6 claim. The top of the mineralized beds has been exposed by bulldozer work near the trenches. A few tens of tons of low-grade uranium ore are recorded as coming from the "Lackey" property. Some of this production probably came from the Lackey No. 6 claim.

The uranium-bearing bed is a lens of dark-purplish and brownish-red medium- to coarse-grained arkosic sandstone. Near ore the sandstone is bleached to a pale brown. The rock is composed of subangular to angular grains of colorless quartz and feldspar, and orange and gray chert with abundant black and dark green mica. Pebbles and chips of dark reddish- and purplish-gray mudstone are sporadically distributed through the sandstone. Near ore these mudstone pebbles and chips are commonly pale green. The host lens is only about 6 feet thick near workings and pinches out several hundred feet southeast of the prospect, where another sandstone lens of similar lithology occurs at a slightly lower horizon. It is about 250 feet below the top of the formation.

Carnotite and vanadium hydromica, locally with sparse malachite and pyrite, form small spots and thin layers, a few inches thick and long. The spots and layers of ore minerals are scattered through pods, a few feet thick and a few tens of feet in diameter, of light-brown sandstone, that are sporadically distributed through the ore-bearing lens. Less commonly the ore minerals occur as patchy coatings on small irregular joints.

Lackey No. 4 prospect

The Lackey No. 4 workings are on a bench on the southwest side of Big Indian Valley about a quarter of a mile north of the head of Spiller Canyon. Development consists of several small pits and trenches; in places overburden has been scraped off the ore-bearing bed. A few tens of tons of low-grade uranium ore are recorded as coming from the "Lackey" property. Some of this ore probably came from these workings.

The ore-bearing lens is chiefly a fine- to medium-fine-grained sandstone composed of clear quartz and feldspar, pink chert, biotite and muscovite, and rare reddish mudstone chips. It lies about 60 feet below the top of the Cutler. Carnotite and vanadium hydromica occur as thin wavy streaks and small spots less than an inch in diameter. Malachite is common to abundant. The radioactivity of the rock in place was about 0.2 mr/hr compared to a general background radioactivity of about 0.05 mr/hr. The upper part of the sandstone lens is generally more radioactive than the lower part.

GCGV No. 1 prospect

The GCGV No. 1 claim is on the lower part of the cliffs bordering the southwest side of Big Indian Valley northwest of Spiller Canyon. An adit about 35 feet long and 8 feet wide and high has been driven into an ore-bearing sandstone. About 60 feet northwest of the adit a small open cut has been dug along the rim. No production is recorded from this claim, but several tens of tons of uranium ore reported from the "Lackey property" probably includes production from the GCGV No. 1 adit.

The ore-bearing sandstone lies about 160 feet below the top of the Cutler Formation. The sandstone is poorly sorted, very fine to medium-grained, and composed of subangular clear quartz and feldspar, biotite, and abundant colored accessory minerals. Small irregular clasts of dark-grayish-red mudstone, partly altered to light grayish green, occur sporadically in the sandstone. The sandstone is irregularly blotched dark grayish red, grayish purple, and pale brown.

Carnotite, vanadium hydromica, and less commonly, malachite occur sporadically as small spots and as ill-defined layers and patches in the sandstone. Most of the ore minerals are in the light-brown sandstone; some is in the grayish-purple sandstone; none was observed in the dark-grayish red sandstone. The basal few feet of the ore-bearing lens contain most of the ore minerals. The ore-bearing lens is about 10 feet thick near the adit and is more than 350 feet wide.

Big Buck (Cutler) mine

The Big Buck workings in the Cutler Formation lie high on the southwest rim of Big Indian Valley about 3 miles south of the Big Indian copper mine and half a mile north of the Mi Vida mine. A dirt access road to the workings branches off the Big Indian Valley road about 2 miles southeast of the Big Indian copper mine.

The claims named Big Buck, which include the Big Buck Nos. 4A, 5-8, 8A, 9, 9A, 10, 10A, 11, 11A, 12 and 12A, extend along the rim of the Big Indian Valley about 1-1/2 miles southeast from the south border of sec. 2, T. 30 S., R. 24 E. These claims enclose a strip of ground, averaging about 1,400 feet wide, that is underlain by the uranium-ore-bearing Chinle Formation. The workings in the Cutler Formation, which are discussed here, lie mostly on the Big Buck Nos. 5 and 6 claims, and are referred to as the "Eldon lease" or as the "old Big Buck workings" to distinguish them from the other mines and prospects in the Chinle Formation on the Big Buck claims.

History

The following note on the location and ownership of the Big Buck claims is drawn from Dare and Durk (1956, p. 5): "The Big Buck claims were located in 1948, by Donald Hayes of Moab, Utah, in partnership with James Bentley and J. W. Brewer. Hayes bought out his partners' interest in the same year and formed a partnership with Donald Adams of Monticello, Utah. The second partnership was later expanded when a 5-percent interest was sold to Edward Saul and to Joseph Adams. The claims were sold to Standard Uranium Corp., in July 1954."

According to C. A. Rasor (U.S Atomic Energy Comm., written commun. 1949), who examined the Big Buck property in November-December 1948, mining began in the summer of 1948. The outcrop of the ore-bearing sandstone was cut back and five short adits, the longest about 30 feet, were driven into the sandstone. Between August 3 and November 4, 1948, many hundreds of tons of rock were shipped to the Monticello, Utah, mill; but part of the shipments proved to be less than ore grade (less than 0.10 percent U_3O_8).

Apparently, the prospect lay idle in 1949 and 1950; but more than 100 tons of low-grade ore were shipped in 1951, and a few tens of tons of low-grade uranium ore were shipped by the same operators in 1952. Mining operations were suspended at this property in September 1952 (Dix, 1953a, p. 5). The underground workings were extended in 1956 and 1957, but apparently little ore has been shipped from this property since 1952.

Although the total production of this mine is small--especially as compared with the later production from the district--the historical importance of this deposit is large. The operation of this mine called attention to the possibility of uranium deposits in units other than the Morrison Formation at a time when interest was mainly focused on the main uranium-vanadium producing area in the Morrison Formation in southwestern Colorado. According to Dix (1953a, p. 5), Charles A. Steen of Moab, Utah, was drilling for ore horizon in the Cutler Formation on claims adjacent to the Big Buck group when he discovered a large ore body in the overlying Chinle Formation. Steen's discovery in turn led to the present continuing development of the Big Indian mining district.

Development and production

The workings in the Cutler formation on the Big Buck Nos. 5 and 6 claims in 1957, consisted principally of two inclines, about 35 feet apart, driven normal to the outcrop and inclined about 12^{o}, about parallel to the dip of the beds. The northwestern incline is about 80 feet long; the southeastern incline is about 275 feet long. In addition to the main inclines there are a number of short adits 10 to 25 feet long and several small cuts along the rim.

Total production of the mine probably amounts to less than 1,000 tons of ore-grade rock. The grade of ore shipped ranged widely and was probably dependent on the selectivity of mining. Assays of the shipped ore shows that vanadium content, as percent V_2O_5, generally ranged between one and two times the U_3O_8 content.

Geology

Two ore-bearing lenses of sandstone in the Cutler Formation are present at nearly the same horizon about 90 feet below the top of the Cutler Formation on the Big Buck Nos. 5 and 6 claims. The lenses overlap near their edges for a distance of about 40 feet. The northwestern lens has only a few mineral occurrences on the Big Buck claims, but several hundred feet northwest on the School Section 2 lease it has been mined from the Big Indian (Cutler) incline.

The main ore-bearing lens on the Big Buck property is about 450 feet long. It is about 15 feet thick near the main inclines but thins southerly to about 5 feet thick and pinches out to the north near the boundary of section 2. The width of that part of the lens that is 10 feet or more thick is about 300 feet.

The main ore-bearing lens is chiefly light grayish brown with purplish-gray and reddish-brown streaks and blotches. Mudstone overlying the sandstone lens is reddish brown with a few grayish streaks. Mudstone underlying the sandstone is purplish brown.

The sandstone is poorly sorted, fine to medium grained, medium to coarse grained, and coarse grained with scattered pebbles, ranging from about 2 mm to 40 mm in diameter and averaging about 8 mm in diameter. The sandstone is composed of subangular to angular, clear quartz and feldspar, pink chert and feldspar, biotite and minor muscovite. The scattered rounded to subangular pebbles consist of clear quartz, pink feldspar, granite, mica schist, and indurated claystone. Thin beds and seams of dark-grayish-red to purplish-red sandy mudstone lie within the sandstone lens. The rock, cemented with calcite, ranges from well indurated to friable. The lens is obscurely cross-stratified in medium-scale trough sets of low-angle cross-beds. Steep northeasterly dipping joints are common at the outcrop. Downdip within the adits, however, the joints become less abundant; none were detected more than 80 feet down any adit from the portal.

The ore minerals include bright-yellow uranium minerals and a dark-gray vanadium mineral. Dix (1953a, p. 2) reported that the following minerals were identified by Abraham Rosenzweig in a specimen from the Big Buck Cutler deposit: carnotite, becquerelite, sooty uraninite(?), and small particles of copper-uranium minerals. The dark-gray vanadium mineral is probably vanadium hydromica.

The ore minerals occur as disseminated grains and in irregular spots generally about 0.5 inch to 3 inches in diameter. Commonly the spots are roughly grouped into clusters not more than 1 or 2 feet across. In places the clusters are concentrated into layers but through most of the mine they are randomly scattered. Dix (1953a, p. 11 and fig. 6) called attention to the presence of concretion-like nodules 0.5 inch to 4 inches in diameter. These consist of rings of differing concentrations of uranium and vanadium minerals and sparse copper minerals impregnating fine-grained sediments with a barite-rich core. Specimens of these concretion-like nodules found in the Big Buck workings in 1957 suggest that they are selective impregnations around and in mudstone pebbles.

An increase in radioactivity down the incline is aparently due to radon concentration away from the well-ventilated part of the mine. Judging from exposures of ore minerals, the rock is randomly mineralized all along the incline. Testing specimens from along the incline with a counter outside the mine indiated no systematic increase in radioactivity of samples from down the adit. Neither joints nor differences in lithologic features influence the distribution of the ore within the sandstone lens. Away from the area of the workings, however, visible ore minerals become more sparse and the radioactivity decreases. The uranium and vanadium minerals seem to be concentrated in the thicker part of the lens.

Big Indian incline (Cutler) prospect

The Big Indian incline in the Cutler Formation is in school sec. 2, T. 30 S., R. 24 E. on the southwest rim of Big Indian Valley about 2.8 miles south of the Big Indian copper mine and several hundred feet northwest of the Big Buck workings in the Cutler.

The incline is about 8 feet wide and high and about 100 feet long; it has been driven southwesterly, about normal to the rim, and is inclined about 11°, paralleling the dip of the beds. About 125 feet southeast of the incline and about 5 feet higher in the lens is a small irregular working about 15 feet long, commonly referred to as the 200-foot adit; the name gives the approximate distance from the south boundary of the deposit. The 200-foot adit explores a small pocket of well-mineralized sandstone and was probably one of the first prospects on the property; in 1954 it was used only for powder storage. A few hundred feet northwest of the Big Indian incline are two small rim cuts that were made prior to 1949 (C. A. Rasor, U.S. Atomic Energy Comm., written commun.). All these workings are in the same ore-bearing sandstone lens. Prospects in another, stratigraphically lower lens on school section 2 are described with the 1,400-foot adit.

Several tons of medium-grade uranium ore have been produced from the school section 2 lease--from the Big Indian incline. The ore shipped had a $V_2O_5:U_3O_8$ ratio of about 2.6:1.

The ore-bearing lens explored by the Big Indian incline lies about 80 feet below the top of the Cutler Formation at about the same horizon as the lens explored by the Big Buck workings, but where these two lenses overlap and pinch out on the Big Buck claims, the Big Indian lens lies about 20 feet higher above the Big Buck lens. The Big Indian lens is more than 400 feet long and attains its maximum thickness of about 15 feet near the incline.

The sandstone is chiefly light yellowish gray to light grayish brown with irregular spots and blotches of purplish gray and grayish red. It is sorted, medium- to coarse-grained sandstone containing scattered pebbles of quartz and metamorphic rocks as much as 0.3 inch in diameter. Mudstone seams, pods, chips, and irregular pebbles, as much as 3 inches across, are contained within the sandstone. The sandstone is composed of subrounded to subangular clear and pinkish quartz and feldspar with sparse mica. The rock is commonly friable, though in places it is well cemented with calcite.

The rock is cut by irregular, northeast-dipping joints. On several of these fractures the host sandstone has been displaced a few inches. The joints are numerous within the first 30 feet from the portal; farther down the incline they are less frequent and less well developed.

The mineralized rock is similar to that exposed in the Big Buck Cutler workings but is judged to be of lower grade. Yellow carnotite and dark-gray vanadium hydromica are irregularly disseminated through the sandstone as isolated grains and as patchy concentration. Some clay pebbles contain concentric bands of vanadium and uranium minerals around a barren core.

Radioactivity increases near the bottom of the incline probably as a result of radon contamination in the part of the mine farthest from the portal. A decrease in radioactivity near a joint about 75 feet from the portal may be due to aeration and lessening of radon accumulation along this joint. The ore minerals show no progressive increase in abundance down the incline, though the face does contain more visible ore minerals than is found in most sections of the walls of the adit, and the grade of the rock here is probably above the average of the lens.

<u>1400-foot adit</u>

The 1400-foot adit is on School Section 2 on the southwest rim of Big Indian Valley about 1400 feet northwest of the south boundary of the section in T. 30 S., R. 24 E., about 2 miles south of the Big Indian copper mine. The incline dips about 11°, paralleling the dip of the ore-bearing sandstone lens, and is about 5 feet wide, 6 feet high, and 45 feet long. It trends S. 60° W., about normal to the rim. There are several small cuts in the same mineralized ore-bearing sandstone lens a few hundred feet northwest of the adit.

Possibly part of the small shipment of medium-grade ore made from the School Section 2 lease in 1953 came from this adit, although all of it may have come from the Big Indian incline, about 900 feet southwest of and 50 feet higher than the 1400-foot adit.

The ore-bearing unit is a conglomeratic arkosic sandstone lens abut 100 feet below the top of the Cutler Formation. The lens is 10 to 20 feet thick near the adit. It abruptly thins to less than 10 feet southeast of the mine; it thins gradually along the outcrop for more than a thousand feet to the northwest.

The sandstone is light yellowish brown blotched with purplish gray and grayish red. The sandstone is poorly sorted, medium and medium to coarse grained, and is composed of subangular clear quartz, gray chert, pink and clear feldspar, and biotite with accessory muscovite and grains of green claystone. Stringers and pockets of pebbles, 4 to 40 mm in diameter, are scattered through the sandstone. These pebbles consist of clear and pinkish quartz and feldspar, gray chert, granitic gneiss, and mica schist. The rock ranges from friable to very firmly cemented. The sandstone is cross-stratified in low-angle trough sets. Mudstone seams and partings in the sandstone are bright to dull red and very micaceous.

The chief ore minerals are yellow carnotite and dark-gray vanadium hydromica. Becquerelite is also present. The ore minerals occur in small spots and irregular patches, 0.1 to 5 inches across. These spots and patches are grouped in irregular clusters and layers which are randomly scattered through the sandstone. The ore minerals occur mostly in the yellowish-brown part of the sandstone but also in some purplish-gray sandstone. The grade of the rock differs greatly within a few inches without apparent system. The overall grade of the rock is very low.

The sandstone is well jointed at the outcrop and in the incline, but the joints have no apparent effect on the distribution of ore minerals. The deposit is probably localized, at least in part, on the flank of an ancient channel-fill. One small fragment of coalified wood, a few inches long, was found in the back of the incline.

Calico Dike prospect

The Calico Dike claim was previously known as the Purple Paint (Dix, 1953, p. 11), as the Vermillion, and as the Jumbo. The claim lies on a small bench about 200 feet above the floor of Big Indian Valley on the southwest rim of the valley about 2 miles south of the Big Indian Copper mine. The top of the ore-bearing lens has been exposed by stripping the overburden, and a small pit, about 20 feet square and 4 feet deep, has been cut into the top of the lens.

The recorded production from this prospect is only a few tons of medium-grade uranium-vanadium ore. Dix (1953a, p. 14) reported assays of two grab samples from the top of the weathered sandstone at this prospect: 0.66 percent U_3O_8, 1.44 percent V_2O_5, 17.1 percent $CaCO_3$; and 1.21 percent U_3O_8, 2.55 percent V_2O_5, and 11.7 percent $CaCO_3$. The sparseness of ore minerals and the low radioactivity of the mineralized rock suggest that the average grade of the deposit is much lower than these grab samples.

The ore-bearing lens is a channel fill, conspicuous because of its dark color and form among light-reddish, horizontally thin-bedded, finer grained units exposed on the cliff face. The lens is about 300 feet wide and about 35 feet thick near the center of the lens, but it thins to less than 10 feet thick a few tens of feet away from the center. It has an exposed length of about 250 feet. The top of the lens lies about 65 feet below the top of the Cutler Formation.

The dominant color of the sandstone is dark reddish brown to purplish black. Areas containing visible ore minerals especially near the top of the lens, are commonly light grayish brown with small irregular streaks and blotches of purplish gray. The sandstone is poorly sorted, very fine to medium grained, and composed of clear quartz and feldspar, pink chert, and biotite and muscovite. Small clay pebbles are common near the base. The rock is firmly cemented with calcite and iron oxides. The lens is partly cross-bedded in small low-angle trough sets.

Carnotite and becquerelite (Dix, 1953, p. 11) and vanadium hydromica occur as disseminated grains and as concentrations in small spots, 0.1 to 3 inches in diameter. The spots occur singly, and are grouped into irregular clusters a few inches to about a foot in diameter; less commonly are coalesced into thin wavy layers a few inches long and a fraction of an inch thick. Concentrations of ore minerals are most abundant near the top of the sandstone lens where the rock is mostly light grayish brown. Visible uranium and vanadium minerals were less frequent in the dark reddish-brown and purplish-black sandstone that make up the bulk of the lens.

Small Fry mine

The Small Fry mine is on the southwest rim of Big Indian Valley about half a mile southwest of the Big Indian copper mine. The workings consist of a single incline about 160 feet long, inclined about 10° paralleling the ore lens, and several small rim cuts. Several tens of tons of medium-grade ore were shipped from this property.

The ore-bearing sandstone lens lies about 20 feet below the top of the Cutler Formation. The lens is about 20 feet thick near the mine portal but thins gradually and irregularly away from the mine. The lens was traced along the rim to about 400 feet southeast of the mine and to about 300 feet northwest of the mine. Away from the area of the mine the lens averages about 7 feet thick. The lens dips about 11° southwesterly and is cut by many irregular joints.

The ore-bearing lens consists mainly of light-grayish brown sandstone mottled with patches of dark grayish purple and streaks of bright red; sandstone containing abundant ore minerals is commonly light grayish brown. The ore-bearing lens also contains thin beds of buff siltstone and bright-red mudstone. The lens, as a whole, is a complex assemblage of beds of slightly differing colors and grains sizes.

The sandstone is poorly sorted, mostly fine grained with pockets of medium and coarse grains and silt; in places it grades to siltstone. The sandstone is composed of subrounded to angular grains of clear and pinkish quartz and feldspar and biotite, with minor muscovite. The rock is firmly cemented with calcite.

Carnotite occurs as disseminated grains, as patchy concentrations, and as thin films along bedding planes. Vanadium hydromica occurs chiefly as small spots a fraction of an inch in diameter, generally surrounded by or intermixed with uranium minerals, and as impregnations of thin beds. The ore minerals tend to be concentrated in clusters of spots and patches irregularly through the sandstone. Malachite is present in small quantities (Dix, 1953a, p. 11). The host sandstone contains visible uranium and vanadium minerals for at least 300 feet along its outcrop. Joints, though conspicuous in the mine, show little influence on ore. The average grade of the mineralized rock is low, though shipments of selected ore have been of medium and high grade. The vanadium-uranium ratio of the shipped ore was about 2.5:1.

Uranium-Vanadium deposits in the Chinle Formation

Mode of occurrence

Relationships within the district

A peculiarity of the Big Indian mining district is that little evidence has been recognized at the outcrop of the lower Chinle to suggest the presence of large uranium ore reserves not far downdip from the rim. No major ore body is exposed at the rim. The principal showings of uranium ore on the outcrop are at the Divide and Serviceberry mines near southern Lisbon Valley; total production and reserves of these mines are small. Two showings of mineralized rock on the rim overlooking Big Indian Valley occur about 1 mile southeast of the Mi Vida mine. A small occurrence of oxidized uranium minerals is found in the lower Chinle about 1 mile southeast of Big Indian rock. An unusual occurrence of radioactive minerals in the upper Chinle has been found at the outcrop just north of Big Indian rock. Many prospectors and mining companies report that the Chinle-Cutler contact in much of the district is anomalously high in radioactivity at the rim and in drill holes, although uranium minerals are not visible.

The large uranium ore deposits in the lower part of the Chinle Formation in the Big Indian district lie almost entirely within a narrow arcuate belt that parallels the regional strike on the southwest side of the Lisbon Valley anticline. Lekas and Dahl (1956, p. 162) stated that the belt "... is confined almost entirely to a strip between the 6,200 and 6,700 feet contours drawn on the top of the Cutler Formation, although not occupying the full width of this strip. Within the strip the ore belt rises up the dip to the southeast." The Chinle in part of the belt, from a point about 3 miles west of the Continental No. 1 incline to near Spiller Canyon, has been removed by erosion. One deposit, as yet undeveloped, lies outside the belt, about one mile southeast of the Continental No. 1 incline. A discovery drill hole in an ore body of unknown size, also outside the belt, was made in 1956 about one mile southwest of the Continental No. 1 incline. Generally though, most scattered exploratory drilling downdip from the belt has not suggested the presence of significant ore bodies. The area updip from the belt has been well tested and no large ore bodies have been found.

The mineral belt has been divided into two segments by erosion of the Chinle in the area near Big Indian rock. The productive part of the northwestern segment extends from near the Big Buck mine to the North Alice mine behind the lower Chinle rim above Big Indian Valley. This segment is relatively well defined by exploratory drilling and contains most of the large mines and ore reserves in the district. The southeastern segment lies near southern Lisbon Valley and includes the area of the Continental No. 1 incline and the Divide incline. The western part of this segment, which extends to about 3 miles west of the Continental No. 1 incline portal, is perhaps not thoroughly tested, but drilling done through 1956 has not found additional large ore bodies. Both the northwestern and southeastern segments, as far as is known, end at the Lisbon Valley fault. Exploratory drilling had not been done at the time of the geologic mapping (1954-1959).

Although most drilling evidence tends to substantiate the presence of but one belt containing large uranium ore deposits in the Chinle in the district, the possibility of other belts or different trends is not yet excluded. The presence of uranium deposits southwest and southeast of the Continental No. 1 incline may signify a second belt lower on the structure or that the segment of the belt including the Continental No. 1 incline and the Divide incline has a somewhat different trend than presently indicated. Future deep drilling, especially in the southeastern part of the district, may be expected to more clearly outline the areas where large uranium deposits may be expected.

As far as is known the belt shows no distinguishing physical characteristics where it is cut by erosion near Spiller Canyon and near an unnamed valley about three miles west of the Continental No. 1 incline. The area between these points probably does contain a thinner lower Chinle and a lower percentage of quartzose sandstone than is characteristic of most of the mines, but the difference is not striking, because mineralization within the belt has affected a wide range of rock types and was apparently not directly related to thickening of the host rock. Analysis of subsurface data by geologists of the Atomic Energy Commission (now in Department of Energy) has shown that the belt is not associated with any pronounced channel into the underlying Cutler Formation. Ore occurs both in broad shallow paleotopographic lows and above paleotopographic highs (Lekas and Dahl, 1956, p. 162). R. R. McLelland (Isachsen, 1954, p. 104) has suggested a possible relationship between the ore bodies and certain permeable lenses in the Cutler Formation that are truncated by the unconformity at the base of the Chinle. N. E. Salo (oral communication) has found that all ore bodies in the northwestern segment of the belt are underlain in part by a distinctive white, fine- to medium-grained quartzose sandstone of the Cutler. Ore in the lower Chinle extends beyond this underlying lithology, but possibly further study may show that the localization of ore bodies is related to the underlying Cutler Formation.

Considering the belt as a whole, there is a general though not progressive change northwestward in the lithology of the host rock. The average grain size of the mineralized host rock tends to decrease and the sandstone beds of the host rock tend to be more uniform toward the northwestern part of the district. In the southeasternmost mine, the Continental No. 1 incline, and as far northwest as the Mi Vida mine and possibly including the La Sal shaft, a considerable proportion of the host rock consists of coarse-grained and conglomeratic quartzose sandstone. In these mines there is a tendency for the ore to be very irregular and the top of the mineralized host rock to be poorly defined. In most of the northwestern mines--the Cord, Radon, and Far West mines--the mineralized portion of the host rock commonly consists of an individual continuous bed of fine- to medium-grained sandstone, and the ore bodies in this bed tend to be more regular in cross section. The ore-bearing units in the San Juan mine are generally beds of silty sandstone; the distribution of ore in these units has not been studied in detail.

Preliminary results of geochemical studies by V. C. Kennedy (unpub. data) show that vanadium, molybdenum, and strontium tend to change markedly in concentration from southeast to northwest in the district. Both vanadium and molybdenum show a pronounced decrease to the northwest and are practically absent in the mines northwest of the Mi Vida mine. Vanadium is also known to decrease downdip within some ore bodies (N. E. Salo, U.S. Atomic Energy Commission oral communication). Strontium, which is low (0.01 to 0.03 percent) in the southeastern mines, increases to a maximum of 0.7 percent in one mill pulp from the Radon mine. Lead, copper, and cadmium are present in some ore bodies in abnormal amounts, but these elements do not show a systematic change in concentration from the southeastern to the northwestern part of the district. The most pronounced differences in lithology and concentration of accessory metals are between the groups of mines from the Continental No. 1 incline through the Mi Vida mine and the group consisting of the Cord, Radon, and Far West mines. The La Sal ore body is in most ways transitional between these groups.

Mineralogy

By Theodore Botinelly

1957

The uranium deposits in the Triassic rocks of the Big Indian district are for the most part unoxidized. A few secondary minerals were found in the Mi Vida mine of Utex Exploration Co. and a few in the Continental Uranium Co. incline No. 1, but these are quantitatively insignificant. Zippeite(?) was found in the Far West mine close to a fault. Most of the mines in the area are deep, and most of the secondary minerals are the result of oxidation after the opening of the mine workings.

The major ore minerals are uraninite, coffinite, and in those mines where vanadium is present, montroseite and micaceous vanadium minerals. Sulfide gangue minerals include pyrite, marcasite, molybdenite or jordisite, galena, sphalerite, chalcocite, and chalcopyrite. Transparent gangue minerals include the detrital minerals of the host rocks, calcite, barite, quartz, chert, and feldspar. A list of minerals identified in these mines is presented below.

The following minerals were identified in hand specimen, and thin and polished sections. These minerals have in large part been reported by other investigators, especially Gross (1956), Gruner and others (1954), and Dix (1953a).

barite	$BaSO_4$
calcite	$CaCO_3$
celestite	$SrSO_4$
chalcopyrite	$CuFeS_2$
chalcocite	Cu_2S
coffinite	$U(SiO_4)_{1-x}(OH)_{4x}$
copper*	Cu
corvusite	$V_2O_4 \cdot 6V_2O_5 \cdot nH_2O$
galena	PbS
greenockite	CdS
hematite	Fe_2O_3
hewettite(?)	$CaV_6O_{16} \cdot 9H_2O$
ilsemannite	(hydrated oxide of molybdenum)
jordisite	(amorphous hydrated molybdenum sulfide)
liebigite(?)	$Ca_2(UO_2)(CO_3)_3 \cdot 10\text{-}11H_2O$
marcasite	FeS_2

malachite	$Cu_2(OH)_2CO_3$
molybdenite(?)	MoS_2
montroseite	$VO(OH)$
pascoite	$Ca_2V_6O_{17}.11H_2O$
pyrite	FeS_2
rauvite(?)	$CaO.2UO_3.5V_2O_5.16H_2O$?
sherwoodite	(not supplied)
sphalerite	(Zn,Fe)S
uraninite	$UO_2 \pm UO_3$
zippeite	$(UO_2)_2(SO_4)(OH)_2.4H_2O$

The following minerals have been reported by various authors but were not found in the specimens examined for this report.

doloresite	$V_2O_4.nH_2O$
fluorite	CaF_2
melanovanadite	$2CaO.V_2O4.3V_2O_5.nH_2O$
metatyuyamunite	$Ca(UO_2)_2(VO_4)_2.5\text{-}7H_2O$
roscoelite	$(Al,V)_2(Al,Si)_3(K,Na)O_{10}(OH,F)_2$
tyuyamunite	$Ca(UO_2)_2(VO4)_2.7\text{-}10\text{-}1/2H_2O$

*Specimen of native copper from Big Buck mine of Standard Uranium Company was supplied by Harold Edwin, geologist for Standard Uranium Company.

The ore minerals fill pore spaces in the host rocks and partially replace the quartz and clay minerals of the host rocks. Generally the ore minerals are fine grained.

Uraninite occurs replacing fossil wood, in part preserving the structure of the wood with great fidelity, as rounded masses surrounding quartz grains, and as irregular replacements of calcite and clay minerals.

Many of the uraninite masses show a botryoidal appearance at magnifications of 1000X or more. Some uraninite masses show a pseudocataclastic texture apparently inherited by replacement of angular fine-grained sedimentary material. One specimen from La Sal mine shows irregular polygonal blocks separated by "shrinkage" cracks suggesting a crystallization from a gel. Uraninite surrounds quartz grains showing corrosion features and replaces calcite along cleavage cracks producing a "graphic" pattern. Coffinite occurs in intimate mixture with uraninite, typically in wood replaced by uraninite.

Montroseite typically occurs as bladed crystals in a radial arrangement. The vanadium clays occur in the pore spaces with little definite structure.

Sulfide minerals are common in the ores. Pyrite is present as massive replacements of the host rocks, as scattered crystals in ore and barren rocks, and replacements of wood. Marcasite for the most part is associated with pyrite.

Galena occurs in high-grade ore sometimes as crystals up to one-quarter inch on edge, but most extensively as extremely small cubes in uraninite. No galena was found except associated with uraninite or coffinite.

Chalcopyrite is rare compared to galena and pyrite, but has been reported from Continental Uranium Co. incline No. 1 and was found in Mi Vida mine, La Sal shaft, Big Buck mine, and Little Beaver mine, and it probably is present in other mines of the district. Chalcopyrite occurs in small irregular masses and very small veinlets; it is associated with the ore minerals. Chalcocite occurs similarly. Malachite is commonly found impregnating and coating rock containing copper sulfides. Native copper was observed in places in the Big Buck mine as thin irregular distorted plates in mudstone near ore.

Molybdenum occurs in part in a mineral identified as jordisite (an amorphous hydrated molybdenum sulfide) and in part in what may be very fine-grained molybdenite. Local high concentrations of molybdenum were found in claystone in the Mi Vida mine and in sandstone in the Continental No. 1 incline. These concentrations of molybdenum give the rock a gray color very similar to that of vanadium ore. Locally, the molybdenum-bearing rock shows a blue coating of ilsemannite, a hydrated oxide of molybdenum, that has formed on the walls after the opening of the mines.

The uranium deposits differ from the uranium-vanadium deposits only by relative lack or absence of vanadium minerals. Uraninite and coffinite are present in both types of deposits; the associated sulfides are the same and the textures seem to be about the same. No difference in gangue was noticed except that the high uranium calcareous ores are red to pink and the uranium-vanadium ores are gray. The pink colors, at least in part, seem to be due to finely divided flakes of hematite.

Paragenetic relations of minerals are complex. Montroseite needles rimmed by uraninite were found in specimens from the Continental No. 1 incline. Other specimens show bladed crystals of montroseite showing "corroded" edges surround by uraninite. The relation of coffinite to uraninite could not be determined; the two minerals are intimately mixed in replacements of carbonized wood and are probably contemporaneous.

Chalcopyrite was found in a few specimens. In the only specimen where paragenetic relations could be interpreted, chalcopyrite occurs as small veinlets cutting uraninite and is thus probably later than uraninite.

Galena most commonly occurs as very small rectangular grains in uraninite. In few sections, calcite partially replaces the galena selectively.

Sphalerite is too rare for its place in the paragenetic sequence to be determined.

Calcite, the most prominent gangue mineral except for the detrital minerals of the host rocks, is replaced by uraninite and other minerals and replaces them. It was probably deposited, dissolved, and redeposited many times, and although in part earlier than the ore minerals, it is probably in part also much later. The red color of much calcite in high-uranium ores seems to be due to finely divided iron oxide.

Barite is earlier than the latest calcite but is also in part later than the ore minerals.

Ore bodies

General description

The large uranium ore bodies in the Chinle Formation in the Big Indian district are irregular in plan and section. They are roughly tabular bodies that range from a few hundred feet to more than 10,000 feet in length, from about 100 feet to more than 1,400 feet in width, and from a thin edge to more than 30 feet in thickness. The ore bodies are generally markedly elongate subparallel to the regional strike with a tendency for the elongation to be slightly more westerly than the strike of the enclosing Chinle beds. Lekas (U.S. Atomic Energy Commission, oral communication) has noted that high-grade portions of the Mi Vida and Big Buck deposit are oriented more or less transverse to the regional strike, and trend southwestward parallel to the local dip of cross-stratified sandstone in the host rock.

The uranium ore is closely associated with the unconformity at the base of the Chinle Formation. Commonly the highest grade ore is found just above to less than 5 feet above the Chinle-Cutler contact. Although in some ore bodies, as in the Mi Vida mine, the ore attains a thickness of more than 30 feet, the base of the ore is approximately coincident with the base of the Chinle. In many ore bodies, as in the Big Buck mine, the uranium mineralization has extended a few inches to a few feet into the underlying Cutler Formation, most commonly where the Cutler is a sandstone. In mines in the northwestern end of the district mineralized rock in the Cutler is less common and the ore generally bottoms a few inches above the contact. This general association of ore may have important exceptions in the extreme north-western part of the district. According to Paul Nash (Homestake Mining Co., oral communication) ore in the recently developed North Alice mine generally bottoms a few tens of feet above the contact. Mineralized rock occurs in the upper Chinle above the main ore body at the Cord mine (Glen Walker, Jen Mining Co., oral communication). At the margin of the ore bodies mapped in the Big Buck and Mi Vida mine, the ore trends to string out in disconnected, thin lenticular zones some few feet above the Chinle-Cutler contact. In the mines to the northwest the thinning ore lens maintains its position at or very near the contact.

Except in areas of the mines characterized by very high grade ore (probably averaging above 5 percent U_3O_8), uranium minerals are not visible. Contouring the radioactivity of mine walls shows that the outlines of ore are commonly extremely irregular and cannot be projected in detail for more than a few feet. This is especially characteristic of the ore in the mines near the Mi Vida and the mines in the southeastern part of the district. Although grossly following sedimentary features the ore crosscuts them in detail. Ore near the northwestern end of the district tends to correspond more closely with sedimentary features.

Relation of ore to lithology

Most uranium is in sandstone, but grain size of the sandstone is not an important factor in controlling ore limits. Within the area mapped in the Big Buck mine the ore occurs in a relatively uniformly fine- to very fine-grained sandstone. Within the Mi Vida mine, the ore occurs in medium to coarse-grained, medium-grained, fine-grained sandstone and in siltstone, although, in general, the higher grade ore is in a medium-grained sandstone. Within the La Sal mine the ore occurs in sandstone with a great range of grain sizes, and some high-grade ore is in siltstone and mudstone. Ore occurs similarly in the Continental No. 1 incline. Within the mines in the northwestern part of the district the ore is more definitely confined to the medium- and coarser-grained sandstone.

With the exception of small areas of extremely high concentration of uranium, where uraninite apparently forms the bulk of the rock, there is no obvious discernible difference in the character of the edge of ore or between high- and low-grade portions of the ore body. The accompanying wall sections of the Continental No. 1 incline and the La Sal mine show that the margins of abnormal radioactivity end rather abruptly on nearly vertical planes that transect lithologic boundaries. In the section shown from the Cord shaft one edge of the ore gradually narrows to a knife edge whereas the margin of the next lens of ore thickens abruptly along section. These apparent anomalous relationships between change in character of the lithology and degree of concentration of radioactivity are very common in all the mines studied. Consequently, as a result of the mine mapping, it was not found possible to judge the grade of ore or the change in grade of ore by simply observing types, or changes in types, of lithology. Careful and sometimes tedious testing with a Geiger counter was essential in locating the outlines of the uranium-bearing rock.

In places mudstone seams and partings are related to local variations in ore, but not in any specific way. That is, the grade may be higher above or below a parting or may end upward or downward against mudstone. Some mudstone seams are as well mineralized as adjacent sandstone beds. An example of apparent control by a mudstone parting was mapped in the Cord shaft mine. Here the wall is nearly at right angles to the dip of the beds. The top of the Cutler is slightly concave upward whereas the mudstone forms a nearly horizontal layer. The geometry and distribution of lithology suggests a small scour. The ore here has been localized along the flanks of the scour and terminates upward at the horizon of the horizontal mudstone parting.

Mudstone partings in the La Sal mine occur within high-grade ore zones and near the margins of ore; within the Continental No. 1 incline mudstone partings occur throughout the ore zone but apparently have not exerted any obvious control on the localization of uranium ore. The distribution of the vanadium minerals is commonly more closely associated with the mudstone seams and lenses than is the distribution of uranium minerals.

Distribution of accessory metals

Vanadium

Uranium and vanadium minerals in the same mine have not always been deposited together in detail. The vanadium minerals tend to follow bedding planes and form somewhat elongate concentrations whereas the boundary of highly radioactive rock commonly forms irregular shaped areas transverse to sedimentary structures. Although there is no sharp distinction between the lithology of rock containing mostly uranium and rock containing mostly vanadium, vanadium minerals more commonly impregnate siltstone, mudstone, and fine-grained sandstone than do uranium minerals. Much high-grade vanadium ore contains little calcite, whereas most rock with visible pitchblende is tightly cemented with visible calcite.

The general outline of vanadium concentrations was mapped in three localities.

The presence of vanadium is suggested in areas in the mine where the rock was definitely darker gray than the surrounding rock. Although the darker gray color may have been due in part to finely comminuted carbonized organic material, or molybdenum minerals, the dark coloring is definitely caused mainly by vanadium minerals.

Divergence in the pattern of localization of the uranium and vanadium minerals is most apparent in the mines in the southeast part of the district where the vanadium-uranium ratio is many times higher than in mines in the northwest part. In many places in the more southeasterly mines, vanadium minerals form broad streaks or bands along bedding plane surfaces, tens of feet distant from areas in which the Geiger counter has indicated abnormal radioactivity. However, within these mines in which the vanadium-uranium ratio is relatively high, commonly high concentrations of vanadium minerals also are commonly intimately associated with high-grade concentrations of uranium oxides.

Molybdenum

Molybdenum is an accessory element in the ores of several mines. Selected hand samples from the Mi Vida mine and Continental No. 1 incline assayed more than 1 percent molybdenum. Spectrographic analyses of mill pulps collected by V. C. Kennedy from the Continental No. 1 incline, Mi Vida, and Big Buck mines show molybdenum concentration ranging from 0.007 to 0.07 percent. The presence of molybdenum minerals was not suspected before these analyses were made. Some gray streaks in sandstone, identical in appearance with vanadium ore, apparently contain only molybdenum minerals. As there appears no simple way to differentiate the two in the mines, probably some molybdenum-bearing rock has been misidentified as vanadium ore. In a few places the molybdenum-rich rock can be recognized by the presence of a thin bluish coating or scattered grains of ilsemannite, an oxide of molybdenum that has formed as the result of oxidation after opening of the mine. The few samples and analyses of molybdenum at hand suggest that molybdenum may be similar to vanadium in distribution within an ore body. It probably occurs separately and intermixed with vanadium and uranium minerals. However, molybdenum is not common in the vanadium-poor ore bodies north of the Mi Vida mine.

Copper

Copper is a minor element in the uranium ores of the Big Indian district. Spectrographic analyses of mill pulp samples collected by V. C. Kennedy suggest that the copper concentration ranges from about 0.007 to 0.07 percent. Copper minerals in small quantities have been found in the Continental No. 1 incline, the Big Buck, Little Beaver, Mi Vida and La Sal mines and probably occur in other mines. Chalcocite, chalcopyrite, and malachite are the most common copper minerals. They occur as irregular thin layers, veinlets, stringers, and blobs both associated with and at some distance from uranium-bearing rock. Malachite, a secondary oxidation product of other copper minerals, is found intermixed with and near unoxidized black uranium and vanadium minerals. Native copper occurs as small thin irregular distorted plates in nonradioactive mudstone in a few places in the Big Buck mine but was not found in other mines.

Relation of ore to carbonaceous material

Visible carbonaceous material is more commonly rare to absent than abundant in the ore in most mines. Fossil wood fragments in the ore-bearing rock are somewhat common in the mines in the area including the Continental No. 1 incline and Mi Vida mine than in the mines in the northwestern end of the district. The presence or grade of uranium ore, however, shows little direct relationship to occurrence of visible carbonaceous material, even though the carbonaceous material may be locally abundant. Most beds in the ore-bearing zone contain only sparcely distributed fossil log fragments and areas of finely comminuted carbonaceous material. Some of these carbonized log fragments and trash have been partically replaced by uranium minerals. Some fragments in the Mi Vida mine were almost completely replaced by ore minerals; some of these contain the cadmium sulfide greenockite (Gross, 1956). In Many places in the Continental No. 1 incline, and the Big Buck, Little Beaver, and Mi Vida mines, the back of the drifts has been carried to a mudstone that contains scattered to abundant carbonized plant trash and fossil logs; but in none of the areas mapped did the ore extend upward into this lithology.

Perhaps the relationship of uranium ore to carbon is too subtle to be seen in the mines. The ore may be related to unrecognized extremely fine-grained plant material or to carbon in another form than fossil plants. W. H. Bucher (Lekas and Dahl, 1956, p. 166) has suggested that a favorable hydrocarbon trapped on the crest of the Lisbon Valley anticline could have served as a precipitant of uranium from solutions. Analyses of five high-grade uranium samples from the Mi Vida mine were reported by Steen and others (1953, p. 8) to have assayed from 0.14 to 0.59 percent organic carbon. Analyses of grab and channel samples of ore from the Continental No. 1 incline by Irving May (U.S. Geological Survey) ranged from 0.1 to 0.9 percent noncarbonate carbon. Analyses by J. P. Schuch (U.S. Geological Survey) of seventeen mill pulps of ore collected by V. C. Kennedy from Big Buck, Mi Vida, San Juan, La Sal, and Radon mines ranged from less than 0.5 percent to about 10 percent and and extraordinary high of one sample from the San Juan mine of 3.2 percent organic carbon. The average organic carbon content suggested by all these analyses is less than 0.5 percent organic (noncarbonate) carbon. Judging from exposures of unmineralized rock in the mines and at the outcrop, the organic carbon content of much barren rock is probably as high as or higher than the carbon content of ore.

Relation of ore to joints and faults

Through-going joints are inconspicuous in most of the mines. In some mines, for example, in the Mi Vida mine, joints are prominent in some parts of the mine and absent in others. The joints commonly strike subparallel to the elongation of the ore body, that is, parallel to the regional strike, but they have little effect on the distribution of radioactive rock. A few joints are radioactive, and though there may be significant exceptions, the general picture suggests that this is due to recent oxidation after opening of the mines.

The only fault mapped in an ore body is judged to be post-ore. Radioactive rock has been displaced by this fault. The surface of the fault as presently exposed is radioactive but this is believed due to dragged fragments of the ore layer and recent oxidation. This small fault with a displacement of only about 5 feet was also observed in the Radon mine where the relationship appeared similar. A fault in the Far West mine exposed in late 1956 has a throw of about 50 feet and is known to continue through the North Alice ore body. Reconnaissance of this faulted portion of the Far West deposit showed that mineralized rock ended abruptly at the fault. The secondary oxide, zippeite(?), was found along and near the fault surface. The fault is judged to be post-ore and to have served as a conduit for percolating oxidizing water. The Continental No. 1 incline and the North Alice mines are close to the Lisbon Valley fault, but this major fault has not been exposed in any of the mine workings. No change in habit or grade of ore was noted in the Continental No. 1 incline in the workings closest to the fault.

Alteration

Alteration of the rock associated with the uranium ore deposits in the Big Indian mining district is negligible. Three features of the host rock may be the effect of the mineralizing solutions. These are (1) the dominantly grayish colors of the ore-bearing beds, (2) pink calcite cement, and (3) epigenetic orange chert.

The dominant grayish and greenish colors of the lower Chinle that contrast strongly with the reddish colors of the upper Chinle may represent an alteration by the ore-bearing solutions. These colors, however, are characteristic of the lower Chinle over much of the Colorado Plateau and show little or no change in non-uranium-bearing areas. Isachsen (1954, p. 101) noted that the gray and green colors appeared to persist higher in the Chinle Formation in mineralized areas than in barren areas. This is noticeable in the area of the Mi Vida deposit but is not characteristic of other ore-bearing areas within the district. In contrast with most of the deposits red-colored sediments are common in the La Sal mine where much of the host rock is reworked Cutler that has apparently not been subjected to any strong bleaching. Although the green and gray colors of the Chinle possibly represent in part the bleaching effect of mineralizing solutions, the effect is to broad to be related to the uranium ore deposits.

Pink to red calcite is common in the ore zone and is characteristic of high-grade uranium ore. The reddish color is due to very finely divided iron oxides, probably hematite, in the calcite. The pink calcite appears to be both contemporaneous and later than the uranium and vanadium minerals. Much of the calcite has been recrystallized subsequent to its original deposition with the ore. The pink color of the calcite is less prominent in the mines containing abundant vanadium minerals. In the mines in the northwestern part of the district where vanadium is very low the colored calcite gives a distinct pinkish cast to the mineralized rock. Pink calcite probably is a reliable guide to ore in the deep drill holes in the area because it is rarely found in non-radioactive rock. However its usefulness as an ore guide is restricted.

A distinctive chert of epigenetic origin is associated with all the uranium deposits in the district. The chert is generally orange to red but ranges from grayish orange and moderate orange pink to moderate reddish orange and moderate reddish brown. At the outcrop it weathers to grayish orange. It has a dull to subvitreous luster. It is brittle and breaks easily into irregular fragments. The microscope shows the mineral to have commonly a peculiar texture approaching the spherulitic; some is banded, some micro-granular, and a few specimens have well-developed quartz crystals projecting into cavities. The textures suggest deposition as a colloid and crystallization from a gel.

The chert occurs typically as subangular to subrounded nodules and irregular fragments from a fraction of an inch to several inches in maximum diameter. It generally is restricted to limy parts of the host rock. In a few places it occurs as discontinuous irregular layers a few feet long and several inches thick. Most chert is found in the ore zone near the base of the Chinle, but a few prominent occurrences in the underlying Cutler near ore have been noted. It has not been found in unmineralized areas more than a few hundred feet from ore. This distinctive chert, although sporadically distributed, is believed to be a useful guide to the presence of uranium ore.

The chert commonly has completely replaced the detrital minerals and calcite cement of the host rock. Its paragenetic position is not clear. It is intergrown with pyrite and an unknown molybdenum(?) mineral and is as least in part contemporaneous with the ore minerals and also later than the ore. Associated calcite is both earlier and later than the chert.

Summary

The uranium ore deposits of Big Indian Wash are typically large deposits measureable in tens to hundreds of thousands of tons. They are irregular roughly tabular bodies that lie close to the Chinle-Cutler contact and range from a few hundred feet to more than 10,000 feet in length, from about 100 feet to more than 1,400 feet in width and from a thin edge to more than 30 feet in thickness. They are generally elongate subparallel to the regional strike and are mostly confined to a narrow arcuate belt that parallels the regional strike. None of the large ore bodies crop out and the belt containing the deposits shows no known distinguishing physical characteristics.

The major ore minerals are uraninite, coffinite, and in the deposits where vanadium is present, montroseite and micaceous vanadium minerals. Oxidized minerals are rare. Molybdenum forms accessory minerals in some deposits. Pink calcite and epigenetic orange chert are associated with uranium ore.

The ore is not controlled in detail by lithology, and carbonaceous material does not appear to be an important localizing agent. Joints and faults are judged to be post-ore. The causes of localization of the ore are as yet obscure.

Mines and prospects

Far West Mine

The Far West mine comprises five claims; Valley, Queen Anne, Split Rock, Quail, Sunday, plus the Far West fraction.

The owner of the claims in 1958 was the Hidden Splendor Mining Company.

The claims cover a strip about 1,100 feet wide extending from the center, west to the boundary of sec. 28, T. 29 S., R. 24 E., San Juan County, Utah. A small part of the Far West fraction is in section 29. The Far West shaft is just west of the boundary between sections 28 and 29 and is approximately 2,600 feet south from the northeast corner of section 29.

The mine's administrative and shop buildings were in the vicinity of the shaft collar, at altitudes ranging from 6,720 to 6,740 feet, on the east side of a narrow flat-bottomed valley that drains northwesterly.

A hard surfaced all-weather road leads to the mine from the main Lisbon Valley road.

Stratigraphy and lithology

The Far West shaft is collared in the Wingate Sandstone and is bottomed in the Cutler Formation about 60 feet below the base of the Chinle Formation. The shaft has been sunk through more than half the entire section of Wingate Sandstone, all of the Chinle Formation and part of the Cutler Formation. (It is 520 feet from the shaft collar to the ore level.)

In the vicinity of the shaft the Wingate Sandstone is grayish orange to reddish brown, generally well sorted, fine grained and crossbedded.

Within the shaft, no information could be obtained concerning the characteristics of the rocks penetrated between the collar and the ore level. The nearest outcrop of the Chinle Formation is about 1/2 mile to the east and the nearest measured section of Chinle, near the Small Fry mine, is 1 1/2 miles to the southeast. In the Big Indian mining district the Chinle can be divided into an upper and lower unit. The upper Chinle comprises a series of dark-brownish-red fine-grained sandstone, siltstones and silty mudstones, generally thin bedded, fair sorted, firmly cemented, and horizontally laminated. The lower Chinle, which comprises from 5 to 20 percent of the formation, is characterized by greenish-gray to yellowish-green sandstones, siltstones, conglomerates, and lime pebble conglomerates, poorly sorted, firm to well cemented, and locally crossbedded.

The lower Chinle is not a well-defined unit and its upper boundary is generally arbitrarily chosen at the change in color from grayish greens to reds, rather than any distinguishable lithologic break.

The mine has been developed by drifts and inclines driven along the contact between the Chinle and Cutler Formations. Hence the exposures of either formation are limited to the height of the workings, which average about 8 feet from sill to back. The North incline has penetrated about 50 feet below the contact; the South incline has exposed a thickness of about 65 feet of lower Chinle on the hanging wall of a fault. Other than these two exceptions, the maximum thickness of Chinle exposed is about 8 feet and average thickness is about 5 feet. On the average, only the upper 2-3 feet of the Cutler Formation is exposed in the mine workings.

The Chinle exposed in the mine is comprised of two lithologic types, sandstone and silty mudstone. The sandstone is the lower of the two units as it always occurs directly on the contact, whereas the silty mudstone overlies the sandstone and occurs on the contact only where the sandstone is absent.

The sandstone is a unit with extremely variable lithologic characteristics. The color ranges from light greenish gray to light orange brown. Grain size ranges from coarse to very fine, although on the average it is medium and poor sorted. The unit is comprised predominantly of subrounded to rounded quartz grains, many with overgrowths, with varying but minor amounts of feldspars, chert, muscovite, and clay. It is generally firmly cemented and calcareous.

Chert forms a conspicuous constituent of the sandstone, largely because of its orange-red colorsand angular shape. No quantitative data were obtained concerning the percentage distribution of chert in the sandstone, but it probably does not represent more than 3 percent of the unit. It often is found as tabular to cylindrical concretionary masses ranging in mean diameter up to 3 inches thick. More commonly it is found as irregularly shaped discrete masses less than 1/4 inch in diameter. The smaller pieces of chert are sometimes angular in outline. Regardless of the size and shape of the chert particles, it is believed that little if any of it is clastic but has formed by relacement of the surrounding material.

Locally the sandstone has been deposited on scour surfaces in the underlying Cutler. At these places the sandstone comprises a mudstone pebble conglomerate. This conglomerate contains pebbles of siltstone and mudstone ranging from 1/4 to more than an inch in diameter. Mixed with the mud pebbles are fine to coarse quartz grains and usually some chert. The mudstone pebble conglomerate fills the lower part of the scour fill and in turn is overlain by coarse to medium-grained sandstones grading upward to finer grained sandstone.

The sandstone is generally firm to well cemented, but this characteristic is quite variable. Cementation is mainly by very fine grained calcite, which locally is so abundant that cleavage faces up to 1/4 inch wide can be seen on broken surfaces. It is suspected that some of the more tightly cemented rock contains fine-grained silica, in addition to calcite, as a cementing agent. Locally the sandstone contains little if any cementing material other than films of light-gray to white clay.

Fine-grained pyrite is sparsely scattered throughout the sandstone and is more prominent in the mineralized portions and the areas containing mudstone pebble conglomerate.

Carbonaceous material is extremely rare except as local flecks and flakes.

In many places the sandstone grades upward to a very fine grained, very calcareous siltstone that ranges in color from greenish gray to light pink. Generally this fine-grained, firmly cemented rock was included as part of the sandstone unit in the mapping of the thickness of the sandstone unit.

Structurally the sandstone unit is generally massive, without having prominent bedding or crossbedding laminae. Locally it contains mudstone splits and intertongues with the overlying silty mudstone. Because of their relative scarcity, no data were obtained regarding orientation of the mudstone splits to determine if they had a common orientation.

Where present the sandstone ranges in thickness from less than 0.1 foot to more than 6 feet. The average thickness is from 1 to 3 feet. Where sandstone is thin it gradually attenuates to a feather edge. The thicker parts of the unit are within scour areas or near faults, where variation in thicknesses is abrupt over short horizontal distances.

Contour maps based on Chinle-Cutler contact (corrected for regional dip) and two cross sections show that the sandstone has apparently filled topographic lows on the truncated surface of the Cutler Formation. The apparent relief on these "paleo-topographic" lows is greater than the thickness of the sandstone and some apparent topographic lows contain no sand. Many geologic variables may be called on to explain the distribution of the sandstone but two possibilities are:

(1) Assuming the sandstone is of fluviatile origin, lack of supply of sediments of sandstone to completely fill the topographic lows prior to deposition of the overlying silty mudstone.

(2) An initial regional dip on the surface of the truncated Cutler beds that was not assumed in correcting elevations based on present regional dip.

Studies in the North Alice mine, adjoining the Far West mine on the north, indicate the sandstone unit becomes thinner and more discontinuous to the north, suggesting that supply of sands transported by the streams was being greatly diminished.

There seems to be no well-defined pattern of sandstone distribution in the Far West. Isopachs drawn for the sandstone in the area between the two faults show some suggestion of thicker sandstone tending northwesterly in a curving pattern, similar to a meander of a stream, but many exceptions occur to the "pattern".

The origin of the material comprising the sandstone unit is uncertain. It could have been derived in part from units in the Cutler Formation that were exposed during deposition. The very poor sorting suggests transport over relatively short distance. Many of the quartz grains are at least subrounded, suggesting they may have been derived from preexisting sedimentary units. Feldspars, though minor in amount, are angular to subangular, although this angularity may be from comminution of larger rounded feldspar pebbles in preexisting sedimentary rock. Many coarse clastic units are known within the Cutler, and these may well have been the source for much of the material that now constitutes this sandstone unit.

The silty mudstone unit overlying the sandstone is exposed throughout the mine, and where the sandstone is absent, it rests on the truncated Cutler. It is greenish gray, silty, grading upward to mudstone, firmly cemented, calcareous, thin bedded to finely laminated. Locally, it is predominantly a siltstone, somewhat poorly sorted, containing scattered rounded quartz grains of sand size. Considerable carbonaceous trash in the form of flakes of carbonized woody material occurs along bedding planes. This material is exposed at many places in the backs of the drifts where locally the material appears to comprise fragments of flattened logs. Fine-grained pyrite commonly occurs near the carbonaceous material. With the exception of the area along the fault in the east part of the South incline, only the lower 2 to 4 feet of the mudstone unit is exposed.

About 65 feet of lower chinle is exposed on the hanging wall side of the fault in the South incline. The entire exposed thickness comprises alternating silty mudstones and siltstone, all greenish gray, firmly cemented and calcareous. The first siltstone unit is 6 feet above the basal sandstone unit and from this it is inferred this is the probable thickness of the silty mudstone unit exposed in the rest of the mine workings.

In the Big Indian mining district, the Cutler Formation comprises about 1,500 feet of alternating conglomeratic sandstones, sandstones, siltstones, and limestones, colored red, brown, lavender, buff, and white. All units are generally lenticular and thickness along strike range from several tens of feet. An angular unconformity both along strike and dip separates the Cutler Formation from the overlying Chinle Formation, so that from southeast to northwest, Chinle beds rest on successively lower units in the Cutler Formation. From the Far West shaft the nearest outcrop of Cutler beds is about 6,000 feet southeasterly near the north end of Big Indian Valley. The nearest exposure to the Far West shaft of the Cutler that correlates with the unit underlying the Far West mine is about 5 miles to the southeast along the escarpment forming the southwest side of Big Indian Valley.

Because of the known lenticularity of the units within the Cutler Formation, a direct correlation between units exposed on the outcrop and those exposed in the Far West mine would of necessity be rather tenuous. Exposures of the Cutler Formation in the mines southeast of the Far West indicate that a persistent sandstone, assumed to be the same unit, can be traced southeastward over most of the distance between the Far West mine and the outcrop on the surface. Thus it is believed the correlation of the unit in the mine and that on the outcrop is reliable.

The thickest exposure of the Cutler Formation in the Far West mine is in the ore pocket at the bottom of the shaft and in the North incline just west of the Far West fault. In the North incline the workings are inclined downward to expose the Chinle-Cutler contact on the hanging wall side of the fault. The vertical displacement on the fault in this area is between 55 to 60 feet. Hence, the North incline has penetrated to a depth of at least 60 feet into the Cutler Formation on the footwall side of the fault. The lower part of the shaft and the ore pocket have been excavated to a depth of about 50 feet below the Chinle-Cutler contact; however these parts of the mine were not inspected to determine the character of the Cutler exposed in them.

Other than the two exceptions noted above, the average thickness of the Cutler Formation exposed in the mine workings is less than 4 feet, and in many places only a few inches of Cutler rocks are exposed in the walls of the mine workings.

In the western part of the mine, from the shaft to about 40 feet east of the 1 south and 1 north drift, the Cutler at the contact comprises a green to greenish-gray mudstone. It is differentiated from the silty mudstone in the

Chinle by the presence of common to abundant green to black biotite along the bedding planes and by lack of carbonaceous material. Other than these two features, the mudstones in the two formations are quite similar.

East of the Far West fault, green mudstone in the Cutler occurs at the Chinle-Cutler contact in the south end of 7 south drift and in the North incline starting about 565 feet east of the fault. The greenish-gray mudstone in the east part of the mine is lithologically similar to that exposed in the western part of the mine.

With the exception of the mudstone, the type rock found below the Chinle-Cutler contact throughout the mine is sandstone. Except for local color differences and degree of cementation it is quite uniform in character. It is light gray to light buff to tan, fair sorted, poor to firm cemented, calcareous, and consists mostly of quartz, feldspars, biotite, and clay with sparse dark accessories. It is commonly crossbedded.

The features that distinguish the sandstone of the Cutler from the overlying sandstone in the base of the Chinle are presence of common to abundant biotite, lack of carbonaceous material, sparse chert, poorer cementation, and common crossbedding. Sandstones of both the Chinle and Cutler contain conglomeratic phases and green mudstone pebbles near the contact. The contact between the two sandstones is commonly difficult to locate in the mine because of lack of identifying characteristics in either unit. At these locations an aid used in identifying the contact is the usually distinct increase in radioactivity of the rock 1 or 2 inches below the contact.

The sandstone of the Cutler Formation color is usually light gray to buff, but locally it is red and in some places a dark gray. The red phase of the sandstone is found at widely scattered localities and generally underlies areas that have not been mineralized with uranium or in which the uranium content of the rocks is very low. However, the gray to buff color of the sandstone of the Cutler beneath many areas relatively barren of uranium is not a visibly different color from that under mineralized areas.

The areas containing dark-gray sandstone of the Cutler are the 3 north and 4 north drifts. The dark streaks appear very similar to well-mineralized vanadium or uranium-bearing rock. However, examination with a Geiger counter failed to detect any radioactive anomaly in these areas within the Cutler.

In the North incline, from the Far West fault east to 6 north drift, a section of Cutler at least 60 feet thick is exposed. This rock is predominantly a uniformly red to reddish-brown siltstone. The thickness of the overlying sandstone of the Cutler is about 6 feet. This siltstone is a light-gray color for a distance of about 10 feet on the footwall side of the Far West fault. It is assumed this local color change is related in some way to the presence of the fault and may be due to bleaching of the rock by solutions moving along the fault zone.

The sandstone in the Cutler is believed to be a unit about 30 feet thick, overlain and underlain by silty mudstones. The mudstone in the west part of the mine represents the overlying unit and the silty mudstone in the east part of the mine represents the underlying unit. The broad area of exposure of the sandstone in the mine is due to the unconformity at the base of the Chinle which truncates Cutler beds at an angle of from 3^{o} to 6^{o}.

It is believed the normal color of the three Cutler units exposed in the mine is red to reddish brown. The lighter hues of the sandstone and the greens and grays of the siltstones and mudstone are believed to be the results of solutions moving along the unconformity separating the Chinle and Cutler. These solutions may or may not have been directly related to agencies of deposition for the uranium minerals.

Heavy mineral studies by P. L. Williams, U.S. Geological Survey (written commun., 1957), indicate a significantly larger percentage of pyrite in the lighter colored than the reddish sand in the Cutler in the Far West mine. This suggests possible reducing conditions for iron, which may also explain the change in color from red to green in the siltstones and mudstones.

Inasmuch as the mine workings do not penetrate far beneath the contact, except at two widely separated places (the shaft and near the Far West fault in the North incline), it cannot be determined if the "bleaching" of the Cutler is restricted only to overlying mineralized areas or if it occurs over much larger areas, not specifically related to overlying ore.

Contact

The contact between the Cutler and Chinle represents an angular unconformity. Contours drawn on this surface indicate a rather even dip of about 6.5^{o} to the west. It is assumed the overlying Chinle beds are nearly parallel to the contact. Dip on the bedding in the Cutler was difficult to measure, due to the thin zone of exposure and the low-angle crossbedding in the sandstone of the Cutler. A reliable dip was obtained on the bedding in the silty mudstone beneath the sandstone in the North incline. Here the beds dip N. 48^{o} W. and dip 13^{o} SW. This suggests an angular unconformity along dip of about 6^{o}, and a variation in strike between the Chinle and Cutler beds of nearly 30^{o}. Regional studies suggest that the average difference in strike between the Chinle and Cutler beds is much less than 30^{o}.

No beds of the Moenkopi Formation have been recognized above the Cutler in the Far West mine. It is not known if this is due to nondeposition of the Moenkopi or whether pre-Chinle erosion removed Moenkopi strata that might have been deposited.

Throughout the mine the unconformity marking the contact is a surface of low relief.

Locally, there are scours into the Cutler, and these scours have created local relief on the contact of 1 to 4 feet. No through-going channel-like scours have been recognized. A few feet east of the Far West fault in the south incline there are at least two scour-like features that can be traced to the southeast in 7 south drift and in the stope east of 7 south drift. These features may be tectonic adjustments related to movement along the fault rather than primarily sedimentary features. Locally--in 4 south drift and 2 north drift--small teardrop-like projections of Chinle "intrude" the Cutler. These projections range in width from about 3 inches to more than 12 inches and penetrate the Cutler from 3 to 20 inches. These are apparently due to solution and removal of the Cutler and flowage by compaction of the overlying material into the voids.

At widely scattered localities in the mine, somewhat rounded boulders of sandstone from the Cutler occur above the contact. These are completely surrounded by Chinle material. The boulders of sandstone are very similar in character to the light-colored sandstone of the Cutler Formation below the contact. Although the surrounding Chinle rocks are tightly cemented with calcite, the cementation material has not penetrated the boulders of Cutler.

Contours drawn on the contact, with elevations corrected for regional dip, portray more details of the configuration of local relief on the contact than do structure contours on the present surface.

These contours, corrected for regional dip, indicate a maximum relief of 20 to 22 feet on the contact in the mine area. Between the two faults in the mine the trend of the lows on the contact is north of west in the south part of the mine and slightly east of north in the north part of the mine. The distribution of the thicker sands in the basal Chinle, but many exceptions to this are found, particularly in the northwest part of the mine. East of the Far West fault, the corrected contours show a more involved pattern that may be related to distortion of the contact due to movement along the fault which was not adequately accounted for in correcting for regional dip.

Structure

The strata in the area of the Far West mine form part of the southwest flank of the Lisbon Valley anticline. Regional attitude of the beds in this area indicates that they strike about N. 10°--15° W. and dip about 8° W. To the northwest the beds curve to the northeast, delineating the northwest plunging nose of the Lisbon Valley anticline.

The trace of the Lisbon Valley fault, near the axis of the Lisbon Valley anticline, intersects the surface about 3,400 feet east of the Far West shaft. At the surface outcrop the beds of the Burro Canyon Formation of Early Cretaceous age have been downdropped against beds of the lower Chinle, representing a stratigraphic throw in excess of 2,000 feet and less than 2,500 feet. About 10 miles to the southwest the throw on the Lisbon Valley fault is near 5,000 feet. Thus the displacement along the fault is decreasing considerably to the northwest. The Lisbon Valley fault strikes northwesterly and dips 50°-60° NE.

Within the Far West mine the Chinle beds strike about N. 18 W. and dip about 7° W. The Cutler beds strike more northwesterly and dip about 13° SW.

Two normal faults, here designated the Radon fault and the Far West fault, are exposed by the mine workings. Both faults strike about N. 50° W. subparallel to the Lisbon Valley fault.

The Radon fault, in the west part of the mine dips from 60°-70° SW. Vertical displacement ranges from 6 to 8 feet. The patterns of distribution of ore and sandstone of the Chinle suggest a possible horizontal component of movement, the downthrown side being displaced to the SE. This indicated horizontal displacement is from 100 to 150 feet.

The Far West fault is 800 feet NE of the Radon fault. The Far West fault dips about 60° to the NE. Vertical displacement on this fault ranges from 40 to 60 feet, the greater displacement being to the SE. Geologic patterns on either side of this fault suggest some horizontal displacement, the northeast or downthrown block being displaced northwest an unknown distance.

The indicated direction of horizontal displacement along both faults is in accordance with the theoretical direction of movement on rocks faulted under tension near the nose of a plunging anticline.

Only thin zones of gouge occur along either the Far West or Radon fault. Locally coarse calcite and some barite-celestite fills openings along the faults. The thickest calcite-filling exposed is along the Far West fault in the south incline where the calcite has attained a thickness of nearly 5 inches. This calcite appears to be confined to filling open cavaties; no replacement features were noted.

Two faults with relatively minor vertical displacements occur in the footwall of the Far West fault. These two faults are exposed in the north and south inclines but were not recognized on their projected extension near the face of 6 north drift.

Near the face of 6 north drift, in a zone extending into the footwall area of the fault there are numerous fractures in the sandstone of the Cutler Formation. Vertical displacements measuring 1 to 2 feet along these fractures are indicated. Some of these fractures extend upward into the overlying Chinle which has been displaced along its base. However, the top of the sandstone of the Chinle shows no displacement and the faults cannot be traced into the overlying silty mudstone.

History and production

The ore body in the Far West mine was discovered by diamond drilling from the surface, during the period of accelerated exploration activity in the Big Indian mining district between 1953 and 1955.

The Hidden Splendor Mining Company purchased the Far West mine from the Almar Mining Company.

Production from the Far West mine was first obtained in 1955. The total recorded production to October 1, 1957, from the Far West mine is over 100,000 tons averaging 0.3 percent U_3O_8 and 0.03 percent V_2O_5.

The mine has been developed from a two-compartment vertical shaft extending from the surface to about 60 feet below the Chinle-Cutler contact, a vertical distance of about 575 feet. It is 520 feet from the collar to the ore level.

Mapping of the workings shows no indication of the range in elevation of the working level. The workings in general follow the Chinle-Cutler contact. The drifts to the south and north are nearly horizontal. All haulage within the mine is by diesel-powered trucks; drainage is a minor problem; thus, no attempt has been made to retain a uniform slope of the drift levels.

The 7 north drift connects to a drift in the North Alice mine to the north. The stope at the south end of 4 south and 5 south drift is continuous with a stope in the Radon mine to the south. In event of emergencies entrance to, or exit from, the Far West mine can be accomplished through openings in the adjacent mines.

The mine has been developed to fully utilize a bulk mining method whereby nearly 100 percent extraction of the mineralized zone can be obtained. Drifts have been driven to the property boundaries. Slots or cross cuts connect the ends of the drifts along the edge of the property. A modified long-wall and panel method of stoping has been developed. The working face extends the full distance between the drifts. Temporary support for the stoped areas is obtained by using vertical stulls of timber and roof bolts. As the face of the stope progressively advances toward the North and South inclines, roof support is removed in the stoped areas back of the face and the stope back is caved. Heavy wire netting restrains the caved material from "flooding" the working area near the face of the stope. As the working faces are seldom more than 8 feet in height, the caving can be well controlled in most areas of the mine.

Near the faults the rock is more fractured and difficult to support. Offset of the mineralized areas along the relatively flat faults will require higher working faces. Some modification of the mining methods near the faults will be necessary to permit complete extraction of the ore.

Except for faulted areas, roof support in all the working levels is by roof bolts and wire mats. Timbering has been necessary to support the back where the faults cross the North and South incline.

The workings formed the triangular shaped area near the shaft which include the repair and maintenance shop, dumping area to the ore pocket, and underground electric and ventilating equipment. The backs of these workings extend about 30 feet above the Chinle-Cutler contact. It has been necessary to gunite the walls and back in this area to prevent spalling of the rock, which quickly disintegrates on exposure to air.

During the fall of 1957 the north incline was being extended to the east toward an ore body that was indicated by drilling from the surface. It is assumed that development of this east ore body will be similar to that completed in the west part of the mine.

Mineralized area

The uranium mineralized area developed in the western and central part of the Far West mine is a segment of a mineralized zone extending northwest into the North Alice mine and southeast through the Cord mine, a length of about 6,000 feet. The width of the mineralized zone ranges from 400 to 1,800 feet.

The mineralized area toward which the north incline is being extended is east of the main mineralized area and is about 1,200 feet long and 600 feet wide. The long dimension trends northwesterly. The limits of the mineralized areas have been determined by diamond drilling from the surface.

Southwest of the Far West mine, the mineralized area is confined to a relatively narrow elongate zone ranging in width from 400 to 700 feet. Near the south boundary of the Far West mine the indicated mineralized area broadens to at least 1,800 feet, this widening taking place both up and down dip. This broader mineralized area continues northwestward through the North Alice mine. However, the areas containing the highest concentrations of uranium become smaller and more widely separated to the northwest, and the average uranium content of the rock decreases markedly.

The distribution of the uranium ore in the Far West mine was mapped by examining the drift walls using a Geiger counter. Locally, in the east part of the North and South incline, in the vicinity of faults, and in at least two exposures of obvious scour features, large-scale wall maps were made to determine distribution of uranium over continuous distances. Radiometric contour maps, with arbitrary limits for different contour values, were compiled to show distribution of variation in radioactivity in these areas. This information was plotted on large-scale wall maps, at a scale 1 foot = 5 feet and 1 foot - 10 feet. For smaller scale plan maps, 1 inch = 100 feet, thickness of ore was measured every 20 feet along the walls of the drift. The lower cutoff for ore was arbitrarily taken as rock with lower radioactivity than 2 milliroentgens per hour. After plotting the data on the plan map of the mine, continuous lines were drawn to determine distribution of thickness of ore. It was found that the lowest convenient isopach interval was 3 feet. Attempts to draw isopach lines on 1 or 2 foot intervals resulted in very irregular patterns that could not be reliably projected between points of observation.

The thicker zones (3-6) feet of the ore trend southwesterly nearly at right angles to the general trend of the mineralized ores. The thickest (more than 6-foot) portions of the ore are more equidimensional to plan and show no definite trend. There is a suggested correlation between thickness of ore and thickness of sandstone at the base of the Chinle. There are, however, many exceptions to this. In the western part of the mine, in 3 south drift, only the basal part of the ore is confined to the Chinle. Near the north end of 2 north drift, the ore attains a thickness in excess of 2 feet, though no sandstone of the Chinle is present. In 5 south drift there is an area barren of ore even though the sandstone ranges in thickness from 2 to 4.5 feet thick.

Thick ore and thick sandstone occur on the hanging wall side of the Far West fault. There is no similar zone along the footwall side of the fault that can be correlated with this. Perhaps continued development to the southeast from the face of 5 south drift will be successful in finding the displaced portion of the high-grade zone that ends on the hanging wall side of the fault.

In general the mineralized zone is confined to the basal sandstone of the Chinle and usually extends downward from 1 to 6 inches into the underlying sandstone of the Cutler. Usually the Chinle-Cutler contact can be detected with a Geiger counter because of the marked change in radioactivity between the two formations. This is very often a sharp change, being detected in a vertical interval of less than 2 inches. Commonly the radioactivity extends upward into the silty mudstone overlying the sandstone of the Chinle. The thickness of the radioactive zone in mudstone of the Chinle depends in part on the intensity of mineralization in the sandstone; the richer the ore in the sandstone the thicker the radioactive zone in the overlying mudstone. Exceptions to this apparent relationship can be found.

Information now available indicates three large-scale features that can be used for guides in a systematic search for ore, in addition to the obvious presence of uranium or minerals. These include sandstone at the base of the Chinle, the Chinle-Cutler contact, and sandstone in the underlying Cutler. Where ore occurs in the mine, at least two of the three geologic features are in close association. Locally, the rocks are barren or only sparsely mineralized, even though all three features are present. The ore zone is generally thicker in areas of thicker basal sandstone of the Chinle, but locally the rock is intensely mineralized and very rich in uranium near the attenuated edges of the sandstone.

As a general guide, it has quite often been found that, in the absence of ore even though the above three features are present, ore can be found down dip. This is not so evident in the Far West mine as in some of the mines to the southeast.

No reliable mineralogic guides to ore, other than actual ore minerals, have been recognized. In some intensely mineralized areas the rock is very well cemented with calcite and often is pinkish brown due to finely divided hematite. Where the rock is poorly cemented, yet is well mineralized with uranium, the pinkish-brown color is not evident. Carbonaceous material within the mineralized area is erratically distributed, generally fine grained, and so sparce that no evident correlation between the occurrence of carbon and uranium can be made.

Authigenic chert, generally pink to orange-red, is common in the ore-bearing horizon. The chert occurs in sandstone of the Cutler and Chinle Formations and in silty mudstone of the Chinle. It occurs as small sand-size particles up to masses several inches in diameter. The larger masses quite commonly have their longer dimensions parallel to the contact. No data have been obtained regarding the relative intensity of chert mineralization in barren and ore-bearing rock. This mineral may be a regional guide to ore or it may possibly be a result of the redistribution of mineral during the color alteration so apparent along the Chinle-Cutler contact.

The color of the sandstone and mudstone in the Cutler may be used as a guide to ground favorable for the occurrence of ore. Where the color of the Cutler at the contact is predominantly red, as compared to gray and buff, the overlying rock is generally barren. The zone of lighter colored, "bleached," Cutler extending below the contact may have resulted from the passage of mineralizing solutions along the contact. Exposures in the mine were insufficient to determine average thickness of the "bleached" zone in the Cutler, but it seems improbable that it extends more than a few feet vertically below the Chinle-Cutler contact.

Ore minerals

The most important uranium mineral in the Far West mine is uraninite. Coffinite is probably present in the more carbonaceous areas within the ore. Secondary uranium minerals are rare but locally appear to be forming on the walls of the mine workings. Near the Far West fault at the north end of 6 north drift, secondary uranium minerals, probably zippeite-like minerals (T. Botinelly, oral commun., 1958), are prominent, being localized near the Chinle-Cutler contact.

Fine-grained pyrite and marcasite(?) are common sulfides. Pyrite appears most abundant in the carbonaceous materials and in the areas most intensely mineralized with uraninite.

An unidentified dark mineral with bluish stain was seen in the walls of 3 North drift. This mineral appears to be similar to molybdenum minerals (jordisite and ilsmannite) known to occur in other mines of the district.

Authigenic minerals other than ore minerals include chert, calcite, barite-celestite, and quartz in the form of overgrowths on quartz sand grains. Unidentified clay minerals are rare to common.

In the vicinity of high-grade ore, the rock is commonly well cemented and reddish brown. The red color is believed to be primarily due to the presence of finely divided hematite.

The ore minerals are extremely fine grained and only locally occur in sufficient concentration to be seen with the unaided eye. Because of this, a Geiger counter must be used to detect mineralized areas.

Black splotches of uraninite are rare, but are most common along the footwall side of the Far West fault, and within a few inches of the fault surface. No uranium minerals have been found within the fault, although obvious secondary minerals occur along the Far West fault in the 6 north drift.

Radon mine

The Radon mine connects to the southeast side of the Far West mine and extends 2,100 feet southeasterly from this common boundary. The collar of the shaft that connects to the mine workings is at an altitude of 6,852 feet on the slope dipping westerly from the southwest rim of Big Indian Valley, and is about 1,500 feet southeast of the shaft at the Far West mine, and about 2,000 feet north of the shaft at the Cord mine. The underground workings, about 600 feet beneath the surface, are in the SW1/4 sec. 28, T. 29 s., R. 24 E., County, Utah. A hard-surfaced, all-weather road leads to the mine from the main Lisbon Valley road; the junction of the two roads is about 1 1/2 miles north of the mine and about 3 miles south of Utah State Highway 46.

The Radon property comprises 10 claims: Far West No. 1, Digger, Astor, Fortunate, Blondy, Daisy D., Yellow Rose, Fourteen, Bobwire, and Pinon. These claims cover an area about 4,000 feet wide in an east-west direction, and 2,000 feet long in a north-south direction. The mine has been developed in the western third of this area, being confined to the Blondy, Fortunate, Astor, Digger, and Far West No. 1 claims.

History and development

The claims on the Radon property were first staked in 1953, and, after several barren exploratory diamond drill holes were completed, ore was discovered by diamond drilling in the fall of 1954 (Love, W. H., 1956, p. 96).

The Hecla Mining Company has developed and mines the ore body through an agreement with the property owners who, through various re-organizations, were first organized as the U and I Uranium Company of Kellogg, Idaho; they later merged with Federal Uranium Corporation, and eventually became known as Radorock Resources, Inc., under which company the property was owned in 1955, when production of ore was first obtained. In 1958, the rate of production from the mine was 250 tons per day. Total production to January 1958, was about 120,000 tons, averaging between 0.6 and 0.7 percent U_3O_8. In February, 1958, a total of 55 men, including supervisory personnel, were employed at the mine. All ore produced is trucked to a concentrating plant in Moab, Utah.

The Radon mine is developed by a series of four main drifts, about 120 feet apart, that parallel the strike of the ore zone. A service incline, about midway between the north and south ends of the property, and at right angles to the strike of the ore zone, connects to the drifts. The haulage level, parallel to the service incline, is 40 feet below the ore zone at the west side of the mine and about 100 feet below the ore zone at the east side. Ore is delivered to the haulage level through vertical chutes or raises that connect to the drifts. Access to the mine workings is via a three-compartment shaft through which all supplies are delivered and all ore removed. Auxiliary or emergency access to the underground workings can be obtained through drifts that connect with the underground workings of the neighboring Far West mine and connecting openings are planned to eventually connect with the Cord mine to the south.

An inclined haulageway has been driven from the northern part of the west drift to remove the ore from the ore body in the northwest part of the mine. Ore is delivered downward to this haulageway, hoisted by winch to the west drift, and delivered by train to the raise connecting to the ore pocket near the bottom of the shaft.

Track is laid in all drifts, the service incline and haulage levels. No trackless haulage methods had been developed in this mine to 1958.

Mining is by a modified long-wall stoping method. The width of each stope is the width between successive drifts. Mining advances from each end of the property toward the service incline. Portable steel stulls are used to temporarily support the stopes during each 5-foot advance, after which the stulls are repositioned near the face of the stope, the stope back of the face is caved, and a new cycle begins. The only openings supported after mining are those used for emergency access to neighboring mines. Roof bolts and timber are used to support openings that must be kept open for sustained periods of time, as the ground will not support itself by natural arching. The average height of the stopes is between 5 and 6 feet.

In general, the geology at the Radon mine is very similar to that at the Cord mine to the southeast and the Far West mine to the northwest. The shaft is collared about 180 feet above the base of the Wingate Sandstone and extends downward through the Chinle Formation, which is about 400-420 feet thick, and 100 feet into the Cutler Formation. The ore is in a thin sandstone unit at the base of the Chinle Formation. This ore-bearing unit was not studied as intensively at the Radon mine as at the neighboring Cord and Far West mine and the following discussion is based on about two days of inspection of the underground workings, study of thin and polished sections, and review of data compiled by the Hecla Mining Company and by members of the Raw Materials Division of the U.S. Atomic Energy Commission in Grand Junction, Colorado.

The bedding at the base of the Chinle strikes N. 10^{o}-15^{o} W. and dips 7^{o}-8^{o} SW., conforming in general to the attitude of the unconformity separating the Chinle Formation from the underlying Cutler Formation. Few exposures of the beds in the Cutler Formation were adequate to determine their orientation; but locally in the northwest part of the mine these beds strike about N. 12^{o} W. and dip 9^{o} SW. These data suggest a very low angle of unconformity between the two formations, but analogy with data obtained in mines to the north and to the south suggest the average angular unconformity is from 3^{o} to 5^{o}.

Contours depicting the present configuration of the unconformity separating the Chinle and Cutler Formations do not indicate linear lows or highs on this surface that would suggest channel-like features. Contours showing this surface, after corrections for regional dip are made, do show local relief of as much as ten feet and suggest a northwest orientation of trough-like areas conforming in general to the orientation of similar type features in the Cord mine and the Far West mine.

A normal fault cuts the ore zone in the northern part of the mine. This fault, a continuation of one exposed in the Far West mine, strikes about N. 50^{o} W., dips steeply to the southeast, and displaces the beds about 4 feet vertically. A small component of horizontal movement has resulted in the downthrown side being shifted to the southeast relative to the upthrown side.

The sandstone at the base of the Chinle ranges in thickness from a feather edge to nearly 6 feet, and averages less than 3 feet. Characteristically this sandstone is medium to coarse grained, fair to poorly sorted, and moderately to well cemented. The sandstone grades upward into a siltstone and mudstone containing several percent of medium to coarse quartz grains and is about 3 feet thick. Overlying the siltstone is dark greenish-gray mudstone which locally contains abundant carbonaceous material and much coarse-grained pyrite.

The basal sandstone is commonly arkosic, containing sparse to abundant, subangular to subrounded pink and gray feldspars, commonly microcline. Clear quartz grains, characteristically more rounded than the feldspar grains, comprise the main part of the rock. Cementation by calcite and by celestite and barite is common. Fine-grained silty material and clay are common binding materials in the coarser grained sandstone; and locally form nearly 50 percent of the coarse sandstone, reflecting poor sorting ordinarily exhibited in the coarser grained material. Carbonaceous material is not usually conspicuous in the ore-bearing sandstone, although fine-grained carbonaceous material may be completely masked by the ore minerals.

The most common and most important ore mineral is uraninite, probably with some associated coffinite near carbonaceous material. Some vanadium-bearing chlorite was observed in thin sections of high-grade ore. Other minerals present include galena, calcite, barite-celestite, chalcopyrite, pyrite, and marcasite. Cobalt bloom, erythrite, and possibly bieberite, were seen in one area; but it is not known what the primary cobalt mineral is or how widely distributed it is. The average uranium content (U_3O_8) of the ore produced is 0.6 to 0.7 percent. Vanadium (V_2O_5) comprises only a small percentage of the ore and the average U_3O_8: V_2O_5 ratio is about 20:1. Semiquantitative spectrographic analyses of samples of ore usually indicated the presence of trace amounts of copper.

Well-formed mineral specimens taken from openings along the fault in the north part of the mine included crystals of whewellite, celestite, pyrite, marcasite, calcite, and strontianite, plus some carbonaceous material (Kennedy, V. C., 1958, written communication). Personnel at the mine report finding unbrecciated uraninite in openings along this fault. A sample of fault-filling material comprised mainly of celestite, pyrite, and marcasite was tested with a Geiger counter and found to be anomalously radioactive though no radioactive minerals were identified.

The ore forms a relatively thin tabular body, conformable with the Chinle-Cutler contact and confined mainly to the sandstone at the base of the Chinle Formation. The ore body ranges in width from 400 to 600 feet, averages 3 to 5 feet thick, and is continuous from the northwest to the southeast end of the property being part of a much longer ore body that extends northwest through the Far West mine into the North Alice mine and extends southeast through the Cord mine. Only a small portion of the ore zone was mapped in detail and this work showed the upper margin of the ore to approximately coincide with the upper margin of the basal sandstone in the Chinle, whereas the bottom of the ore locally extends a few inches below the Chinle-Cutler contact, although in general bottoming at the contact. Richer portions of the ore zone locally are confined to, in, and near mudstone partings within the ore-bearing sandstone.

The down-dip margins of the ore zone roughly coincide with the down-dip extension of the basal sandstone and also are near the change from sandstone to siltstone in the underlying Cutler Formation. The up-dip margin of the ore zone does not show relationship to change in lithology of either the basal sandstone or the underlying Cutler Formation. Within the ore zone, equally high grade ore is found within coarse-, medium-, and fine-grained sandstone. Carbonaceous material is so sparsely distributed that there seems to be relationship between distribution of ore and carbonaceous material.

The thickness of the ore in general is greater in areas where the basal sandstone in the Chinle Formation is thicker, but locally ore occurs where the basal sandstone is very thin or absent. Conversely some areas of thick sandstone are low in ore. Near the northeast end of the service incline the basal sandstone looks equally favorable for ore as further down dip, but it is barren of ore. Detailed mapping in this area failed to discover any visible control or reason for termination of ore in this direction.

Cord Mine

Jackie, Jen, and Uncle Ben claims contain the mine workings. The Pisco, Falsie, and Bowlegs claims, also part of the Cord property, adjoin on the east and south. Book and page numbers are not known.

The owner in 1957 was the Jen Mining Co., a subsidiary(?) of the Combined Metals Co. Mr. C. E. Tuttle, (?) Nevada, is president of Combined Metals. Mr. Samuel Craig was the mine manager in 1957 and Mr. William Franklin was the mine foreman. Mr. Dale Bittle was chief sampler. In 1957 about 40(?) miners were employed underground on a two(?) shift daily six-day week basis.

The Cord mine is located in the NW1/4 sec. 33, T. 29 S., R. 24 E., Salt Lake Principal Meridian. It lies in the northwestern part of the Big Indian mining district, San Juan County, Utah.

The Big Indian mining district is reached by U.S. 160 and Utah 46. A black-topped district access road connects with Utah 46 about 6 miles east of La Sal Junction or about 3 miles west of La Sal. About 3 miles south of Utah 46 a black-topped road branches off the district road and leads to the Far West and Radon mines. About three-quarters of a mile south on the Far West-Radon road a black-topped road branches off to the southwest and leads to the Cord shaft. The shaft is about one mile from the junction with the Far West-Radon road.

Stratigraphy

The stratigraphy of the Cord property is typical of the Big Indian mining district. The shaft is collared in the upper part of the Wingate Sandstone of Late Triassic age, and penetrates the lower Wingate, the entire Chinle Formation of Late Triassic age, and a few tens of feet of the Cutler Formation of Permian age. The stratigraphically deepest workings lie about 70 feet below the top of the Cutler.

The Wingate Sandstone, as exposed near the shaft, is a light-yellowish to orangish-gray, fine- to very fine-grained, quartzose, crossbedded sandstone. The contact with the red beds of the Kayenta Formation (Late Triassic?), which conformably overlies the Wingate, is about one-half mile south of the shaft.

The Chinle Formation does not crop out on the property and was not examined in the shaft. Exposures about one mile east show that the upper Chinle is a sequence composed dominantly of reddish mudstone with irregularly interbedded lenses of reddish fine- to medium-grained sandstone. At the outcrop along Big Indian Valley the lower Chinle is separable from the upper Chinle by difference in color. The lower Chinle is various shades of gray, chiefly greenish gray and yellowish gray; reddish colors characteristic of the upper Chinle are rare. The contact between the upper and lower Chinle is not exposed in the mine workings but nearest outcrops suggest the lower Chinle is about 40 feet thick and the upper Chinle about 360 feet thick.

About 5 to 12 feet of the basal part of the lower Chinle is exposed on the ore level. The basal part of the lower Chinle exposed in the mine consists of about equal proportions of sandstone and mudstone, but the proportions vary greatly in different parts of the mine.

The sandstone is chiefly light to medium gray, and, more rarely, yellowish gray. Grain size ranges from very fine to coarse and conglomeratic. The fine-grained sandstone commonly grades to silty mudstone. The conglomeratic sandstone contains granules and pebbles chiefly as flakes and irregular clasts of green mudstone commonly ranging from about one-eighth of an inch to one inch in diameter; granules and small pebbles of quartz occur sporadically in the coarse-grained sandstone. Most characteristic, however, is poorly sorted medium-grained sandstone with a visible admixture of coarse grains; as a rough estimate perhaps two-thirds of the sandstone in the mine is of this type. The sandstone is composed chiefly of clear quartz and feldspar and orange-tinted chert with rare black accessory minerals. The sandstone is firmly cemented with calcite and contrasts in this with the more friable sandstone of the underlying Cutler. In a few places, as near 97,000 E., 101,765, N., the calcite cement forms a visible crystalline matrix with reflecting crystal faces about one-fourth of an inch to an inch across. Bedding is generally obscure. Over short distances the sandstone appears to be horizontally stratified, but gently dipping mudstone partings suggest that much of the sandstone is cross-stratified at a very low angle; the cross-strata dip an estimated 2° to 4° southward.

For the most part, the sandstone of the Chinle forms a single continuous discrete unit that lies directly on the unconformity between the Chinle and Cutler Formations.

The unit is commonly divided into separate lenses by thin mudstone partings, a few millimeters to about 0.1 foot thick. These partings commonly had an initial southward dip. Changes in grain size across boundaries defined by the mudstone partings are frequent. The partings persist downdip from a few feet to about 50 feet. In a few places grayish-green mudstone seams, from about 0.1 to 1.0 foot thick, are included within the sandstone unit. Generally, these mudstone seams are found in the upper part of the sandstone unit where they are essentially tongues of the overlying mudstone unit. Mudstone seams generally thin southward and pinch out as mudstone partings.

Thickness of the sandstone unit ranges from a feather edge to more than 8 feet. In places in the northeastern and northwestern parts of the mine, as near 96,915 E.-101,535 N. the top of the sandstone unit was not exposed, but comparison with sandstone thicknesses in nearby mines suggests that the maximum thickness of the unit is probably less than 10 feet. Sandstone is absent along the southern and southwestern edge of the mine workings southeast of the shaft. It is thickest in the northeastern and eastern and westernmost mine workings. The pinchout of the sandstone unit as seen in the mine workings forms a shallow arc that trends roughly northwestward. The presence of thick sandstone in the southwesternmost part of the mine suggests, however, that the zero isopach contour must trend southwestward from near the shaft and perhaps forms a closed contour defining a local pinchout. The isopach contours are irregular but northwest trends are most common. The thicker sandstone in the northeastern part of the mine trends roughly westward. Trends of the thicker sandstone in the southeastern and westernmost parts of the mine are not known.

Over most of the mine the sandstone unit rests directly on the Cutler Formation and shows little change upward from the unconformity. In places in the northeastern part of the mine, however, as near 96,900 E.-101,670 N., cobbles and boulders as much as 1.5 feet in diameter of friable grayish-yellow sandstone of the Cutler occur just above the contact in well cemented light-gray sandstone of the Chinle. The possible effects of unrecognized local warping and initial dip cannot be evaluated, because no marker beds are present in the Chinle. The paleotopographic pattern is extremely irregular. Relative highs and lows of different breadth and amplitude are scattered almost randomly through the mine area. Trends are, for the most part, indefinite though a general tendency toward a southwesterly trend is suggested. The highest elevations are in the extreme northern and northwestern part of the mine; the lowest, in the southeastern part of the mine. Total relief amounts to about 16 feet. Slope gradients, except in the southeastern part of the mine, are generally low.

The sandstone unit is generally thickest over the relative lows. The correspondence, however, is inexact. Thick sandstone (more than 6 feet thick) extends far beyond well-defined lows. The sandstone does not appear to pinch out along the flank of a well-defined high, though such a high may exist beyond the mine workings.

Contours showing the top of the sandstone unit before folding are generally somewhat smoother than those drawn on the unconformity. Most relative highs and lows shown on the unconformity are diminished by compensating sandstone thickness; most small features are eliminated. The general patterns of the corrected contours drawn on top of the sandstone unit and those drawn on the unconformity are similar. The highest contours on top of the sandstone unit are on the north and northeast; the lowest on the southeast.

The sandstone was probably deposited by shallow streams locally encroaching from the north. The sandstone was most likely derived from similar sandstone in the Cutler Formation. The source may have been local--from a paleotopographic high located over the crest of the Lisbon Valley anticline several miles to the southeast. The sand was not deposited in distinct channels but was spread out as a thin sheet over an irregular topography of low relief.

The mudstone in the lower Chinle is light gray to grayish green. As used here, "mudstone" includes both siltstone and claystone and all mixtures of these grain-sizes, because it is impracticable to distinguish them underground. Most of the mudstone has a high proportion of visible silt particles. Mudstone immediately overlying or interbedded with sandstone commonly contains noticeable amounts of fine- to very fine sand grains. Mudstone occuring as partings in sandstone commonly has a slippery feel, suggesting that it is mainly composed of clay-sized particles. Generally the mudstone is firmly cemented, though commonly it is not as well indurated as adjacent sandstone. In the eastern part of the mine near 97,000 E.-101,765 N. the calcite cement forms large irregular crystal faces that give the mudstone the appearance of coarse-grained marble. In places the mudstone contains small irregular calcite veinlets. The mudstone rarely shows stratification. A few darker, perhaps more clayey streaks, suggest that it is horizontally laminated. Little can be said about the composition of the mudstone, because of the limitations set on macroscopic identification by the particle sizes. Fragments of mica plates are commonly observed, but mica is markedly less abundant and smaller sized in mudstone of the Chinle than in mudstone of the Cutler. This difference is especially helpful in placing the contact between the Chinle and Cutler where Chinle rests directly on similarly colored mudstone in the Cutler.

Over most of the mine area mudstone of the Chinle rests on the basal sandstone unit, but along the southwestern and western edges of the mine the mudstone rests directly on the unconformity. The mudstone commonly is more sandy in an interval of a few inches up from the contact--especially where it rests directly on sandstone of the Cutler. Where the mudstone rests on mudstone of the Cutler, as just southeast of the shaft, the contact may be obscure. Generally though, the distinction can be made on the basis of color change, difference in mica content, local sandiness in the Chinle, and lateral relations. The unconformity beneath the mudstone of the Chinle is generally relatively smooth; distinct scour features are lacking. In places in the southeastern part of the mine mudstone of the Chinle projects peculiarly into the Cutler. These projections may be due to the pressure of overlying rocks that forced poorly indurated mudstone into cracks in the Cutler, the cracks being widened in the process. Carbonaceous material is generally sparce--perhaps most commonly absent--in the lower Chinle exposed in the mine. Carbonaceous material occurs as minute black flakes commonly ranging from very fine to fine grain size. Rarely large fragments of flattened carbonized logs occur, chiefly in the sandstone unit. These range from irregular masses with dimensions measurable in a few inches up to 2.0 feet in maximum diameter and up to several feet in length. The larger carbonized fragments are jet black, have a vitreous luster, and an irregular fracture; they commonly show remnants of woody structure detectible with the aid of a hand lens. The larger carbonaceous fragments are commonly mineralized with calcite and pyrite, and in places uraninite.

Nodules of orange chert occur sporadically in the lower Chinle, most commonly near the contact. These may be mistaken for detrital material, but they are probably epigenetic, and will be further discussed under the heading of mineralogy.

The Cutler Formation consists of sandstone, conglomeratic sandstone with mudstone pebbles, and mudstone. The sandstone ranges from grayish red and orange red to grayish yellow, or a mottling of these colors. The conglomeratic sandstone matrix has similar colors and contains greenish-gray to grayish-red mudstone pebbles. Red colors are uncommon at the contact; the prevalent grayish-yellow color results at least in part from alteration of the reds. The sandstone ranges from silty and fine grained to coarse grained with scattered quartz pebbles as much as an inch in diameter. Mudstone pebbles occurring in the conglomeratic sandstone are commonly irregular discoid, one-sixteenth to one quarter of an inch thick and about one-half inch to 2 inches in diameter. The sandstone is poorly to fairly sorted--generally somewhat less well sorted than the overlying sandstone of the Chinle. The sandstone of the Cutler is composed of subangular clear quartz and feldspar, biotite and muscovite, and abundant black and colored accessory minerals. Near the Chinle contact the sandstone of the Cutler is generally poorly cemented--probably the effect of alteration. Even blocks of Cutler occurring as boulders in the Chinle are strikingly less well cemented than the surrounding Chinle. Away from the contact the sandstone of the Cutler is generally firmly cemented with calcite. Much of the Cutler in the mine is obscurely cross-stratified in small trough sets with low- to medium-angle cross-laminae; in part it is horizontally stratified.

Mudstone of the Cutler is grayish red to greenish gray. The greenish-gray color is due to alteration and is restricted to Cutler near the Chinle contact. Mudstone of the Cutler comprises all proportions of siltstone to claystone. Siltstone varieties grade in places to fine-grained sandstone. Most mudstone in the Cutler contains abundant biotite flakes that are conspicuous on parting planes. It is firmly to well cemented with clay and calcite. Bedding is commonly obscure, but where observed the mudstone is horizontally stratified.

Most sandstone in the Cutler exposed in the mine is in a single unit about 30 to 35 feet thick. This unit underlies about half the mine at the Chinle contact. Stratigraphically higher similar lenses of sandstone also occur in the northwestern part of the mine. The sandstone is generally reddish mottled with yellowish gray and firmly cemented on the haulage level, but with few exceptions yellowish gray and poorly cemented as exposed on the ore level immediately beneath the unconformity. The exceptional areas of red sandstone just beneath the unconformity are largely restricted to the upper part of the major sandstone unit. They are only a few feet to about 25 feet thick and a few tens of feet long.

Mudstone makes up a little less than half of the total Cutler exposed in the mine. Most of this is sandy to silty and red and occurs beneath the major sand unit of the Cutler it is not exposed on the ore level. Above the sand unit, however, is a grayish-green mudstone unit about 1 to 5 feet thick that underlies the Chinle in the western part of the mine. In places, as just south of the shaft, the mudstone is grayish red, probably the original color of the unit. The mudstone is not exposed far downdip below the contact, but, like the sandstone, is probably reddish some distance below the contact. Greenish-gray mudstone also occurs as an isolated lens in the southeastern part of the mine and as clay pebbles in sandstone in a small area enclosing the lens.

Sandstone of the Cutler similar to the major sandstone unit of the Cord mine is found in other mines to the north immediately beneath the Chinle host rock. The continuity of this unit from the Cord north to the Radon, Far West, and North Alice mines cannot be proved on the basis of mine exposures, but M. A. Lekas and N. E. Saylor (oral communication, 1957) reported that drill hole information suggested that a single sandstone unit of the Cutler immediately underlies the Chinle in all the mines from the Mi Vida and Standard northwest through the Cord, and to the North Alice.

Structure

The Cord mine is on the southwest flank of the Lisbon Valley anticline, the major fold of the district. The axis, which trends northwestward, lies about one mile north of the shaft. The Lisbon Valley anticline is one of the salt anticlines of the Paradox basin and lies on the southwestern margin of salt anticline region.

The Lisbon Valley fault, the major fault of the district, lies about one mile north of the Cord shaft. The fault trends northwestward paralleling the axis of the Lisbon Valley anticline. As a system of closely related faults it extends about 40 miles from about 10 miles northwest of the Big Indian district to Slick Rock, Colorado, about 15 miles southeast of the district. Two small faults with stratigraphic throws of about 50 feet and 5 feet are exposed in the workings of the Far West mine and Radon mine about one-half of a mile and one-quarter of a mile north of the Cord shaft. No faults, however, are known to exist on the Cord property itself.

The Wingate Sandstone exposed at the surface of the Cord property contains a system of northwesterly trending vertical joints. These joints, however, are not reflected in the lower Chinle. Only a few irregular minor fractures without definite trend are found in the rocks exposed in the mine workings.

The average dip of the Chinle and younger rocks as determined from structure contours drawn on the unconformity at the base of the Chile is about N. 10° W. 7-1/2° SW. Owing to irregularities of the surface on which the Chinle was deposited, the contours show many minor irregularities. Contours drawn on top of the basal sandstone unit of the Chinle Formation are smoother and show the same average dip and strike. The Cutler Formation beneath the unconformity shows about the same strike but a steeper dip--N. 15° W. 8-10° SW.

History and description

The claims making up the Cord property were located in 1952(?) following the major discovery by C. A. Steen at the present site of the Utex Co. Mi Vida mine about 4 miles southeast. Ore was discovered on the property in 1953(?) by diamond drilling and was blocked out in 1954(?) and 1955. Shaft sinking began in 1955(?) and production started in 1956(?). The mine was sold by the original owners, the E. L. Cord Co., to the Jen Mining Co., Inc., a subsidiary of Combined Metals Co. in 1956.

The shaft has three compartments, two for cages and buckets and one holds a ladder and ventilation pipe. The underground workings are on two levels. The ore level is on the Chinle-Cutler contact and is inclined about 7-1/2° westward. The haulage level is nearly flat but in part is inclined slightly toward the shaft. The collar elevation of the shaft is about 9,920 feet. The ore level station at the shaft is about 6,300 feet. The haulage level station at the shaft is about 6,260 feet.

Workings on the ore level are mainly divided into two roughly perpendicular sets of drifts. One set of drifts, numbered north from the shaft, is nearly parallel to the strike of the Chinle beds; the other set of drifts, numbered east and west from the central drift, the "east cross-cut," is about parallel, with the regional dip. Spacing of drifts is not regular, but in the eastern part of the mine the drifts average 160-180 feet apart. Most of the mine was still being developed during the period of study in mid-1957, but some stoping had begun in the western and northwestern part of the mine on the Jen and Jackie claims. The company plans to extend the ore level workings several hundreds of feet further east and also to the north(?).

The haulage level workings consist of one long nearly level northeast-trending drift, "the east cross-cut," about paralleling and underlying a dip-drift, "the east cross-cut" on the ore level. From this long drift five haulage drifts branch off paralleling strike drifts on the ore level.

All track is on the haulage level. Broken rock on the ore level is scraped to raises leading to the haulage level. Ore is stored in chutes at the bottom of the raises until loaded into bottom-dumping cars. The cars are trammed on the haulage level to the shaft where they are opened automatically. The ore is dumped into a pocket where it is loaded into the buckets with a scraper and then hoisted to the surface.

Mining on the ore level is a modified room and pillar method--or long wall retreating(?). The pillars are made by driving drifts 10 to 20 feet away and parallel to older drifts. The old drifts are caved. The pillars are then removed--so far as practicable.

Ore deposits

The ore in the Cord mine lies mainly in a single tabular lenticular body in the lower Chinle near the contact with the Cutler Formation. The one foot-percent contour approximately outlines rock generally considered minable. As thus defined, the long axis of the ore body trends northwesterly (N. 30°-50° W.). The ore body is more than 900 feet long; it extends beyond the property boundary on the north and has not been fully defined on the south. It ranges in width from a few tens of feet to more than 600 feet and averages about 400 feet. Thickness of the ore body ranges from a few inches to more than 6 feet and probably averages about 3 feet. Several satellite ore bodies lie outside the main ore body and have lengths and widths measureable in a few tens of feet to more than a hundred feet. Other small bodies as yet not exposed probably exist in the ground adjacent to the mine workings.

Samples were collected by company personnel at about 5-foot intervals from the centers of the working faces of the drifts. Where feasible, channel samples were made of the entire face. Sample thicknesses ranged from 5.5 to 8.5 feet and most commonly were 6.5 or 7.0 feet. Grades of these samples ranged from barren to about 6 percent eU. The samples were assayed on the property with a laboratory scaler. Each sample point is assigned an average including the assays ten feet away on each side. The variation in assay feet of ore between sample points only 5 feet apart may be extreme.

The northwesterly trend of the ore body by the one-foot-percent eU contour is also reflected in general by contours of higher and lower value. In addition, however, high-grade areas as outlined by the 8-foot-percent eU contour have axes that show distinct subsidiary trends ranging from southwesterly to westerly. These trends are about parallel with the direction of the regional dip and probably of the initial dip of the sediments. Similar subsidiary trends within a large ore body were noted by M. A. Lekas and N. E. Saylo in the Utex Co. Mi Vida mine (oral communication, 1957). Less well mineralized material as outlined by the 0.5-foot-percent eU contour generally forms a narrow band around the material of higher grade outlined by the one foot percent eU contour and thus encloses an area with similar trend to the ore body as a whole.

The Cord deposit is part of a much larger deposit that forms a mineralized belt of ground practically continuous for about 5 miles from east of the Standard Uranium Co. Big Buck mine through the Cord workings to beyond the present workings of the North Alice mine. The belt of mineralized ground is very irregular in width but over much of its length the belt averages more than 1,000 feet wide as defined by the 0.1-foot-percent contour shown on unpublished mapping of the northwest half of the Big Indian district by M. A. Lekas and N. E. Saylo, U.S. Atomic Energy Commission (written communication, 1957). The mineralized belt crosses the southern part of the Cord property. The approximate center of the belt lies just north of the common boundary between the Jen and Jackie claims. The Cord property includes about 1,500 feet of the belt along its length; the average width of the belt on the Cord property is about 700 feet. The belt as a whole trends northwesterly; the Cord ore body is parallel to this trend. Lekas and Dahl (1956, p. 162) pointed out that practically all of the ore deposits of the Chinle lie within a belt that is confined within a strip between the 6,200 and 6,700 foot contours on the base of the Chinle and that within this strip the mineralized ground rises up dip as one proceeds southeastward. The Cord deposit as known from existing workings lies between the 6,215 and 6,370 foot contours. The axis of the main ore body rises from about the 6,300 contour on the northwest to about the 6,340 foot contour on the southeast. The axis of the main ore body rises similarly in relation to the structure contours drawn on the top of the basal sandstone unit of the Chinle. The low value of 2 mr/hr was selected as being above the average maximum background radioactivity of the mines studied in the Big Indian district. Comparison with the assay foot ore distribution map suggests that rock with radioactivity of about 2 mr/hr generally approximates rock with assay-foot values of one-foot percent or more. The edge of "ore" as defined by the 2 mr/hr contour and the one-foot percent contour are about the same. General experience in all the mines in the district suggests that rock with radioactivity of 2 mr/hr or more aproximates what miners consider ore. The highest contour value used, 20 mr/hr, was determined by the maximum sensitivity of the counter. Rock with radioactivity of 20 or more mr/hr invariably contained visible uranium minerals. In the following discussion the term "ore" will be used for rock with radioactivity of 2 or more mr/hr or for rock with a foot-assay value of 1 or more foot-percent eU.

In the Cord mine most ore is in the basal sandstone unit of the Chinle Formation. Most generally the limits of ore are approximately defined by the limits of the sandstone unit. Frequently however, the ore also extends above the sandstone unit into the overlying mudstone, and where the underlying Cutler is sandstone down into the Cutler as well. The general characteristics of the ore are illustrated in the wall section across the ore body along the east cross-cut.

Ore is mostly in fair- to poorly sorted medium-grained sandstone with a visible admixture of coarse grains. This is the dominant rock type, probably making up 60 to 70 percent of the unit. However, where the fair to poorly sorted medium-grained sandstone is interbedded or adjacent to noticeably finer or coarser grained sandstone, the ore is generally higher grade in or largely confined to the medium-grained sandstone. Generally, only the gross aspects of the sandstone are reflected by the distribution of ore. Detailed lithologic features, such as mudstone partings and bedding planes, rarely have a strong influence on ore distribution. Thus, in the 50 feet northeastward along the east cross-cut from the 3-south drift though mudstone partings are numerous most are cut across by the contours showing radioactivity. On the other hand, one prominent mudstone parting 42 to 53 feet northeastward from the 3-south drift approximates an axis through a small pod of high-grade (20 or more mr/hr) rock. The bottom of a large high-grade pod 37 feet northeastward to 3 feet southwestward of the 3-south drift is approximated by a mudstone parting; the high-grade extends further than the mudstone parting and for a short distance near the middle part of the pod extends below this parting. An example of apparent local control of ore distribution by a bedding plane and change of grain size is in the north drift Cord mine. Here the section is about parallel with the strike of the beds. The ore is mostly confined to a coarse-grained sandstone for a distance of about 20 feet. To the southeast the ore also extends into medium-grained sandstone and here the top of the ore is fairly well defined by a lenticular mudstone seam that also marks in part a change in grain size from medium to fine. The examples given illustrate the difficulty in generalizations about the Cord ore body in relation to lithology. Though mudstone partings and seams and changes in grain size locally influence ore distribution the relations are not specific.
That is, ore may be higher or lower grade or end upward or downward against a mudstone parting or seam, or a bedding plane. Probably most mudstone partings are as well mineralized as the adjacent sandstone.

Parts of the Cord ore body are exceptional in that they are in mudstone beyond the known limits of the basal sandstone unit. Thus there is a small isolated pod in mudstone in 2 S. 2W-0 drift and ore extends beyond a feather edge of the sandstone unit near the junction of 2 S-0 drift with 2 S. 3W-0 and 2 S. 3 W.-0 drifts.

The 2 S. 3W.-0 drift, Cord mine shows the habit of ore in mudstone. The ore forms irregular pods a few tens of feet long and a few feet thick; the grade is somewhat lower than the ore body as a whole. The mudstone is the typical greenish gray characteristic of the Chinle. No differences in grain size were recognized. Like mudstone in other parts of the mine silt content was estimated to be higher than clay content. Bedding is not evident. As far as could be determined the entire exposed mudstone was uniform from bottom to the top of the exposure and not dissimilar lithologically from mudstone that is commonly barren in other parts of the mine. The area mapped does differ from other mudstone areas in containing scattered irregular small veinlets of calcite, short small irregular joints and irregularities in the Cutler contact and in color of the Cutler. The irregularities in the Cutler are discussed in a subsequent paragraph; they do not appear to have localized ore. The calcite veinlets and irreugular joints are not typical of other areas of mudstone containing ore such as in 2 S. 2W.-0 drift and are believed to be contemporaneous or later than the ore.

Ike Mine

The workings of the Ike mine consist of a two-compartment shaft that is 550 feet deep to the slusher level. The main workings are developed on the 450-foot level, and consist of two haulage drifts, one that trends northward essentially along the strike of the Cutler-Chinle contact, and the other that trends southward along the strike of the contact. Cross-cuts follow the ore zone up dip from these drifts. Cross-cuts also extend down dip from the south drift, following the ore layer. Ore from these workings is slushed into ore shoots that drop it down to the slusher level. It is not known when shaft-sinking began or when production started.

The ore in the Ike mine is mostly in sandstone in the lower part of the Chinle, but sandstone in the upper part of the Cutler is mineralized in a few places along the 450 level and the workings up dip.

Actually, the Cutler-Chinle contact is not well defined and its position is perhaps debatable. Good sandstone in the Cutler is exposed along the north drift on the 450-level, in places along the south drift on the 450 and the workings up dip, and in a few places in the workings down dip from the 450. This sandstone is fine to medium grained, rather well sorted and clean, massive though cross-laminated, and mostly of medium hardness; neither feldspar grains nor mica is conspicuous. Where exposed it is dominantly yellowish or gray, but in most places 10 to 20 feet from ore it is reddish or maroon in color (typical Cutler color).

In most parts of the mine this "good Cutler sandstone" is overlain by a greenish-gray mudstone, as much as 3 or 4 feet thick. This mudstone is massive, with no bedding evident; sand grains and mica are generally sparse. Commonly the contact of this mudstone with the underlying sandstone is sharp but very irregular, and in places "boulders" of the underlying sandstone are in the lower part of the mudstone.

In places this mudstone pinches out, and the sandstone is in contact with Chinle ore sand. In the southeast part of the mine (near sta. RPF-4), this mudstone underlies a sandstone (bed #2, sta. 4) that looks like good Cutler, although it does contain a few fragments of carbonized wood. This sandstone is exposed in places in the southeast part of the mine, though its limits are not completely exposed, nor is its thickness evident in most places.

The "Cutler sandstone" of the southeast part of the mine is overlain by a conglomerate composed of flattish shale pebbles in a matrix of medium-grained sand. These pebbles may have been derived from the massive greenish-gray mudstone, but as most of them are flattish, more likely they were derived from thin layers of mud deposited in local pools. This conglomerate contains little mica.

The ore sand itself is a unit of lenticular structure and varied lithologic character. Where it is present, however, its base is sharply defined, and this stratigraphic plane has been used as the base of the Chinle, for mapping purposes. When the ore sand is absent, this stratigraphic plane is still sharp and easily recognized, for the mudstone overlying the ore sand is conspicuously layered, with thin silty layers, and with rather abundant fragments of fossil wood. Thus this mudstone can be seperated from the underlying massive mudstone where the two are in contact. Because this is a recognizable plane, and because it is exposed almost everywhere in the mine, it is used as the Cutler-Chinle contact.

The ore sand is dominantly medium grained, but commonly it grades to coarse grained, rarely to fine grained. Much of the medium- to coarse-grained sandstone contains pebbles and fragments of mudstone, and some of the sandstone is conglomeratic. The sand is dominantly quartz but probably is fairly argillaceous; feldspar and mica are sparse. Small masses of orange chert are scattered through the ore sand, but rather sparsely so.

The ore sand is dominantly cemented with calcite. Where barren the sandstone is medium soft and not conspicuously calcareous, but where mineralized to average grade ore it is fairly hard and crystal faces (1/4 - 1/2 inch) of cement are commonly seen. In the highest grade ore the sandstone is so hard and dense as to appear like jasperoid, but I don't know whether the cement is actually silica or calcite.

Although the evidence is not conclusive, the "ore sand" appears to be a selective mineralization of sandstone at the base of the Chinle rather than mineralization of a lithologically and stratigraphically unique and distinct sandstone bed. It is likely, however, that there is a favored lithologic type of sandstone, which contains most of the ore, but this material appears to grade by facies change into the less favorable and barren sandstone along a single bedding unit. Mineralogic changes accompanying mineralization, however, have made enough changes in the ore as to make it difficult to define completely the original lithologic characteristics of the favored host rock.

The favored host rock probably was medium to coarse grained, relatively clean of argillaceous material, mostly nonconglomeratic (though a few mudstone pebbles may be present), and without conspicuous bedding or laminations. In contrast, the "ore sand" where it is low grade or barren is commonly thinly and irregularly bedded, obviously argillaceous, and commonly is a mudstone- and limestone-pebble conglomerate.

Nearly everywhere the sandstone is mineralized, and certainly almost everywhere it is more than weakly mineralized, the sandstone is reddish in color, and the intensity of the color is a rough guide to grade of ore. The mineralized sandstone, also, is obviously calcareous (except possibly the highest grade ore, which might be siliceous), and the habit of this cement, along with the ore minerals, gives the rock the appearance of a coarser grain size than is probably real. These characteristics (color, calcareous cement, and apparent coarser grain size) are evident even where the massive, fine-grained sand of the Cutler is mineralized.

The base of the ore sand is sharp and well defined, but upward there is no definable limit in most places, and the ore fades out upward. In general the sandstone beds become more shaly upward, commonly becoming a mudstone-pebble conglomerate, with mudstone layers. Fossil wood, most of which is flattened to thin carbonized layers, and which contains much iron sulfide, increases in amount upward in this rock. Thus the upper limit of the ore sand is an arbitrary one in most places, and probably has not been picked consistently throughout the mine.

The strucutre of the ore sand is complex and ill-defined. For the most part it is a composite of lenses without clear cut bedding planes so that the lithologic characteristics grade vertically as well as laterally. This relationship suggests to me that the ore sand might have been deposited under conditions of sheet wash rather than in streams. On the other hand, in places along the edges of the ore sand masses, and especially along the edge in the north part of the westernmost workings, the ore sand pinches abruptly and has the habit of a cut-and-fill lens. Hence, the ore sand must have been deposited in part at least by stream action, but in places it might have been more like sheet wash.

Contours drawn after removing regional dip show that the bottom of the ore sand is in shallow basin-or channel-like depressions in most parts of the mine, though in part of the southwest part of the mine the ore sand is on a relatively large "high," and some of the thickest ore sand is there.

In general the ore is highest in grade in the lowest foot of the ore sand, grading upward, though in places there are high-grade spots 2 or 3 feet above the base. I can see no obvious reason for ore localization (except possibly the real "hot spots" that might be replacement of fossil wood) unless it is a matter of a fairly subtle lithologic favorableness. The sand (at least after being mineralized) appears to be more "sandy" in the lower part. And, when the ore dies out but the sand continues, the sand appears to contain more argillaceous material, commonly in the form of mudstone pebbles. (Admittedly, one must consider the possiblity that the mineralization so altered the rock that the mudstone and limestone pebbles are largely destroyed for megascopic recognition.)

Lisbon Valley, Utah, 7/31/57

sta. RPF-4

Ike mine, coordinates 91,875 N., 99,785 E.
At this point the following section is exposed:

	Feet
5. Mudstone, greenish-gray, much like unit 1 in appearance, but thinly bedded; with sandstone partings and shale pebble conglomerates in sand matrix; contains abundant fossil wood (carbonized and pyritized)	2.0+
4. "Ore sand;" bottom contact is well defined, top grades upward and is ill defined; consists dominantly of medium-grained sandstone, of medium hardness, with sugary look of quartz overgrowths but obvious with some calcite cement, especially in upper part; dominantly of light gray color but with some light reddish brown in lower part where mineralization is best; contains some fine as well as some coarse-grained sandstone with shale pebbles. Upper half of unit contains an increasing amount upward of thin-bedded sandstone, with shale partings and thin layers and shale pebbles, and also an increasing amount upward of thin-bedded sandstone, with shale partings and thin layers and shale pebbles, and also an increasing amount of fossil wood, part carbonized and part replaced with pyrite. Bedding planes in upper part of unit contain a fairly conspicuous amount of mica, a little of which is biotite. Radioactivity is concentrated in the lowest foot, decreasing in amount upward, and the upper half is barren or essentially so. (Note: where the bottom part of the "ore sand" is fairly rich, as here, some ore minerals have sneaked down into the top few inches of the underlying shale-pebble conglomerate	5.0
3. Shale-pebble conglomerate, of thin platy pebbles of green-gray shale like that below, in sand matrix; micaceous but not abundantly so	1.0
2. Sandstone, light-brown to light-gray, massive, rather fine grained, fairly hard and obviously somewhat calcareous, but in places fairly soft like the "sugar sand," which it resembles in appearance; contains a few fragments of fossil wood (carbonized); micaceous but not conspicuously so	3.5
1. Mudstone, greenish-gray massive	0.3

sta. RPF-5

This station is near the southwest edge of the ore sand. At this point it is about 2 feet thick and is composed of a limestone- and shale-pebble conglomerate, very much like RPF-2a, except that it is reddish (even more reddish than RPF-2b, and also even more mineralized than 2b). The reddish color is mostly in the sand matrix, but some of the limestone pebbles are also tinged with red.

Big Buck mine

The workings of the Big Buck mine are the southeast continuation of the Mi Vida mine workings, the underground workings of the two mines form connected and continuous openings. The Big Buck ore body is southeast of the head of the canyon locally known as Steen's canyon, and is about 1,500 to 2,000 feet southwest of the rim of Big Indian Valley in the SE1/4 sec. 11, T. 30 S., R. 24 E. The mine administration buildings and ore bins are about 2,000 feet further west near the portal of the adit that crosscuts to the ore body.

The mine is owned and operated by the Standard Uranium Corp., which owns the Big Buck group of 15 claims paralleling the southwest rim of Big Indian Valley. A number of these claims are contiguous with the east boundary of the claims on which the Mi Vida ore body has been developed. The Big Buck ore body is near the central part of the Big Buck group of claims, having been developed on the Big Buck 9, Big Buck 9A, and Big Buck 10 claims.

Two roads lead to the mine. One extends nearly due east to the mine from a junction with U.S. Highway 160, about 7 miles west of the mine. This road is hard surfaced from the main highway to the foot of Steen's canyon, from which point it is graveled to the mine area. The other road, branching from the main Lisbon Valley road, some 4 miles to the north of the mine, has been constructed along the top of the southwest rim of Big Indian Valley. This unsurfaced road is narrow with local steep grades near the mine and is used mainly by passenger vehicles; whereas the road to the west from the mine is the main road for truck haulage of ore from the mine.

History and development

The Big Buck claims were located in 1948 by three individuals from Moab, Utah: Donald Hayes, James Bentley, and J. W. Brewer. Several changes in ownership of the property took place prior to July 1954, when the claims were sold to Standard Uranium Corp. This company, by diamond drilling from the surface, discoverdd and defined the limits of the ore body during the early part of 1954. The first ore was produced and shipped February 2, 1955 (Dare and Durk, 1956, p. 5). Total production to January 1, 1958, was >250,000 tons averaging between 0.2 and 0.3 percent U_3O_8. By the early part of 1959 the original ore body had been nearly depleted, but continuing exploration had discovered additional ore bodies several hundred feet to the southeast, which could be developed and mined from the existing facilities in the Big Buck mine.

The Big Buck mine has been developed by driving an adit approximately 2,000 feet long from the west to reach the ground a few tens of feet below the ore body. Raises, both vertical and inclined, were driven to the ore level from the adit level. The ore body was developed by a series of drifts and crosscuts, and mining was by room-and-pillar method (Dare and Burk, 1956, p. 11). Trackless haulage was used on the ore level; all ore was removed through the raises to the adit level and where it was moved by train to the ore binds near the portal. Ore is trucked to a concentrating plant in Moab, Utah.

An auxiliary opening for mine personnel and limited removal of ore is through an incline to the surface at the northwest end of the ore body. This incline is part of the Mi Vida workings, but is utilized by the Standard Uranium Corp. through an operating agreement with the owners of the Mi Vida mine.

Geology

The ore zone at the Big Buck mine is in the lowest 10 to 30 feet of the Chinle Formation and the upper few feet, generally less than 5 feet, of the Cutler Formation. The altitude of this ore zone ranges from about 6,600 feet on the northeast side of about 6,570 feet on the southwest margin. The altitude of the surface above the ore body ranges from 6,900 to 7,000 feet; thus the ore body is overlain by about 400 feet of barren rock. As the Chinle Formation averages about 400 feet thick, only a thin layer of the Wingate Sandstone caps the slope above the ore body.

At the surface the bedding strikes about N. 30° W. and dips 7°-8° SW. The unconformity at the base of the Chinle Formation strikes N. 27° W. and dips 9°-10° SW. The bedding in the Cutler Formation on the southwest side of Big Indian Valley, near the Big Buck mine, strikes about N. 30° W. and dips 16° SW and becomes more gently inclined toward the southwest. The angular unconformity between the Cutler Formation and the overlying Chinle Formation in the vicinity of the Big Buck ore body probably averages about 5°.

The host rock for the ore is a sandstone unit at the base of the Chinle Formation. This unit ranges in thickness from 10 to 30 feet, is gray to greenish gray, ranges from fine-grained silty sandstone to coarse-grained sandstone. Although it was not studied intensively throughout the mine, the host sandstone is believed to be generally much finer grained than the host rock in mines to the northwest in the Big Indian mining district.

In the area where detailed mapping of the ore zone was done, the ore-bearing unit was uniformly fine grained to silty, and tightly cemented with fine-grained calcite. In general the sandstone unit is massive and nearly horizontally bedded; however obscure crossbedding is indicated by inclined parting planes, many of which contain thin films of carbonaceous material. Jointing is relatively inconspicuous.

The base of the sandtone unit is at the unconformity separating the Chinle from the underlying Cutler Formation. In general, the unconformity is a surface of low relief, but locally is markedly irregular with local relief of 1 to 2 feet. Thin lenses of mudstone pebble conglomerate, seldom more than a few inches thick, occur locally at the base of the sandstone.

Overlying the ore-bearing sandstone unit is gray to greenish-gray shale and mudstone containing common to abundant carbonaceous material, mainly macerated pieces of carbonized plant material. The base of this mudstone unit generally forms the top of the stoped areas and hence seldom more than a few inches of it are exposed in the mine, and where exposed was commonly more than 10 feet above the floor of the stopes, thus negating close observation within the mine. Locally where broad expanses of thin unit were exposed in the backs of stepped-out areas, ripple marks were observed within it.

Commonly less than 3 feet of the Cutler Formation was exposed in the mine workings. Where exposed the lithology of the Cutler is mainly medium grained sandstone, less well cemented than the ore-bearing sandstone, and differentiated from sandstone of the Chinle by containing common green biotite and lack of carbonaceous material. Near the southwest margin of the ore body a rather persistent zone or discontinuous band of pinkish- to orange-red chert has nearly completely replaced a band of coarse calcite about 2 feet below the Chinle-Cutler Contact. This is in contrast to several of the other mines in the district, where chert is most common at or a few inches above the contact. Where this chert occurs in the Big Buck mine the Cutler is very fine grained sandstone, tightly cemented with calcite, dark brown to purplish in color. Surrounding and paralleling the outline of the chert, the sandstone has been "bleached" to a gray to greenish gray; this "bleached" band ranges in width from a few millimeters to several inches. This relationship between the chert and the lighter colored rock suggests a redistribution of material within the rock accompanying the formation of the chert; the redistribution probably resulted in migration of hematite or the reduction of ferric to ferrous ions. Thin sections of the cherty material, commonly show fine-grained pyrite subparalleling the outline of the chert masses, suggesting an exclusion of iron during formation of chert, the iron having recrystallized as pyrite or marcasite. This pyrite-chert relationship is impossible to detect without the aid of the microscope, although commonly the chert has discontinuous films of dark-gray material at its borders, the gray material perhaps being finely disseminated iron sulfides. Examination of hand specimens suggests that near the more horizontally oriented masses of chert, the dark film is more prominent along either the upper margin or the lower margin of the chert band. It was impossible to determine the original orientation of the hand specimen to determine if perhaps the dark-gray or iron film occurred at the top or at the bottom margin of the chert.

The ore minerals are commonly so fine grained and sparsely disseminated that determination of their gross relationship to the features in the host rock was impossible. Presence of uranium minerals is usually determined only with the aid of instruments to measure the radioactivity of the rock. Locally, higher concentrations of the ore minerals form dark-gray splotches within the rock or along parting planes. Joint surfaces on mine workings that had been exposed to the air for several months locally have thin films of brightly colored green and yellow fine-grained secondary uranium and vanadium minerals. Many of the areas of darker stained rock may be concentrations of fine-grained carbonaceous material. Widely separated concentrations of copper minerals, especially sulfides, commonly have limited halos of green copper carbonates.

Ore minerals identified in thin and polished sections of the ore include uraninite, montroseite, and vanadium hydromica(?). Chalcocite and marcasite were observed in one location in the mine; fine-grained and very sparse chalcopyrite was questionably identified in a polished section of ore. A hand sample, collected by one of the miners, contained abundant discrete grains of native copper. This native copper occurred along the contact between the Chinle and Cutler Formations and extended about an inch into the Cutler and formed dendritic masses nearly an inch in diameter. The grains of native copper in the Chinle commonly were within or closely associated with pellet-like masses of bentonitic clay. Nothing is known of the overall distribution of native copper in the mine area. Galena is common within the high-grade uraninite specimens and possibly is mainly of radiogenic origin. This galena commonly shows sharp boundaries against quartz and very irregular to ragged boundaries against pyrite and uraninite, and contains submicroscopic inclusions of foreign material. Pyrite, lesser amounts of marcasite, calcite, and hematite, plus chlorite and clay, form varying amounts of the mineralized rock.

Microscopic relations suggest the main ore minerals, uraninite and montroseite, are confined mainly to the interstitial areas between the clastic grains of the host rock. Interstitial clay and calcite cement have been replaced. "Shatter" texture of the larger masses of uraninite suggests it may be an inherited texture resulting from replacement of silt or crushed wood. Polished sections show that locally some of the quartz grains have been partially to nearly completely replaced by the uraninite. Pyrite occurs scattered within the uraninite and as thin films around some of the quartz grains, suggesting a later age than the uraninite. Paragenetic relationships between the minerals cannot definitely be determined; but it is believed there has been more than one generation of galena, pyrite, and calcite, and possibly there has been more than one generation of uraninite. These multiple generations of the minerals may have been closely related in time, and may represent local solution, slight redistribution, and reprecipitation, all having occurred during a single phase or during successive surges of the mineralizing process.

It is very difficult to determine the relative percentages of uranium and vanadium content of the ore, as it is difficult to determine distribution of vanadium minerals except in areas of relatively high concentration of montroseite, which locally is somewhat altered to corvusite. However, according to the average assay data of the ore that has been shipped to concentrating plants, the percentage of V_2O_5 in the ore is slightly more than double the percentage of U_3O_8.

The ore body is tabular and concordant with the basal sandstone unit in the Chinle Formation. It is elongate in a northwest-southeast direction, and is approximately three times as long as it is wide; the maximum width being about 300 feet. Within the Big Buck mine it is about 900 feet long, but the northwest extension of it continues several hundred feet into the Mi Vida mine. The higher grade portion of the ore is commonly in the lower part of the basal sandstone; however it is the practice within the mine to remove nearly the entire thickness of the basal sandstone and ship it as ore. Apparently there is sufficient uranium in the more intensely mineralized portion to permit complete extraction of the ore sand within the limits of the ore body.

No study was made to determine if there are any obvious geologic factors that control the southeastern limits of the ore body.

Big Buck No. 11A claim

The Big Buck No. 11A claim is on the southwest rim of Big Indian Valley about 2 miles north of Big Indian Rock and about a mile southeast of the Big Buck workings. A truck trail to the property branches off the Big Indian Valley road about a mile north of Big Indian Rock. The truck trail passes about 40 feet below the mineralized outcrop.

The Big Buck No. 11A claim is part of the Big Buck group of claims which were located by Donald Hayes in 1948 and are now part of the Standard Uranium Corporation's holdings in the district. (See history of Big Buck workings.) Possibly part of the deposit is on the adjacent Big Buck No. 12 claim.

The workings consist of a few small rim cuts into outcropping mineralized rock. The ore was sent down a chute about 35 feet long to a truck station on the access road. Though there is no recorded production from this claim, probably several tons of medium-grade uranium vanadium ore were shipped from these workings in 1953. The prospect was idle when examined in October 1953.

The ore occurs in the lower part of the basal unit of the Chinle Formation. The basal unit at this locality is about 75 feet thick and consists of about 60 percent gray sandstone and 40 percent greenish-gray mudstone. Carbonaceous material--fragments of coaly fossil plant material--is abundant in irregular layers in the sandstone. The unconformity at the base of the Chinle at this locality cuts out a prominent light-orange fine-grained crossbedded sandstone unit in the Cutler Formation.

A dark-gray vanadium mica and a bright-yellow mineral of the carnotite group are the ore minerals. The ore minerals are mainly in irregular layers and pods in sandstone containing abundant carbonaceous material. The mineralized outcrop is only a few tens of feet wide and a few inches to a few feet thick. This mineralized outcrop is one of the few in the Chinle Formation in the Big Indian mining district, and probably is the closest to the large deposits that characterize the district. The nearest workings of the Big Buck mine, one of the large mines of the district, lies about a quarter of a mile west of this outcrop.

Idle Day and Big Buck 12A

The Idle Day and Big Buck 12A claims are on the southwest rim of Big Indian Valley about 1 3/4 miles north of Big Indian Rock. Because of uncertainty about the boundaries of the claims, at the time the mineralized outcrops were examined in 1953, both claim names are given; probably the occurrences are on the Big Buck 12A claim. A jeep train branching from the access road to the Big Buck 11 workings passes about 100 feet below the prospect. A drill site access road branching from the roads around the Mi Vida mine goes through the claim on a bench about 100 feet above the prospect.

According to a notice on the property, the Idle Day claim was located May 31, 1951, by C. H. Christensen, E. L. Christensen, and Donald Hayes. The Big Buck 12A claim is part of the Big Buck group of claims located by Donald Hayes in 1948. (See history of Big Buck workings.) The claims become part of the Standard Uranium Corporation's holdings in 1954. The claim is undeveloped and no production is recorded from it. A few hundred pounds of ore were removed probably for sampling, in the period 1953-56.

Two occurrences of mineralized rock crop out about 300 feet apart at this locality. The ore minerals present include a dark-gray vanadium mica and a bright-yellow mineral of the carnotite group. The minerals are found in a carbonaceous trashy zone near the basal sandstone of the Chinle Formation. The trash consists of small fragments of brown to black coalified wood. Limonite is abundant and probably indicates the former presence of pyrite.

Both pods of ore are small with thicknesses of a few feet. These occurrences are among the few mineralized outcrops at the base of the Chinle along the rim of Big Indian Valley. The mineralized outcrops are unlikely to be continuous with any of the large ore bodies of the district because the nearest known large ore body lies about a half mile northwest of the Idle Day claim.

Uranium and Vanadium deposits in the Morrison Formation

Geographic distribution

Uranium-vanadium deposits are irregularly distributed along nearly the whole length of outcrop of the middle part of the Morrison Formation in the Lisbon Valley area. An exception is the relatively unprospected Morrison on the southwest side of South Mountain between Lackey Basin and upper Pack Creek which contains no known prospects. A part of the area containing very few deposits is the outcrop around Greasewood Canyon in the eastern part of the area.

Most of the developed deposits are small, probably ranging from a few tens of tons to a few hundreds of tons of uranium-vanadium ore. The relatively large deposits are few and tend to be closely grouped. Most individual deposits within the groups range from a few hundred to a few thousand tons; the aggregate ore of the major groups ranges from a few to many thousands of tons. There are three major groups in the Lisbon Valley area: in the northern part of the area the Yellow Circle group in upper Kane Springs Canyon, and in the southern part of the area the Waterfall group on the northeast side of Deerneck Mesa and the Frisco group on the west side of East Canyon. Two relatively large individual deposits, each containing about 10,000 tons, are in the southern part of the area: the Happy Jack mine on the east side of Peters Canyon and the Sunset mine on the east side of East Canyon. The largest deposit is in the north-central part of the area, the Rattlesnake mines. This deposit, which is relatively isolated, may contain about as much ore as combined in all other uranium-vanadium deposits in the Morrison Formation of Lisbon Valley area.

Stratigraphic distribution

In the Lisbon Valley area uranium-vanadium mineral deposits have a large vertical range within the Morrison Formation. The deposits are found throughout the Salt Wash Member and in the lower one-third of the Brushy Basin Member, a vertical range of about 450 feet. However, most ore deposits, including all the large ones, are in the upper one-third of the Salt Wash Member, generally in the uppermost relatively thick and persistent ledge-forming unit of sandstone, as in the outcrops bordering Dry Valley in the southwestern part of the area. Deposits in the middle and lower part of the Salt Wash, including a few deposits of moderate size, occur sparsely throughout the area but are characteristic of the northern part, north of Kane Springs Canyon.

Deposits in the lower part of the Brushy Basin Member of the Morrison Formation occur sporadically throughout the area but are most common in the eastern part as near McIntyre and Little Indian Canyons. Most of the deposits in the Brushy Basin are very small, and even in aggregate these deposits are quantitatively unimportant.

Character of the host rocks

Salt Wash Member

The uranium-vanadium ore deposits in the Salt Wash Member of the Morrison Formation are in sandstone lenses, which are generally a complex assemblage of small and large irregular units. The ore-bearing sandstone lenses range from a few hundred feet to several thousands of feet in width and from a few tens of feet to more than 100 feet in maximum thickness. The lengths of the ore-bearing lenses are not known but are estimated to be many times their known width and for the larger lenses are probably measurable in miles.

One of the larger ore-bearing lens is that containing the Frisco group of mines and neighboring prospects. This lens is near the top of the Salt Wash Member and is more than 4,000 feet wide and 90 feet thick. An example of a relatively small lens containing a significant ore deposit is the lens of the Blue Jay mine. This lens where at least 10 feet thick is about 300 feet wide, attains a maximum thickness of about 35 feet and is more than 1500 feet long.

The upper and lower boundaries of the ore-bearing sandstone lenses are generally sharp. The base is a diastem along which channeling has removed a few feet to a few tens of feet of the underlying mudstone unit. Locally the basal part of the sandstone lens contains abundant irregular pebbles and cobbles of mudstone. The top few feet of the lens is commonly finer grained than most of the unit, is horizontally bedded, and is separated from the overlying mudstone by a distinct planar contact or intergrades with it through a few inches.

The character of the lateral boundaries of the lenses are less well known, because where the lenses are thin they crop out poorly. Available exposures suggest that as the lenses thin they both intertongue and intergrade with adjacent mudstone.

Ore-bearing sandstone is mostly very light colored; pale shades of orange and pink are dominant. Barren sandstone tends to be darker; grayish red and reddish brown are dominant. The sandstone is speckled with minute spots of limonite. In some barren sandstone the limonite spots have a distinct reddish cast as opposed to the more common brown and orange-brown hues.

Ore-bearing sandstone ranges from very fine grained to coarse grained and pebbly but is chiefly fine to medium grained. In interbedded units of differing grain size, the finer grained unit is frequently more intensely mineralized. The sandstone is composed of quartz with variable small amounts of clear feldspar and dull-white grains, probably composed of altered feldspar, tuffaceous material, or weathered chert. The dull-white grains are conspicuous in mineralized layers because they are commonly not coated with ore minerals. The sandstone is mostly cross-stratified in trough sets of low to high angle cross beds. The average dip-direction of the cross-strata in ore-bearing sandstones of the upper part of the Salt Wash in the Lisbon Valley area range from northeast to east-southeast (Craig and others, 1955, fig. 26). Horizontally bedded units and apparently structureless units are common, expecially near the top and in the thinner parts of the complex lenses.

Mudstone occurs within the ore-bearing sandstone as irregular lensing layers, seams, and partings and as irregular grains, pebbles, and cobbles. The mudstone layers or clasts commonly mark diastems within the ore-bearing lens of sandstone. Mudstone within, underlying, and locally above mineralized sandstone is commonly altered to grayish green or light gray; the prevailing color of mudstone away from the mineralized rock is grayish red. The alteration is apparently the result of reduction and removal in solution of iron from the originally grayish red mudstone (Huff and Lesure, 1965, p. 22). The close association of the color change of the mudstone with sandstone impregnated with vanadium and uranium minerals suggests that the change was part of the mineralizing process.

Carbonaceous material is a common constituent of ore-bearing sandstone and also occurs sparsely in mudstone within the sandstone. It ranges from minute grains to large flakes of black carbonized wood and from vaguely identifiable small twig-like fragments to logs more than a foot in diameter and more than 10 feet long. The larger pieces of fossil wood although generally in part carbonized, are frequently mostly replaced by calcite or chert. The carbonaceous material is generally most abundant in the lower part of the sandstone a few inches to several feet above the basal disconformity of the lens and in sandstone above conspicuous diastems within the ore-bearing lens. Larger flakes and pieces of carbonized material commonly occur along bedding planes or in "trash pockets"--pod-like lenses of poorly sorted sandstone containing abundant mudstone pebbles.

The ore-bearing sandstone is generally moderately well cemented by calcite. In places exposed faces of the ore-bearing sandstone is friable as a result of weathering, but poorly cemented sandstone within mines is rare. Sandstone at the top and less commonly at the base of the ore-bearing lens is more firmly cemented than the rest of the lens. Intensely cemented sandstone is rare within the ore zone though it is characteristic of many small reddish-gray barren lenses.

Brushy Basin Member

The ore-bearing sandstone lenses in the Brushy Basin Member of the Morrison Formation are in most respects similar to those in the underlying Salt Wash Member. The lenses in the Brushy Basin however, on average are much thinner than those in the Salt Wash. They commonly are only a few tens of feet thick and a few hundred feet wide. The host sandstone is generally darker, more poorly sorted, and more firmly cemented, than host sandstones in the Salt Wash. The sandstone units in the Brushy Basin frequently contain small well-rounded pebbles of red, green, orange, and gray chert. Carbonaceous material, especially large fragments of fossil wood, is not abundant in the sandstone.

Mineralogy

The uranium-vanadium ore deposits in the Morrison Formation of the Lisbon Valley area, as exposed in 1960, are all of the oxidized type. Studies of ore deposits elsewhere on the Colorado Plateau indicate that the primary ore consisted of low-valent unoxidized minerals such as uranite, coffinite, and montroseite. These minerals oxidize to carnotite, tyuyamunite, vanadium hydromica, and other vanadates (Botinelly and Weeks, 1957).

The ore deposits in the Morrison all contain more vanadium than uranium. The ratio of vanadium oxide to uranium oxide deposits having recorded production ranges from about 4:1 to 16:1. The ratios may differ between nearby deposits with little apparent system, but generally deposits on the southwestern part of the area, as those near East Canyon and Dry Valley, have a higher V_2O_5:U_3O_8 ratio than deposits in other parts of the Lisbon Valley area. Vanadium minerals are dominant in all the Morrison deposits and color the mineralized rock gray.

The ore minerals fill interstices between sand grains, replace cement, clastic grains, and fragments of fossil wood. Rarely they coat joint surfaces. Alteration of the minerals of the host rock and introduction of gangue minerals is negligible. The sandstone cement has been apparently redistributed near some ore bodies. In parts of the area copper has been introduced in small amounts in the uranium-vanadium ores.

The minerals of the uranium-vanadium deposits in the Morrison Formation are mostly ultra fine grained, of micaceous habit, and complexly intermixed or intergrown. Because of their exceedingly fine grain size and habit of occurrence most of the ore minerals can be positively identified only by X-ray powder pattern and spectrographic analysis. Except for several specimens studied by Alice D. Weeks, U.S. Geological Survey, the mineralogy of the Morrison ores in the Lisbon Valley area was studied only in field reconnaissance.

Uranium minerals

Carnotite [$K_2(UO_2)_2(VO_4)_2 \cdot 1\text{-}3H_2O$] was the field name given all bright-yellow radioactive minerals. The "carnotite" of the field descriptions of mines and prospects probably includes much of the similar yellow radioactive minerals tyuyamunite and metatyuyamunite and perhaps zippeite. Because the uranium-vanadium deposits in the Morrison of the Lisbon Valley are not calcium-rich, carnotite is probably more abundant in these deposits than its calcium analog tyuyamunite. Carnotite has been positively identified by mineralogists at two localities in the area: Bridger Jack Mesa north of Kane Springs (Hess and Foshag, 1927) and from the Blue Jay mine south of Browns Hole (A. D. Weeks, U.S. Geological Survey, written commun., 1953).

Tyuyamunite [$Ca(UO_2)(VO_4)_2 \cdot 5\text{-}8\ 1/2H_2O$] and metatyuyamunite [$Ca(UO_2)_2(VO_4)_2 \cdot 3\text{-}5\ H_2O$] were identified by A. D. Weeks from the Blue Jay mine.

Uraninite (UO_2) was recognized in small amounts in a single specimen from the Blue Jay mine (A. D. Weeks, U.S. Geological Survey, written commun., 1953). The uraninite was surrounded by an orange mineral substance that gave almost no X-ray pattern. This orange mineral can be referred to as gummite, a general term for an amorphous mixture of fine-grained minerals that are alteration products of uraninite, and that consist chiefly of hydrated uranyl oxides whose identities are unknown.

Vanadium minerals

The fine-grained micaceous vanadium mineral that colors mineralized rock gray in the Morrison was referred to in field descriptions as vanadium hydromica. The field term probably includes vanadium-bearing chlorite, roscoelite [K, (Al, V)$_2$ (Al, Si$_3$) O$_{10}$ (OH, F)$_2$], dark vanadates, and perhaps some vanadium oxides.

Corvusite [$F_2O_4 \cdot 6V_2O_5 \cdot nH_2O$] was the field term given to the mineral coloring the ore bluish-gray as contrasted with the more neutral gray of the vanadium hydromica ores. As a field term it probably includes vanadium-bearing clay minerals, dark vanadates, and possibly some vanadium oxides. Corvusite was noted in several mine workings in the Waterfall group and in the Blue Jay mine.

Hewettite ($Ca\ V_6O_{16} \cdot 9H_2O$) was the field name given a bright- to dark-red mineral in vanadium ores. The field name probably includes the vanadates similar to hewettite, metahewettite, and barnesite. Hewettite was noted in the field descriptions of the mines of the Frisco and Waterfall groups, the Profit No. 1 mine, and the Buck Horn mine.

Volborthite [$Cu_3(VO_4)_2 \cdot 3H_2O$] or tangeite [$CuCa(VO_4)(OH)$] was noted in the field descriptions of several mines and prospects in the southeastern part of the area. The mineral is yellowish green, vitreous, and fibrous and commonly occurs on joints associated with vanadium hydromica and copper prospects.

Rossite [$CaV_2O_6 \cdot 4H_2O$] and metarossite [$CaV_2O_6 \cdot 2H_2O$] were identified by Weeks and Thompson (1954, p. 56-57) from deposits, including the Buck Horn mine, near the southeast edge of the area. These light-yellow vanadates occur sparsely as coatings and veinlets.

Other minerals associated with ore

Copper minerals are associated with the uranium and vanadium minerals in ore deposits in the Morrison in the southeastern part of the area, near the Lisbon Valley fault, and locally on the west slope of the La Sal Mountains. The most common copper minerals are the green carbonate malachite and the blue carbonate azurite. Chalcocite (Cu_2S) was found in small nodules in the Buck Horn mine by D. R. Shawe (U.S. Geological Survey, written commun., 1956).

A bright-green, very finely micaceous or clay mineral occurring in thin bands and spots commonly a few feet from vanadium ore was noted in several mines and prospects near Peters and East Canyons in the southwestern part of the area. The mineral is sparse but conspicuous because of its color. It was commonly referred to in the field as a chromiferous clay because of its similarity to the mineral of the chromium-bearing layer associated with vanadium-bearing layers in sandstone at Placerville, Colorado (Fisher, R. P., 1942). Possibly the green material includes several minerals. Among them may be "pintadoite," a light-green vanadate described by Hess and Schaller (1914) from deposits along East Canyon. The original description of pintadoite is judged to be so incomplete that no more of the mineral can be recognized and no X-ray pattern could be obtained from the National Museum sample of the mineral (Weeks and Thompson, 1954, p. 47).

Uranium-vanadium deposits in the Morrison Formation in the adjacent La Sal quadrangle closely resemble in metal content and habit of occurrence the Morrison ores in the Lisbon Valley area. The mineralogy of the La Sal quadrangle ores, which has been studied in detail by Carter and Gualtieri (1965, p. 46-49), is suggestive of the variety and sequence of minerals that might be expected in the similar ore deposits in the Morrison Formation of the Lisbon Valley area.

Size and shape

The uranium-vanadium deposits in the Morrison Formation in the Lisbon Valley area show great variations in size and shape. The deposits in the Salt Wash Member are on average much larger and more varied in shape than those in the Brushy Basin Member.

Most of the mines are in small to medium-size deposits that have known production and estimated reserves whose aggregate is measurable in tens to hundreds of tons. A smaller number of relatively large deposits are measurable in thousands of tons, and a few very large deposits are measurable in tens of thousands of tons.

In general the deposits are roughly tabular and elongate, and consist of interconnected or closely clustered ore bodies. The ore bodies are concentrations of oxidized uranium and vanadium minerals in irregularly lensing layers. They commonly parallel sedimentary features of the host sandstone such as major diastems but they cut across details of stratification. The ore layers locally split and enclose barren or weakly mineralized rock. Most ore layers in the Morrison have fairly sharp boundaries defined by the gray coloration given the host rock by vanadium hydromica. In places, as in several large deposits in the Waterfall group of mines, the boundaries are indefinite as the layers grade out or split into many thin discontinuous streaks. Lateral gradation is more common than vertical gradation. Some ore bodies are vaguely defined zones of spots of ore minerals; this is the "rattlesnake ore" of miners.

The lenticular ore bodies are generally elongated along the trend of the host sandstone, about parallel to current-induced sedimentary structures such as dip-directions of cross strata, and to the axes of thicker portions of the host sandstone. These ore bodies are commonly several tens to a few hundred feet long and a few to many tens of feet wide. Most of the ore layers are 1 to 3 feet thick but local maxima of more than 5 feet are common in the large deposits.

A conspicuous feature in many of the deposits, especially those in the upper part of the Salt Wash Member, are layers of ore minerals that bend sharply across bedding to form irregular C-, S-, or complexly curving elongate bodies known as rolls. The rolls commonly are higher grade than adjoining or nearby stratiform layers or ore minerals. The roll boundaries are generally sharp and the mineralized rock in the roll frequently breaks almost cleanly from the adjacent barren rock. In some mines, rolls form most of the mineable ore. In plan most rolls are straight to slightly curved linear bodies. In individual deposits and in groups of deposits the rolls generally show a common trend. Most rolls are a few feet thick and wide and several tens of feet long.

Ore bodies in the Morrison also consist of mineralized fossil logs and "trash pockets," irregular stubby lenses of poorly sorted sandstone containing clay pebbles and carbonized plant debris. The mineralized logs and trash pockets are generally much higher grade than other ore bodies. The larger logs are more than 1.5 feet in diameter and have lengths of more than 20 feet. The trash pockets are small features, generally less than 2 feet thick and 5 to 20 feet in diameter.

The dimensions of the deposits are somewhat arbitrary because of judgments involved in the inclusion of bordering ore bodies, especially in groups of mines such as the Frisco and Waterfall groups. In these groups, which contain deposits fairly typical of the economically significant ones in the area, most large ore deposits are estimated to be about 200 to 600 feet in diameter. The relatively large deposit of the Happy Jack mine of Peters Canyon apparently consisted of interconnecting ore bodies in an area about 600 feet long and about 150 to 250 feet wide.

The very large deposit of the Rattlesnake mine is probably more than 1,000 feet long and about 500 feet wide. Drill hole records and mine exposures suggest that the Rattlesnake deposit is a complex cluster of irregular ore bodies ranging from a few feet to a few hundred feet in long dimension.

The size and shape of the deposits and ore bodies in the Morrison Formation of the Lisbon Valley area appear unrelated to tectonic structures such as folds and faults. Layers of ore in and near faulted ground, such as in the deposit of the Rattlesnake mines, are crushed and displaced along faults. Some joint faces are lined with a film of uranium and vanadium minerals, as at the Rattlesnake, Blue Jay, and a few other mines, but these minor features do not affect the shape of the ore layers. A perhaps unique exception is the apparent deflection of ore layers along joints at the Bonanza No. 1 mine; it was not determinable, however, whether the joints were pre- or post-ore. Joints are an inconspicuous feature in most of these deposits. Joint sets most frequent in the mines are subparallel to the rim and are related to the geomorphology resulting from erosion rather than to tectonic stresses.

Suggestions for prospecting

Some geologic associations of uranium-vanadium deposits in the Morrison Formation on the Colorado Plateau are useful guides in exploration, even though the factors that control localization of the deposits are not fully understood. Tectonic structures, faults and folds, do not control the regional or local distribution of the deposits; their significance is restricted to their influence on the exposure and position of the ore-bearing sandstones (Fisher, 1942, p. 388; Johnson and Thordarson, 1966, p. 32). Sedimentary features of regional and local extent appear paramount in controlling the distribution and shape of the deposits.

Among the regional sedimentary factors are the facies of the Salt Wash Member of the Morrison Formation. The known uranium-vanadium deposits in the Salt Wash Member are in the sandstone and mudstone facies of delineated regionally by Craig and others (1955, p. 137-138; 161). The Lisbon Valley area lies entirely within this relatively favorable facies. A detailed study of the thickness, proportion, and continuity of stream deposits that make up the Salt Wash Member enabled Mullens and Freeman (1954) to define a more restricted lithofacies that contained most uranium-vanadium deposits in the member. The favorable lithofacies includes that part of the Salt Wash Member that is more than 200 feet thick and composed of 20 to 55 percent stream deposits, contains 90 to 200 feet of stream deposits and has a 5 to 18 percent mean deviation in the thickness of stream deposits. The Lisbon Valley area lies entirely within this favorable lithofacies. Mullens and Freeman (1957, p. 521-525) suggested that the parameters of the lithofacies may also be measures of favorable factors of transmissibility of the Salt Wash Member permitting concentrations of uranium and vanadium from metal-bearing solutions.

Because in most mining districts the uranium-vanadium deposits are restricted to a single zone of sandstone lenses within the Salt Wash, the total lithologic aspect of the member is an inexact guide to ore (Mullens and Freeman, 1957, p. 523). In the Lisbon Valley area most ore deposits, including nearly all the large ones, are in the upper one third of the Salt Wash Member. The presence of ore in the lower or middle parts of the Salt Wash or in the Brushy Basin Member, is on empirical grounds, a negative guide to ground favorable for large ore deposits in the Lisbon Valley area.

Sedimentary features found most useful in U.S. Geological Survey exploration in the Morrison Formation are thickness and color of the ore-bearing sandstone, and abundance of carbonaceous material. These features and a numerical system for evaluating favorable ground are discussed by D. B. Weir (1952). They are generally applicable to the search for ore in the Lisbon Valley area. Empirical observation within the area suggests that grain size, and stratification of the ore-bearing sandstone are features also useful in appraising favorable ground.

Thickness.--All significant deposits are in host sandstone lenses whose maximum thickness is at least 25 feet. Large deposits are probably restricted to lenses with an original thickness of more than 35 feet. Not all thick sandstones are favorable, however, and apart from the minimum figures given, there is little correlation between the thickness of the ore-bearing sandstones and size of the contained ore deposit. Because many ore deposits occupy the thicker part of the host sandstone lenses, relative thickness of parts of the host lens is also a factor to be weighed in delineating favorable ground.

Carbonaceous material.--Carbonized plant material ranging in size from minute flakes to large logs is present in practically all sandstone containing ore deposits. The form and distribution of carbonaceous material may vary considerably from place to place within and near the ore deposit. Visible carbonized plant material is one of the simplest and most useful guides to host sandstone favorable for ore.

Altered mudstone.--Mudstone within and underlying sandstone containing ore has been altered from red to gray. Analysis of U.S. Geological Survey drill holes shows that the gray mudstone beneath the sandstone is generally thickest below the ore but extends beyond the deposit (D. B. Weir, 1952, p. 20-21). In the Lisbon Valley area exposures of the mudstone below ore-bearing sandstone are too infrequent to evaluate the relation of thickness of gray mudstone to ore, but with few exceptions some gray mudstone was below sandstone containing ore deposits. Similarly, mudstone seams, partings, flakes, and pebbles in sandstone near ore were mostly greenish gray. Gray mudstone is, however, probably dominant within the sandstone of the Salt Wash Member in the Lisbon Valley area so that its presence is only a very broad guide to favorable ground. A large amount of red mudstone in a potential host sandstone is a readily visible negative guide to ore.

The ratio of barren to mineralized ground is high even in ground judged to be favorable by the above criteria. Common mining development and exploration practice is to drift along thin seams of mineralized rock along the trend of the ore deposit as revealed by trend of rolls and the elongation of lens-like ore bodies. Because the trends of the deposits and contained ore bodies are generally parallel to sedimentary features of the host rock, the average azimuths of dip-directions of cross beds, of current lineation scours, logs, thick parts of lenses, and similar directional depositional features may be helpful in projecting ore deposits, whose trends are unknown or indefinite. Lines of exploratory holes drilled from the surface should be laid across the inferred trend of nearby deposits and should be spaced according to the average size of the deposit.

Within the Lisbon Valley area are several belts containing relatively large amounts of favorable ground. The belts contain more numerous and larger uranium-vanadium deposits than ground outside the belts. Within these belts the deposits may be expected to contain thousands to tens of thousands of tons of ore and to be hundreds of feet in diameter whereas deposits outside the belt contain hundreds of tons of ore and are only tens of feet in diameter. They have relatively thick and continuous compound lenses of sandstone at the ore-bearing horizon in the upper one-third of the Salt Wash Member. The belts trend parallel to the sedimentary trends of the host sandstone lenses and the elongation of the contained ore deposits. The belts probably mark persistent channelways of the braided streams that deposited the sandstones of the Salt Wash. For the most part the belts trend northeasterly parallel to the inferred regional trend of the Salt Wash streams in this area (Craig and others, 1955, p. 147, 151; Johnson and Thordarson, 1966, p. H45-H46, pl. 3). Some belts have an easterly to southeasterly trend that may reflect the local diversion of Salt Wash streams along southeast-trending topographic highs above salt-cored folds.

Color.--Sandstone containing significant ore deposits in the Salt Wash Member are invariably light colored--mostly very pale orange to very light yellowish gray, weathering about the same or very light brown. Sandstone with a reddish cast, ranging from light grayish red to dark reddish brown, are generally barren. Limonite specks in ore-bearing sandstone are tan to brown; in sandstone not associated with ore they are red (R. C. Dickinson, U.S. Atomic Energy Commission, written commun., 1953).

Grain size.--Fine- to medium-grained sandstone contains most of the ore. Some coarse-grained sandstone, especially that containing carbonaceous wash and grayish-green mudstone pebbles is mineralized. Generally however, where beds of differing grain size are present, the finer grained clean sandstone is commonly more intensely mineralized. Silty and clayey sandstones are mostly barren.

Sedimentary structures.--Sandstone lenses made up of fairly uniform dominantly horizontally bedded units appear relatively unfavorable for ore. Most sandstone lenses containing significant ore deposits are dominantly cross-bedded and are also characterized by a diversity of bedding types in the stratigraphic subunits that make up the lens. This diversity of bedding types results in weathering of ore-bearing sandstone to a characteristic irregular outcrop as at the Sunset mine.

Outcrops of the ore-bearing sandstone including the Frisco group of mines on the west-side of East Canyon and the Sunset and neighboring mines on the east side of East Canyon are interpreted to be a transverse section of a belt of favorable ground. Projection of channels at the base of the ore-bearing sandstone and trends of the long dimensions of the contained deposits indicate a northeasterly trend for this belt. The belt to the southwest includes the Happy Jack mine of Peters Canyon and connects with the northeasterly trending belt of favorable ground in the northern part of the Abajo Mountains area (Witkind, 1964, p. 98, fig. 37). To the northeast this belt probably joins the belt of favorable ground that includes the Waterfall group of mines.

The outcrop of the ore-bearing sandstone along Dry Valley from near the Wilson mine to the eastern mines of the Waterfall group are interpreted as a nearly longitudinal section of a belt of favorable ground. The dip directions of crossbeds in the ore-bearing sandstone indicates that this belt trends southeasterly. This trend of favorable ground probably is the result of deflection of Salt Wash streams by local highs along the southeast-trending, salt-cored Lisbon Valley and Dolores anticlines. The southeastern part of this belt is unknown. It probably lies south of the outcrops of the Salt Wash Member in the southeastern corner of the Lisbon Valley area; possibly it connects with belts of favorable relatively thick and ore-bearing sandstone that includes large mines within the Slick Rock mining district of Colorado (Shawe and others, 1968, p. A62-A64; Johnson and Thordarson, 1966, pl 1).

The probable width and trend of the belt of favorable ground that includes the very large deposit of the Rattlesnake mines is uncertain. The Salt Wash Member is very poorly exposed near the mines and the sedimentary trends of the ore-bearing sandstone were not determined. Most likely the belt trends northeasterly parallel with the apparent trend of the Rattlesnake deposit, and marks a major channelway across the salt-cored Lisbon Valley anticline of northeast-flowing streams that deposited the upper part of the Salt Wash. The belt including the Rattlesnake deposit may connect with the La Sal Creek mineral belt described by Carter and Gualtieri (1965, p. 40, 73). The belt of favorable ground probably curves eastward near La Sal as a result of deflection of the northeast-flowing Salt Wash streams by topographic highs above the salt-cored Pine Ridge anticline east of La Sal.

The trend and extent of the belt of favorable ground that includes the Yellow Circle group of mines is uncertain. Sedimentary trends in the host sandstone lenses in the Yellow Circle group range from north-northwest to east-northeast (R. C. Dickinson, U.S. Atomic Energy Commission, written commun., 1953; Farrow and others, 1955, p. 17, fig. 5). The areas of favorable ground and of mineralized rock are elongated northeasterly. A southwestward projection of the belt from the Yellow Circle group includes only a few small deposits. A northeastward projection of the belt from the Yellow Circle group, however, includes the significant White Fawn and Fault deposits. Northeast of the Fault mine the Salt Wash Member is deeply buried; the belt may curve toward the southeast parallel to the salt-cored fold of Pack Creek.

Estimates of the number, extent, and trends of the major belts of favorable ground in the Lisbon Valley area involve much subjective field judgment. Johnson and Thordarson (1966) recognized nine belts, whose general trend is northeasterly. Many of these belts include deposits of smaller average size than included in the belts.

Except for relatively small areas of outcrop in most of the belts of favorable ground the ore-bearing horizon is more than 600 feet below the surface. In the belts in the southern part of the area the Dakota Sandstone forms the principal surface outcrops. In the belts in the northern part of the area the Mancos Shale and thick Quaternary deposits are at the surface. The spacing of drill holes in the exploration for uranium-vanadium deposits in these belts must be based on the dimensions of the nearest large and very large ore deposits. Drillers may encounter difficulties locally in penetrating silicified sandstone in the Burro Canyon Formation and in penetrating gravels containing resistant boulders derived from the Burro Canyon and from igneous rocks of the La Sal Mountains.

Outcrops within the favorable belts of ground have been thoroughly prospected, but some near-surface ore deposits in the belts may remain to be found by stripping away thin to thick landslide material. Exploration outside the favorable belts is warranted in relatively shallow ground, although the expectation of finding large deposits is small. In and around the La Sal Mountains few uranium and vanadium ore deposits are known, but this may be a reflection of the few and poor exposures of the potential host rock rather than to a true dearth of mineralization. The Morrison Formation on the northeast side of the hogback extending from Lackey Basin to the head of Pole Canyon may contain undiscovered ore deposits; the ore horizon in this part of the area is mostly covered by unmapped colluvium. The collapse structures of Sapnish Valley may also merit exploration. The ore-bearing horizons of the Morrison Formation are exposed in only a few of these structures, but they show many similarities to mineralized of sandstone pipes in southeastern Utah (Keys and White, 1956; Kerr and others, 1957), northwestern New Mexico (Hilpert and Moench, 1960; Wylie, 1963) and northern Arizona (Granger and Raup, 1962, p. A7-A12; Finch, 1967, p. 83-84).

Mines and prospects

The mines and prospects in the Morrison Formation of the Lisbon Valley are described chiefly from notes made in the period 1953-1959. Data were also drawn from unpublished earlier data by R. T. Russell, J. D. Strobell, Jr., R. K. Kirkpatrick, and H. R. Wardwell. Some of the mines visited during the early part of the study period were probably greatly enlarged during the late 1950's. Much of this later development is not described.

The mines and prospects are described in a rough geographic order from north to south in the area. Mine and claim names are informal. They were not checked against legal records. Where possible the names of the mines and claims were determined by inquiry of miners working the properties. Some names were ascertained from posted claim notices. Where other information was lacking the names used in this report were drawn from the unpublished data of Kirkpatrick, Wardwell, Russell, and Strobell, and from Johnson and Thordarson (1966, pl. 1). Because the names of many properties have been changed frequently in the past, some names of mines and claims, and groups of mines used in this report, are probably obsolete.

Some groups of mines and prospects described below, such as the Mill Creek group of mines, are arbitrary geographic groupings made here for ease of description. Some of the group names, such as the Yellow Circle and Frisco, are vey old, but the limits of these groups have been changed frequently in the past.

Mineralized rock is easily recognized in the Morrison Formation because the common vanadium minerals color the rock gray and the uranium minerals color the rock yellow. Estimations of grade are more difficult though the shade of gray and the radioactivity are guides. In the following descriptions, except where otherwise noted, the term "ore" is applied to all mineralized rock more than 1 foot thick.

The estimated size of the ore deposits in the Morrison is based where possible on records of production and reserves compiled by the Atomic Energy Commission. Where records are lacking or incomplete the estimate is based largely on reconnaissance of the accessible workings.

Mill Creek group of mines

The Mill Creek group is a designation given here to several mines scattered along the north and south rims of upper Mill Creek in secs. 1 and 2, T. 27 S., R. 23 E., and sec. 31, T. 26 S., R. 24 E. Included are the Al Rodgers, New Al Rodgers Nos. 1 and 2, Bud No. 1, Foxey Dan, Sure Fire, and Horse Creek claims. The workings mostly consist of rim cuts, trenches, and short adits. On the Al Rodgers property is the largest mine of the group. It consists of short adits leading to small stopes as much as 75 feet behind the outcrop. Many of these properties were staked and worked on a small scale in the early 1940's. Recorded production from all these properties for the period 1949-1956 is small.[1] The average grade of the shipped ore is 1.38 percent V_2O_5 and 0.22 percent U_3O_8, a ratio of 6.3:1.

The deposits are in gently west dipping beds of sandstone in the upper part of the Salt Wash Member of the Morrison Formation. The mineralized rock is commonly associated with diastems and fossil plant material. Rolls of ore are sparse. Vanadium hydromica and carnotite are the ore minerals. On the Al Rodgers claim sandstone between two thin mineralized layers is stained dark brown by limonite.

[1]Terms used in describing estimated production imply the following approximate figures:

very large	10,000 tons
large	1,000 tons
moderate	100 tons
small	10 tons
very small	<10 tons

Freeda prospects

The Freeda prospects are in low hills in southeastern Spanish Valley in secs. 8 and 17, T. 27 S., R. 23 E. The workings consist of several small open cuts and a short adit in the upper part of the Salt Wash Member of the Morrison Formation. Thin streaks of vanadium hydromica occur in steeply southwest dipping beds of sandstone. A very small amount of ore was shipped from these prospects in the 1950's. The average grade of the shipment was 1.90 percent V_2O_5 and 0.50 percent U_3O_8, a ratio of 3.8:1.

Indian Queen prospect

The Indian Queen prospect is in the low hills in southeastern Spanish Valley in sec. 16, T. 27 S., R. 23 E. The prospect is a short adit in the upper part of the Salt Wash Member of the Morrison Formation. Thin streaks of vanadium hydromica occur in steeply southwest dipping beds of sandstone near a collapse structure in which Mancos Shale has been dropped into the Morrison Formation. A very small amount of ore was shipped from this prospect in the 1950's. The average grade of the shipment was 1.22 percent V_2O_5 and 0.17 percent U_3O_8, a ratio of 7.2:1.

Western Brumley Ridge group of mines

Western Brumley Ridge group is a name given here to include many small mines and prospects on the southwestern tip of Brumley Ridge in secs. 10, 11, 14, and 15, T. 27 S., R. 23 E. Included are the Renegade, Little Faun, Yellow Spot, Sunrise, Sundown, Hattie, Black Ace Nos. 1 and 2, Black Buzzard, Dry Pine, North Brumley Nos. 2-4, Black Diamond, Yellow Boy, and Wahoo claims. The working on these claims consists of rim cuts, open pits, and short adits generally leading to small stopes. Most of these claims were staked in the early 1940's, and probably some produced a very small amount of vanadium ore in the period 1940-1944. Very small to small amounts of ore were, according to records, shipped from the following claims of the group in the period 1949-1956: Renegade, Little Faun, Sunrise, Hattie, Black Ace Nos. 1 and 2, and North Brumley Nos. 3 and 4. The average grade of the recorded shipments is about 1.48 percent V_2O_5, and 0.31 percent U_3O_8, a ratio of 4.8:1.

The mines and prospects are in sandstone units in the upper part of the Salt Wash Member of the Morrison Formation. Most of the larger workings are in the sandstone units near the top of the member but prospects on the Hattie, Sundown, Dry Pine, and Yellow Boy claims are in the lower part of the member. The deposits consist of irregular layers, lenses and rolls of dark-gray mineralized sandstone. Vanadium hydromica and carnotite are the dominant ore minerals. An unidentified green finely micaceous or clay mineral locally stains the ore-bearing sandstone. The ore minerals mostly impregnate sandstone and sandy shale that contain carbonized plant debris. Some silicified fossil trees are partly replaced by ore minerals.

Big Three prospect

The Big Three prospect is on the hillslope north of Brumley Creek in sec. 6, T. 27 S., R. 24 E. The property includes the Big Three and Big Three Nos. 1-7 claims. The property has produced a very small amount of ore through 1956. Average grade of shipped ore was 1.93 percent V2O5 and 0.33 percent

U_3O_8, a ratio of 5.9:1. The deposit is in poorly exposed west-dipping sandstone beds in the upper part of the Salt Wash Member of the Morrison Formation.

Slide prospect

The Slide prospect is on the hillslope south of Brumley Creek in sec. 7, T. 27 S., R. 24 E. The property includes the Slide, Slide Nos. 1-4, and P. Nut Nos. 1-3 claims. The workings consist of two short adits about 150 feet apart. The property had no recorded production from 1949 through 1956, and was inactive in 1957. The deposits are in very poorly exposed west-dipping beds in a sandstone lens more than 40 feet thick. The ore minerals, vanadium hydromica and sparse carnotite, occur in irregular layers and streaks in siltstone and sandstone and in pod-like lenses and rolls, trending about S. 75° E., in sandstone.

Buckskin mine

The Buckskin mine is on the north side of Brumley Creek in secs. 5 and 6, T. 27 S., R. 24 E. The mine is on the Buckskin Nos. 1 and 2 claims which were located in 1940. The mine consists of rim cuts and a short adit leading to more than 100 feet of underground portal. West of the portal of the adit are caved workings. In the period 1949-1956 the mine produced a small amount of ore, whose average grade was about 1.35 percent V_2O_5 and 0.24 percent U_3O_8, a ratio of 5.6:1.

The deposit is in west-dipping beds near the base of a lens of sandstone, more than 60 feet thick, near the top of the Salt Wash Member of the Morrison Formation. The sandstone contains seams 1 to 6 inches thick of carbonaceous mudstone; vanadium hydromica and carnotite are mostly concentrated in and near these seams and in carbonized fossil wood. A single roll, which trends about N. 80° E., was noted.

Chess Ridge mines

The Chess Ridge mines are on the north side of Dorry Canyon in sec. 7, T. 27 S., R. 24 E. Included are the Chess Ridge Nos. 1-3 and Groundhog claims. The principal workings are on the Chess Ridge Nos. 3 and 1 claims. The mine on the Chess Ridge No. 3. claim is near the west edge of the group and consists of irregular stopes driven northwestward from the rim about 80 feet. About 1,500 feet east of this mine are similar workings driven at several levels eastward about 80 feet from the rim on the Chess Ridge No. 1 claim. On this same claim about 500 feet farther east is an irregular adit driven northward about 120 feet from the rim. The claims of this group were located in the period 1938-1941, and it is probable that each of these mines produced small amounts of vanadium ore in the early 1940's. In the period 1949-1956 records show that the group produced a small amount of ore, principally from the Chess Ridge No. 1 claim. The average grade of the shipped ore was 1.94 percent V_2O_5 and 0.16 percent U_3O_8, a ratio of 12.2:1. The total production of the group, including several rim cuts away from the principal workings, is estimated to be moderate. The mines were inactive when visited in the fall of 1957.

The deposits are in gently west dipping beds of sandstone in the upper part of the Salt Wash Member of the Morrison Formation. The mine on the Chess Ridge No. 3 claim appears to be more than 100 feet higher in the Salt Wash than the mines on the Chess Ridge No. 1 claim. The ore minerals, vanadium hydromica and carnotite, mostly impregnate sandstone and shale containing abundant carbonized plant fragments. The mineralized rock occurs as scattered and clustered spots, vague streaks and sets of streaks and irregular layers as much as 5 feet thick, and as partial replacement of silicified fossil logs.

Hatchet prospects

Several small workings on the slopes bordering Dorry Canyon in sec. 6, T. 27 S., R. 24 E. are tentatively identified as being on the Hatchet claims. The workings consist of a short adit and pit on the south side of the canyon and a rim cut on the north side of the canyon. A very small amount of ore is recorded as coming from the Hatchet No. 3 claim in the period 1949-1956. The average grade of the recorded shipments was 3.32 percent V_2O_5 and 0.59 percent U_3O_8, a ratio of 5.6:1. The deposits are in poorly exposed, west-dipping beds of sandstone near the middle and in the upper part of the Salt Wash Member of the Morrison Formation. The ore-bearing beds are in lenses about 10 to 45 feet thick and probably less than 100 feet long. The ore minerals, vanadium hydromica and minor carnotite, occur chiefly in streaks in limonite-stained, thin-bedded, carbonaceous sandstone.

Blue Goose mines

The Blue Goose mines are in hills north of the junction of Brumley and Pack Creeks in sec. 15, T. 27 S., R. 23 E. Included in this group are the Blue Goose, Blue Goose Nos. 1 and 2, Big Buck No. 2, Grand View, Chipmunk, and Seep claims. Several of these claims were located in 1912, and the group was intensively mined as early as 1915. The workings consist chiefly of many open cuts and short adits leading to irregular stopes. The group has produced a moderate amount of ore, chiefly in the early 1940's and early 1950's. Average grade of recorded shipments is 1.32 percent V_2O_5 and 0.32 percent U_3O_8, a ratio of 4.1:1.

The workings are in steeply southwest-dipping beds of sandstone in the upper part of the Salt Wash Member of the Morrison Formation. A small prospect is in the basal sandstone unit of the Brushy Basin Member of the Morrison. The ore occurs chiefly as extensive layers and pod-like lenses of vanadium hydromica containing spots and thin bands of carnotite in carbonaceous sandstone below diastems marked by mudstone seams and pebbles. Ore also occurs in rolls, in fossil trees, and as impregnations of mudstone pebbles, and of lenses of carbonaceous trash in sandstone.

Lower Brumley Creek group of prospects

Several prospects are in the hills east of the junction of Brumley and Pack Creeks in secs. 14, 15, and 22, T. 27 S., R. 23 E. Included are small cuts and short adits on the Brumley, Jim Wade, Amarillo, and unidentified claims. The Jim Wade and Amarillo claims were patented in 1915. In 1958, when this part of the area was mapped, none of the properties were active. None of the workings have produced a significant amount of ore and the aggregate production from all the prospects in this part of the claim is estimated to be small. The deposits are in sandstone lenses near the top of the Salt Wash Member of the Morrison Formation. The ore consists of bands of low-grade vanadium hydromica with sparse carnotite impregnating carbonaceous sandstone and mudstone and partial replacements of silicified tree fragments.

Bluebird prospect--(Upper Pack Creek)

About 0.6 mile northeast of the Canary mine is a short adit in west-dipping beds near the base of the Salt Wash Mewmber of the Morrison Formation. The adit is now filled with rubble but judging from the size of the dump the underground workings are small. The mine probably on the Bluebird No. 13 claim was operated by the Sunray Mining Company in the middle 1950's, but the estimated total production is negligible. The adit is driven in carbonaceous sandy mudstone overlain by light-gray, very fine grained sandstone. The mudstone is gray at the adit but grades to red within a few tens of feet. No mineralized rock was found in the outcrop or in the dump.

Canary mine

The Canary mine is about 2 miles east of the M4 Ranch on slopes north of Pack Creek in sec. 19, T. 27 S., R 23 E. The workings consist of several short adits leading to caved drifts and an open cut about 75 feet long. The Canary claim was located in 1912 and patented in 1915. The total production from the mine is estimated to be small. The average grade of recorded shipments in the period 1949-1956 is 0.68 percent V_2O_5 and 0.10 U_3O_8, a ratio of 6.8:1. The mine is in steeply west dipping beds in the top sandstone lens of the Salt Wash Member of the Morrison Formation. Minerralized rock at the outcrop consists of a zone of carbonaceous sandstone and mudstone pebbles weakly impregnated with vanadium hydromica and sparse carnotite. A bright-green finely micaceous or clay mineral locally stains the ore-bearing sandstone. Azurite and malachite occur as widely scattered specs.

Eight Ball prospect

The Eight Ball prospect is on the south side of Hell Canyon in sec. 30, T. 27 S., R. 24 E. The workings consist of trenches and two short adits. Total production from this property is estimated to be very small. The prospect was inactive when examined in October 1958. The deposit is in steeply southwest dipping strata near the base of the Salt Wash Member of the Morrison Formation. The adits are driven near the top of a bed of gray, fine-grained sandstone which is overlain by a unit, about 5 feet thick, of interbedded yellowish-gray mudstone and dark-gray shale containing macerated carbonized plant material. Vanadium hydromica occurs in the carbonaceous shale. A bright-green very fine micaceous or clay mineral stains the sandstone along bedding planes. No carnotite was seen.

Red Devil prospect

The Red Devil prospect is on the north slope of Hell Canyon in secs. 21 and 28, T. 27 S., R. 24E. The Red Devil Nos. 1 and 2 claims were located in 1955. The workings consist of four short adits leading to small stopes; two of the adits were inaccessible in 1957. The total amount of ore mined from this prospect is very small. The average grade of the recorded shipments was 3.44 percent V_2O_5 and 0.84 percent U_3O_8, a ratio of 4:1.

The deposit is poorly exposed, steeply west dipping beds of sandstone near the top of the Salt Wash Member of the Morrison Formation. Vanadium hydromica and carnotite are the chief ore minerals; azurite and malachite are common; hewettite and volborthite are sparse. The mineralized rock occurs in irregular layers in sandstone containing abundant carbonized plant debris, in rolls, and in and around fossil logs. The ore bodies are small, generally less than 5 feet long and apparently randomly scattered through the ore-bearing lenses.

R. O. Metals prospects

The R. O. Metals prospects are on the south slope of Hell Canyon in sec. 28, T. 27 S., R. 24 E. The workings consist of an open cut and two short adits, about 15 feet apart vertically. The prospects are estimated to have produced a small amount of high-grade vanadium-uranium ore in the 1950's. The deposits are in steeply northwest dipping beds in a sandstone lens in the upper part of the Salt Wash Member of the Morrison Formation. Sandstone containing carbonaceous material and pebbles of mudstone impregnated with vanadium hydromica and sparse carnotite.

Bridger Jack group of mines

The Bridger Jack group of mines is an arbitrary name given here to include several small mines and many prospects on the southeastern part of Bridger Jack Mesa. This part of the mesa which lies north and northwest of part of Kane Springs Canyon is locally known as Blue Hill. The mines and prospects are in sec. 2, T. 28 S., R. 22 E., secs. 35 and 36, T. 27 S., R. 22 E., and sec. 31, T S., R. 23 E. Included in this group are the Top, Blue Hill, and Blue Hill Nos. 1-3, Robin, Robin No. 1, Big Bowl, Hope Nos. 1, 5, and 6, Sauer, Old Powder, Old Powder No. 6 claims and School Section 2 property.

The mines consist chiefly of rim cuts, small irregular open pits, and short adits. Most of the claims in this group were staked in 1939 and 1940 and probably yielded a small amount of vanadium ore in the early 1940's. Most of these properties were inactive when this part of Bridger Jack Mesa was mapped in 1956. However, the School Section 2 property has a recorded production, for the years 1949-1956, of a small amount of ore averaging 1.62 percent V_2O_5 and 0.24 percent U_3O_8, a ratio of 6.7:1. The Blue Hill claims have also in this same period produced a small amount of ore averaging 1.56 percent V_2O_5 and 0.20 percent U_3O_8. There has also been very small amounts of ore produced in 1949-1956 from the Top, Big Bowl, and Hope No. 1, No. 5, and No. 6 claims. The aggregate production from all the workings in this group including that for the years 1940-44 is estimated to be moderate.

The ore deposits of the Bridger Jack group are in sandstone lenses scattered through the Salt Wash Member of the Morrison Formation from about 30 to 300 feet above the base of the member. They are in a complex graben but show no apparent relations to the faults. The ore minerals, chiefly vanadium hydromica with minor carnotite, impregnate sandstone in irregular layers, streaks, and spots. Generally the mineralized rock contains carbonized plant debris or overlies carbonaceous mudstone. A few large pieces of fossil trees are partly replaced by ore minerals. Rolls of ore are rare. Most of the deposits are less than 100 feet across and show no apparent preferred orientation.

Fault and Sunnyside prospects--(Kane Springs Canyon)

The Fault and Sunnyside prospects are on the north side of Kane Springs Canyon in sec. 31, T. 27 S., R. 22 E. The prospects are in fractured ground near faults along the east side of the Kane Springs graben. The Fault prospect pits are in steeply easterly dipping sandstone beds near the top of the Salt Wash Member of the Morrison Formation. The Sunnyside workings consisting of pits and a short adit are in steeply westerly dipping sandstone beds near the middle of the Salt Wash. The Fault claim was located in 1939, the Sunnyside claim in 1940; neither claim has any recorded production. Both claims contain small amounts of spotty and streaky impregnations of sandstone by dark-gray vanadium hydromica locally flecked with bright-yellow carnotite. The mineralized rock commonly contains carbonized plant material.

Bluebird prospect

The Bluebird prospect is on the south side of Kane Springs Canyon about 0.7 mile north-northeast of Kane Springs in sec. 1, T. 28 S., R. 22 E. The prospect pits are in fractured east-dipping sandstone beds in the upper part of the Salt Wash Member of the Morrison Formation. Thin layers of mineralized sandstone are bounded locally in part by partings of carbonaceous shale. The claim was located in 1940, but has no recorded production.

Lucky Break and Upper Rim prospects

The Lucky Break and Upper Rim prospects are on the north side of Black Ridge about 1 mile northeast of Kane Springs in sec. 31, T. 28 S., R. 23 E. The workings, which consist of rim cuts and short adits, are in a sandstone lens near the top of the Salt Wash Member of the Morrison Formation. Thin-bedded sandstone and shale containing carbonized plant material is irregularly impregnated with vanadium hydromica and minor carnotite. These claims were located in the early 1940's, and have no recorded production.

Lucky Strike mine of Black Ridge

The Lucky Strike mine is on the west side of a small unnamed canyon on the north slope of Black Ridge about 1.5 miles northeast of Kane Springs in sec. 31, T. 27 S., R. 23 E. The workings consist of several short adits and an open cut parallel to the rim about 1,000 feet long. The Lucky Strike claims were located in 1916 and probably produced a small amount of vanadium ore in the 1910's and 1920's. The mine also produced a small amount of ore during the early 1940's. Records show that in the period 1949-1956 the mine yielded a moderate amount of ore averaging about 1.43 percent V_2O_5 and 0.23 percent U_3O_8, a ratio of 6.2:1.

The mine is in sandstone beds in the upper part of the Salt Wash Member of the Morrison Formation. The beds dip about 6° to 10° north-northeast. Vanadium hydromica and carnotite impregnate the sandstone beds in irregular layers about parallel to diastems or seams of carbonaceous shale. Rolls and mineralized fossil trees are common. The apparent dominant trend of the rolls is roughly southeast. The dominant trend of fossil trees in the mine area is probably about due south.

Buster group of claims

The Buster group of claims is north of Kane Springs Canyon in secs. 29 and 32, T. 27 S., R. 23 E. The group, as here considered, includes the Buster Nos. 1-3, New Buster, Pitchblende Nos. 1 and 2, Black Streak claims, and the School Section 32 property. The workings consist of numerous rim cuts, pits, and short adits. An underground mine, which consists of several adits, irregular drifts, and stopes on different levels, is near the north end of the group.

The deposits are in fractured, steeply northwest to west-dipping beds of sandstone in the middle and upper part of the Salt Wash Member of the Morrison Formation. The deposits consist of streaks, spots, and pod-like layers of vanadium hydromica, containing disseminated carnotite. Rolls of ore are uncommon. Some silicified and carbonized tree fragments are richly mineralized. Much of the ore in sandstone is associated with thin-bedded carbonaceous sandstone or seams and partings of carbon-rich shale.

During the vanadium-mining period of the 1940's, this group is estimated to have produced a small amount of ore, probably mostly from workings in section 29. In the period 1949-1956 the group has produced a small amount of ore, mostly from workings in section 32. The average grade of the shipped ore is 1.05 percent V_2O_5 and 0.23 percent U_3O_8, a ratio of 4.6:1.

Snowflake and Sunflower mines

The Snowflake and Sunflower claims are on the mesa north of Pole Canyon in sec. 28, T. 27 S., R. 23 E. The workings are scattered along about 1,000 feet of outcrop and consist of pits, rim cuts, and inclined adits leading to irregular drifts and stopes. These claims were located in 1912, and patented by 1915. The mines have probably been intermittently active since the claims were located and have produced a moderate amount of ore, probably mostly in the early 1940's. Shipments of a moderate amount of ore from these claims has been recorded for the period 1949-1956. The average grade of the shipped ore was 1.54 percent V_2O_5 and 0.26 percent U_3O_8, a ratio of 5.9:1.

The deposits are in fractured, down-faulted, steeply north dipping beds of sandstone near the middle of the Salt Wash Member of the Morrison Formation on the north flank of the Pole Canyon anticline. Vanadium hydromica and carnotite are disseminated in irregular bands in thin-bedded sandstone and interbedded mudstone, commonly near the contacts of these rock types. The ore minerals are also apparently localized by accumulations of fine to coarse fragments of carbonized plant debris and by carbonized and silicified tree fragments. Some ore layers interconnect with thicker rolls of ore. The rolls trend about S. 80° E. (H. K. Thurber, U.S. Bureau of Mines, written commun., 1954). Some ore minerals coat fractures in sandstone. Individual ore bodies are commonly a few feet thick and a few tens of feet across. The bodies are irregular and erratically distributed in an area at least 1,000 feet long parallel to the northwest strike of the outcrop and more than 100 feet wide downdip. The apparent trend of the deposit is about due east.

Hidden Log group of claims

The Hidden Log group of claims is on the mesa north of Pole Canyon in secs. 27, 28, 33, and 34, T. 27 S., R. 23 E. The group, as here considered, includes the Hidden Log Nos. 1 and 2, White Pearl Nos. 1 and 2, and New Deal Nos. 1 and 2 claims. These claims contain many small pits, trenches, and rim cuts. The principal workings are on the Hidden Log No. 2 claim in sec. 34 in the eastern part of the group and consist of several adits leading to irregular stopes. Large parts of the mine are now inaccessible, because of caved ground.

The Hidden Log claims were located prior to 1930 and relocated in 1935. The claims probably yielded a small amount of vanadium ore in the early 1940's. In the period 1949-1956, the Hidden Log group of claims have produced a small amount of ore, probably all from the Hidden Log No. 2 claim. The average grade of the shipped ore was 1.47 percent V_2O_5 and 0.28 percent U_3O_8, a ratio of 5.3:1. The claims were inactive when examined in August 1957.

Most of the mineralized rock on these claims is in sandstone beds estimated to lie near the middle of the Salt Wash Member of the Morrison Formation. The stratigraphic level of the ore deposits is uncertain because the member contacts are locally obscured. Some outcrops of mineralized rock are in the upper part of the member. The upper contact of the member is covered by landslide and gravel deposits. The lower contact is hidden by a fault about 50 feet south of the main workings, along which the Morrison has been dropped against the Entrada Sandstone. Displacement on this fault is estimated to be about 200 feet on the Hidden Log No. 2 claim. Several minor faults having displacements of only about 2 feet cut the ore-bearing beds. The ore-bearing beds dip steeply (15°-30°) to the northwest and north. All the structure appears to be post-ore.

The host rock is fine-grained sandstone containing discontinuous partings and seams of mudstone as much as 5 inches thick. Vanadium hydromica, carnotite, and hewettite impregnate sandstone and carbonaceous shale. Several roll concentrations of ore as much as 3 feet thick are present. The rolls trend northeast and southeast. Most ore bodies apparently were 1 to 3 feet thick and 5 to 30 feet across. The extent of the Hidden Log No. 2 mine suggests that the deposit is less than 500 feet in diameter.

Upper Kane Springs Canyon group of prospects

The Upper Kane Springs Canyon group is a name given here to include many small prospects, which lie near the head of the canyon west of the Yellow Circle group of mines, in sec. 33, T. 27 S., R. 23 E., and secs. 3 and 4, T. 28 S., R. 23 E. Included are the Weary, Brown Rock, Little Rat, Dinosaur, Dip, Blue Bonnet, Bart and Bart No. 1, and New Shiela claims. The workings consist of rim cuts, trenches, and short adits. The aggregate production from all these claims is small. The average grade of the recorded shipments is about 2.05 percent V_2O_5 and 0.47 percent U_3O_8, a ratio of 4.4:1. Most of the prospects are near the basal or in the middle part of the Salt Wash Member of the Morrison Formation. The ore-bearing beds dip steeply southwestward on the south flank of the Pole Canyon anticline. Vanadium hydromica and carnotite impregnate carbonaceous sandstone and mudstone and silicified logs.

Yellow Circle group of mines

The Yellow Circle group of mines is near the head of Kane Springs Canyon in secs. 2 and 3, T. 28 S., R. 23 E. Access to the mines is by an improved road that joins U.S. Highway 160 about 2.4 miles north-northeast of Kane Springs.

According to miners in the area the limits of the Yellow Circle group have been differently placed by different owners and lessees. The group, as here considered, comprises the Yellow Circle Nos. 1-6, Chapparal, Primero, Carol B., Fraction, Maybe, Forked Canyon Lode, Exchequer, Protection, and Dony Nos. 1 and 2 claims. Many of these claims were located in the 1910's and during 1917 and 1918 produced a large amount of uranium ore (Huleatt and others, 1946, p. 27). There was intermittent mining on these claims in the 1920's and 1930's. In response to wartime needs for vanadium, the group produced a moderate amount of ore in the period 1939-1944. The average grade of the recorded shipments of vanadium ore was 1.88 percent V_2O_5. Several of the mines in this group were reactivated in 1949 and were in fairly continuous operation through 1956. In this latter period the group produced a large amount of ore, whose average grade was 1.69 percent V_2O_5 and 0.32 percent U_3O_8, a ratio of 5.3:1. The total production of the Yellow Circle group is estimated to be second only to the Rattlesnake mines among the groups of mines in the Morrison Formation in the Lisbon Valley area.

The larger workings on the Yellow Circle group of claims can be somewhat arbitrarily divided into five mines. On the south side of the canyon near the southwest edge of the group is the Dony mine, which consists of an inclined adit that leads to drifts penetrating ground about 400 feet southeast of the rim; short drifts and stopes have been driven from both sides of the main haulageway. About 800 feet northeast of the Dony mine is the Little Devil mine which consists of adits on two levels leading to larger irregular stoped areas as much as 200 feet from the rim. Near the center of the group extending for more than 500 feet along the rim on the north side of the canyon is the North Wall mine which is a complex on several levels of rim cuts, adits, and irregular stopes as much as 200 feet from the rim. Also near the center of the group but on the south side of the canyon is the South Wall mine which consists of adits and stopes on at least three levels; several of the adits and drifts in this mine are aligned southeasterly parallel to local trends of ore bodies. About 500 feet northeast of the eastern workings of the North Wall mine is the Big Stop mine on the south side of the canyon. It is an irregular stoped area more than 150 feet in diameter. Many parts of the mines that date from the 1940's are now inaccessible because of caved ground. In addition to the major workings many rim cuts, small pits, and adits leading to small stopes, have been dug on the Yellow Circle group of claims, especially southwest of the Little Devil mine and north of the North Wall mine.

The Yellow Circle group is in the upper part of the Salt Wash Member of the Morrison Formation. The deposits occur in two sandstone lenses. According to sections by Huleatt and others (1946, fig. 37) and by Wardwell (Union Mines Development Corp., written commun., 1946) the lower sandstone lens is as much as 60 feet thick and the upper sandstone lens is as much as 35 feet thick. The sandstone lenses are separated near the South Wall mine by about 25 feet of red, gray, and green mudstone, which thins northward. Most of the deposits are in the lower lens. The sandstone is light brownish gray, and speckled with limonite. R. C. Dickinson (U.S. Atomic Energy Commission, written commun., 1953) noted that specks near ore horizons are tan to brown; specks in sandstone not associated with ore are red. The sandstone is medium to coarse grained, commonly friable, and in thin to thick horizontal beds and in crossbeds. It contains interbedded partings and seams of green mudstone. Green mudstone also occurs as pebbles along diastems in the sandstone. Carbonized plant material occurs in both sandstone and mudstone. Silicified logs are locally common in the host sandstone. According to R. C. Dickinson (U.S. Atomic Energy Commission, written commun., 1953) orientation of crossbeds, current lineation and fossil logs indicate that the lower sandstone unit has a sedimentary trend of about N. 60°-70° E., the upper unit about N. 10° E.

The ore minerals, chiefly vanadium hydromica and carnotite, occur in the sandstone in even and irregular layers commonly parallel to diastems, in pod-like lenses commonly associated with carbonized plant debris, as replacement of silicified and calcified fossil logs, and in rolls. The ore layers are as much as 4 feet thick and are generally thickest where they form parts of rolls. In the Dony mine at the south end of the group the rolls trend N. 40° to 60° E. Similar trends of rolls were noted by Wardwell (Union Mines Development Corp., written commun.,1946) in now inaccessible workings in the central part of the Yellow Circle group.

White Fawn mine

The White Fawn mine is about 0.5 mile north of the Yellow Circle Group on the mesa between Kane Springs and Pole Canyons in secs. 34 and 35, T. 27 S., R. 23 E. Claims covering the mine and prospects are the White Fawn Nos. 1 and 2, Inspiration, Jessie Balsley, and United States Treasury. The southernmost of these claims abut those of the Yellow Circle group. The mine and associated prospects extend for more than 500 feet along the outcrop and consist of several trenches, rim cuts, and two inclined adits about 35 feet long. Production from these workings were probably included with that of the Yellow Circle group through the 1940's. Ground immediately east of the mine was tested by five drill holes by the U.S. Bureau of Mines in 1943; the holes were barren (Huleatt and others, 1946, p. 27). In the period 1949-1956, a small amount of ore was shipped from this property. The average grade of recorded shipments is 1.64 percent V_2O_5 and 0.30 percent U_3O_8, a ratio of 5.5:1.

The deposit is in gently south dipping beds in the uppermost ledge-forming sandstone lens of the Salt Wash Member of the Morrison Formation near the faulted crest of the Pole Canyon anticline. The host rock in the mine area is jointed but not offset. The sandstone is light brownish gray and fine grained. Little mineralized rock is visible in the underground workings. Gray streaks of vanadium hydromica apparently mark a roll-type ore body that was at least 2.5 feet thick and trended N. 65° E., parallel to a neighboring joint. Some carnotite is intermixed with vanadium hydromica in a streak of ore at the outcrop.

Fault mine--(Pole Canyon)

The Fault mine is on the south side of upper Pole Canyon in sec. 35, T. 27 S., R. 23 E. Access to the property is by an unimproved forest road about 2 miles to the southwest of the property that joins the improved road that connects the Yellow Circle group of mines to U.S. Highway 160 north of Kane Springs. The property includes the Fault, Fault Nos. 1-3, and Cedar claims. The claims were probably located in the late 1940's. In 1957, the mine consisted of three adits each about 100 feet long, leading to interconnecting stopes. Older underground workings are obscured by an open pit and caved ground.

The mine is in faulted and jointed steeply northeast dipping beds of sandstone near the top of the Salt Wash Member of the Morrison Formation. The sandstone is fine to coarse grained and contains patches of macerated plant material. Green mudstone is interbedded as thin seams. The deposit is in a zone of normal faults that truncate the north flank of the Pole Canyon anticline. Near the mine the beds have been offset downward about 200 feet on the north side of a major southeast-trending fault. Minor faults having displacements parallel the major faults. The ore deposit appears to trend southeasterly about parallel to the faults. Small lenticular ore bodies, consisting of carbonaceous sandstone impregnated with vanadium hydromica and carnotite, are cut by the minor faults. Commonly the ore layers are less than 2 feet thick, but they appear to be thickened by drag locally along faults. Potential ore-bearing ground southeast of the mine is covered by landslide.

Total production from this property through 1952 is moderate. Average grade of the recorded shipments is 1.82 percent V_2O_5 and 0.44 percent U_3O_8, a ratio of 4.1:1.

Unidentified prospect in upper Pack Creek

An unidentified caved adit in fine-grained laminated sandstone near the base of the Salt Wash Member of the Morrison Formation is on the south side of Pack Creek in sec. 33, T. 27 S., R. 24 E. The workings were judged to date from the 1940's or earlier. The prospect was probably for vanadium but no mineralized rock was recognized in the outcrop or in the dump.

Porcupine mine

The Porcupine mine is about 1 mile southeast of Kane Springs in sec. 7, T. 28 S., R. 23 E. The workings, which consist of rim cuts and short adits, are in a sandstone lens near the top of the Salt Wash Member of the Morrison Formation. The mine has produced a small amount of ore in the early 1940's, and in the early 1950's. The average grade of the recorded shipments in the period 1950-1956 is 1.73 percent V_2O_5 and 0.28 percent U_3O_8, a ratio of 6.2. Much of the ore is associated with thin-bedded carbonaceous sandstone, tree fragments, and clay galls. Vanadium hydromical is the dominant ore mineral; carnotite is present but not conspicuous. The host sandstone is limonite stained and contains streaks of a bright-green fine mica or clay mineral.

Black Canyon group of claims

The Black Canyon group of claims is an arbitrary name given here to include several small mines and prospects near the mouth of Black Canyon in secs. 16 and 17, T. 28 S., R. 23 E. Included are Bliss Pasture Nos. 1-3, Black Canyon No. 1, Prince Albert, Lizard, Carol Lee, Black Rock, Mary Knoll, Blackstone Nos. 1 and 2, Lulu Belle, and Last Chance claims and the Rust and Sears property in School Section 16.

The claims contain many rim cuts, small pits, and stub adits. The larger mines also have irregular adits and crosscuts leading to stoped areas mostly within a few tens of feet of the rim. The largest mine is on the Prince

Albert claim, which was located in 1939. The mine was active in the early 1940's, the average grade for the years 1949-1956 was 1.46 percent V_2O_5 and 0.17 percent U_3O_8, a ratio of 8.6:1. The Last Chance and Black Rock claims, and Rust and Sears property each have irregular underground workings of several hundred feet in length. Each of these properties has produced a small amount of ore in the early 1950's. Shipments from the Last Chance mine averaged about 1.88 percent V_2O_5 and 0.29 percent U_3O_8, a ratio fo 6.5. The ore from the Black Rock mine averaged about 1.96 percent V_2O_5 and 0.26 percent U_3O_8, a ratio of 7.5:1. Ore from the Sears and Rust property averaged 1.31 percent V_2O_5 and 0.23 percent U_3O_8, a ratio of 5.7:1. Small shipments of ore are also recorded from the Lizard and Mary Knoll claims of this group. The average grade of all recorded shipments from the Black Canyon group of claims is 1.64 percent V_2O_5 and 0.23 percent U_3O_8, a ratio of 7.1:1.

The uranium-vanadium deposits occur in several sandstone lenses in the upper half of the Salt Wash Member of the Morrison Formation. There are at least four ore-bearing sandstone lenses, having maximum thickness of about 20 to 50 feet and extending a few hundred to probably several thousand feet along the outcrop. Most of the deposits are in the second and third sandstone lenses below the top of the member. On these claims the deposits are with few exceptions in the middle or lower part of the host sandstone lenses. The deposits, which probably average less than 500 feet in diameter, contain small more or less randomly scattered ore bodies of sandstone impregnated with vanadium hydromica and carnotite. The ore bodies are irregular tabular bodies and pod-like lenses commonly associated with carbonized plant debris and about parallel to diastems between bedding units. Some layers interconnect with thicker rolls of ore. Mineralized logs are an important source of high-grade ore. Neither the ore bodies nor the deposits show an obvious preferred orientation, but northeasterly to easterly trends are probably most frequent. An unidentified green clay or very fine mica is locally conspicuous in streaks in the mineralized sandstone.

Gray Horse claim

The Gray Horse claim is about 2 miles west of Browns Hole on the south side of Muleshoe Canyon in sec. 21, T. 28 S., R. 23 E. The workings in January 1956, consist of an inclined adit and drift about 200 feet long and contained ore-grade material as much as 18 inches thick in a shallow channel trending east-southeast (J. W. Hasler, U.S. Geological Survey, and M. H. Salsbury, U.S. Bureau of Mines, written commun., January 1956). The deposit is in a lens of sandstone in the lower part of the Salt Wash Member of the Morrison Formation. A small amount of ore averaging about 0.13 percent U_3O_8 was discovered by drilling in late 1956 and early 1957 as part of a Defense Minerals Exploration Administration contract (N. L. Archbold, U.S. Geological Survey, and M. H. Salsbury, U.S. Bureau of Mines, written commun., August 1957).

Magee mine

The Magee mine is about a mile west of Browns Hole on the north side of Muleshoe Canyon in sec. 22, T. 28 S., R. 23 E. The deposit is in the middle one-third of the Salt Wash Member of the Morrison Formation, about 200 feet above the base of the member. The workings consist of an adit, which in the period 1949-1956 produced a small amount of ore averaging about 0.91 percent

V_2O_5 and 0.14 percent U_3O_8, a ratio of 6.5:1.

Gramlich group of claims

The Gramlich group of claims are on the mesa on the south side of Browns Hole in secs. 26-28 and 33-35, t. 28 S., R. 23 E. The claims are served by improved and unimproved roads that connect with U.S. Highway 160 about 1.5 miles northwest of La Sal Junction.

The Gramlich Exploration Co. lease in the mid-1950's, comprised about 90 claims, including the following: Blue Goose Nos. 1-4 and 7, Blue Goose 5-7 Fractions; Donna M and Donna M No. 1; Shirley J and Shirley J No. 1; Red Rock Nos. 1-12 and Red Rock No. 1 Fraction; Redbird; Mary Jo Nos. 1-12; Blue Jay and Blue Jay Fraction; Old Tree; Bluebird or Bad Luck; Dugout and Dugout No. 1; Rose; Sunset and Sunset Nos. 1 and 2; Pine Tree; Golden West and Golden West Nos. 1-11; Joan; San Juan and San Juan Nos. 1-6; Grand View Nos. 1-7; Rosebud and Rosebud No. 1; and Sunnyside.

The principal workings are on the Blue Jay, Pine Tree, and San Juan claims. Rim cuts, trenches, and irregular stub adits, less than 20 feet long, are widely scattered on many claims along the outcrop. Most of the mining on this group of claims was in the vanadium-buying period of 1942-1944. In the early 1950's, a moderate amount of uranium-vanadium ore was produced from the group, mostly from the principal workings; small amounts of ore were also shipped from the Joan and Sunnyside claims.

The Blue Jay mine, in 1955, consisted of rim cuts, several stub adits, and two winding east-trending adits merging into a single drift about 200 feet from the rim. The two adits reach a face about 400 feet from the rim and have many small irregular crosscuts and stopes which generally are a few tens of feet in longest dimension. This mine probably produced a moderate amount of vanadium ore in the early 1940's; records show that in the period 1949-1956, it produced a moderate amount of ore averaging about 1.45 percent V_2O_5 and 0.46 U_3O_8; a vanadium-uranium ratio of 3.2:1.

The Pine Tree mine consists of rim cuts, stub adits, and an irregular drift more than 50 feet long. The Pine Tree mine probably produced a moderate amount of vanadium ore in the early 1940's; records for the period 1945-1956 show that a moderate amount of ore was shipped averaging about 1.84 percent V_2O_5 and 0.19 percent U_3O_8, a vanadium-uranium ratio of 9.7:1.

The San Juan mine was begun in 1953 as a large open cut more than 100 feet across; an adit was driven in late 1954, and underground workings probably were several hundred feet in length in 1956. The San Juan mine through 1956 has produced a moderate amount of ore averaging about 1.80 percent V_2O_5 and 0.33 percent U_3O_8, a vanadium-uranium ratio of 5.5:1.

The deposits are in sandstone lenses interstratified with mudstone in the upper half of the Salt Wash Member of the Morrison Formation. The ore-bearing horizons range from about 200 to 250 feet above the base of the Salt Wash Member, which is about 340 feet thick in this part of the area. The ore-bearing lenses range from about 30 to 100 feet in maximum thickness and from about 100 to 1,000 feet in width; the lenses appear to be generally elongated easterly or northeasterly.

The lens in which the Blue Jay adit is driven is probably representative of the ore-bearing lenses near Browns Hole. The dimensions of this body are fairly well known, because it has been explored by many drill holes (F. M. Byers, U.S. Geological Survey, and P. V. Filo, U.S. Bureau of Mines, written commun., February 15, 1957). The lens generally ranges from about 15 to 30 feet in thickness and reaches a maximum thickness of about 40 feet. The edges of the lens were not located, but reconnaissance of the outcrop and contours of the isopachous map of part of the lens suggest that the lens ranges from about 400 to 600 feet in width. The lens thins markedly about 1,600 feet east of the portal of the adit, and probably pinches out about 2,000 feet east of the portal of the adit. Mineralized rock is generally confined to the thicker part of the lens which apparently occupies an irregular east-trending channel. Mudstone underlying the mineralized portion of the lens is generally altered to grayish green; the thickness of this altered mudstone is as much as 8 feet.

The host sandstone of the Blue Jay deposit is light gray to light brown, fine to medium grained, and in part in thin horizontal beds but dominantly in trough sets of low-angle cross laminae. Carbonaceous material consisting mostly of carbonized plant debris is common and locally abundant. Greenish-gray mudstone occurs as partings and as thin seams along minor diastems between sets of beds. Other sandstone units near Browns Hole are for the most part similar to the sandstone of the Blue Jay deposit but many are reddish gray or reddish brown less conspicuously cross-bedded and less carbonaceous.

The ore deposits tend to be confined to the thicker part of an ore-bearing sandstone lens though not necessarily to the thickest sandstone lens present. Generally at any one locality only one lens of sandstone is mineralized but commonly on nearby claims different lenses are mineralized. For example, the Pine Tree mine is in a stratigraphically lower sandstone lens than the ore-bearing lenses of the Sunnyside mine or the Blue Jay adit. Exceptionally, as near the Blue Jay adit, two sandstone lenses contain ore.

The ore deposits consist of layers of sandstone and pieces of fossil wood irregularly impregnated and in part replaced by dark-gray vanadium and bright-yellow uranium minerals. These minerals were identified in the field as vanadium hydromica and carnotite but study of a specimen of high-grade ore suggests that the mineralogy is at least locally complex. The specimen, which was from a mineralized log in the Blue Jay adit, was studied by Alice D. Weeks of the U.S. Geological Survey. She reported: "The specimen contains small remnants of pitchblende and has been highly oxidized and replaced by tyuyamunite, part of which was dehydrated to metatyuyamunite. One X-ray pattern showed a little carnotite, but most of the bright yellow and greenish-yellow is tyuyamunite. The orange and pale-brown is mostly 'limonite'-stained tyuyamunite. Some of the orange mineral surrounding the black gives almost no X-ray pattern and could be referred to as 'gummite.' I would guess that a pitchblende-replaced piece of wood become oxidized to becquerelite, etc., and in turn altered to tyuyamunite and then became stained with iron oxide. Under a binocular you can see the waxy dull brown grading into yellow" (A. D. Weeks, written commun., October 15, 1953).

The mineralized layers are commonly in pods a few feet thick and less than 10 feet long. More persistent layers are generally relatively thin. The lenses and layers are mostly parallel to carbonaceous diastems and horizontal beds but cut across the dominant low-angle crossbeds. Rolls of ore are relatively scarce. High-grade ore is associated with large fragments of carbonized and silicified wood, including fossil logs more than 1 foot in diameter and 20 feet in length, and with pods of sandstone containing abundant carbonized flakes of plant material. The mineralized layers, pods, and fossil material that form the ore bodies are discontinuous and in part randomly distributed. Study of the mineralized rock in the sandstone lens of the Blue Jay adit shows, however, that the ore bodies tend to be clustered in the lower half of the thicker part of the host sandstone lens so as to constitute a mineable deposit.

Blue Bird mine--(West Coyote Creek)

The Blue Bird mine is about 1.2 miles east-northeast of La Sal Junction in sec. 3, T. 29 S., R. 23 E. The principal workings are several irregular adits and stopes more than 70 feet from the outcrop. In addition there are several rim cuts, a few tens of feet to a few hundreds of feet long, on the blue Bird and the adjacent Junction and Junction No. 3, or Little Joe claims. These claims probably produced a moderate amount of ore in the early 1940's. A moderate amount of ore shipped from this property in the 1950's averaged 1.01 percent V_2O_5 and 0.23 percent U_3O_8, a vanadium-uranium ratio of 4.4:1. The deposits are in a sandstone unit in the upper part of the Salt Wash Member of the Morrison Formation. The ore minerals, chiefly vanadium hydromica, impregnate sandstone in irregular layers along carbonaceous partings. High-grade ore is associated with carbonized and silicified pieces of wood.

Highway prospect

A prospect on the Highway, or Roadside, claim is about 2.5 miles east of La Sal Junction near Utah Highway 46 in sec. 2, T. 29 S., R. 23 E. The workings of a rim cut, less than 100 feet long, and about 30 feet of irregular underground workings. A small amount of vanadium ore probably was shipped from this property in the early 1940's. The prospect is in a poorly exposed, light-brownish-gray to light-reddish-brown sandstone unit, more than 15 feet thick, near the top of the Salt Wash Member of the Morrison Formation. Mineralized sandstone is in lenses, a few inches thick and a few feet long, in an area about 20 feet across. The ore minerals are vanadium hydromica and carnotite. Remnants of mined-out rolls are judged to trend northeasterly.

Coyote prospect

The Coyote prospect is about 3.1 miles east-southeast of La Sal Junction in sec. 12, T. 29 S., R. 23 E. The workings consist of an adit leading to a small irregular stoped area. A small amount of vanadium ore is estimated to have been produced from these workings in the early 1940's. Records show that a very small shipment of ore from this claim, made in 1951, averaged about 1.73 percent V_2O_5 and 0.49 percent U_3O_8, a vanadium uranium ratio of 3.5:1.

Rattlesnake mines

The Rattlesnake mines are about 4 miles east-southeast of La Sal Junction in sec. 12, T. 29 S., R. 23 E. In 1957, the principal access to the mines was by way of improved and unimproved roads that connect with Utah Highway 46 about 2 miles west of La Sal. Trucks also used an unimproved road that connects with Utah 46 about 2 miles east of La Sal Junction.

At the time of mapping the Rattlesnake property was being exploited through two large mines, an open pit, and an incline leading to underground workings. The open pit is on the southeast side of a prominent flat-topped hill whose summit is more than 400 feet above the surrounding lowlands. In 1957 the Rattlesnake pit was roughly 400 feet long and 250 feet wide in the ore zone; plans indicated that it would be at least 500 feet long and 350 feet wide when completed. On the east side of the hill, about 1,350 feet northeast of the pit is the portal of the inclined adit. The adit is more than 800 feet long and has been driven southwesterly toward the pit. About 220 feet from the portal is an irregularly shaped stoped area as much as 260 feet long perpendicular to the adit and as much as 150 feet wide.

The deposits are in the upper part of the Salt Wash Member of the Morrison Formation, mostly in a small graben on the north side of the northwest-trending Lisbon Valley fault. Along the main fault the Salt Wash has been dropped relative to the San Rafael Group. The maximum displavement on the property is about 400 feet. A smaller fault, roughly parallel to the Lisbon Valley fault, is intersected by the adit; this fault is within the Morrison Formation and near the incline displaces the rocks on the south side of the fault downward about 30 feet. Although all the mine workings are within the graben, mineralized rock is reported from drill holes northeast of the graben.

The Rattlesnake deposit reportedly was found at the outcrop in 1952. A small irregular underground mine, whose portal was near the Lisbon Valley fault, explored the south side of the deposit in 1953. Diamond drilling, in 1953 and 1954, discovered ore bodies northeast of the fault. Removal of overburden for the open cut began in 1954, and mining from the pit began in 1956. The inclined adit was begun in 1955, and yielded some ore in the same year. By the end of 1956, the Rattlesnake property had yielded a very large amount of ore averaging about 0.84 percent V_2O_5 and 0.28 percent U_3O_8. Reserve estimates, made in 1957, suggest that the total production from this mine will equal or exceed the total production from all other uranium-vanadium deposits in the Morrison Formation in the Lisbon Valley area.

The hill north of the Rattlesnake pit is capped by resistant, partly silicified sandstone of the Burro Canyon Formation (Lower Cretaceous). Red mudstone and minor sandstone of the Brushy Basin Member of the Morrison Formation underlies the hillslopes. The Salt Wash Member forms the bedrock on only a small part of the property near the fault. Outcrops are rare. The slopes are covered by landslide material. The material consists of large, irregular masses of mudstone derived from the upper part of the Morrison Formation and blocks of sandstone derived from the Burro Canyon Formation. In places the sandstone blocks have been firmly cemented by caliche to form resistant layers of breccia. Parts of several landslide masses were well exposed in the walls of the open cut in 1957.

The Rattlesnake ore deposit is in a unit of sandstone beds near the top of the Salt Wash Member of the Morrison Formation. The sandstone unit ranges from about 35 to 55 feet in thickness. Drill hole information suggests that the ore-bearing unit thins to the northeast and probably also to the southeast, but it remains thick along the northeasterly line connecting the pit and the incline. The sandstone is mostly light brown, fine to medium grained and in even to irregular horizontal thin beds and in lensing sets of low-angle crossbeds. The ore-bearing unit contains a small amount of mudstone in thin lensing seams, in partings between sets of beds of sandstone, and as irregular pebbles in sandstone. Carbonized pieces of wood and accumulations of macerated plant material are sparse to common throughout the ore-bearing sandstone.

The dominant ore minerals are vanadium hydromica and carnotite. Sparse amounts of hewettite and black vanadium oxides (probably montroseite and corvusite) are reported by company geologists. These minerals are fine grained and mainly fill the pore spaces of the sandstone; small amounts of the ore minerals impregnate or replace thin mudstone seams and pebbles. Carnotite is especially abundant in and around some of the carbonized plant fossils. In the sandstone around some masses of ore is a vague but conspicuous irregular thin border impregnated by a bright-green very fine grained flaky mineral, probably a chromium-bearing clay or mica.

The ore bodies are uneven tabular layers that lie nearly parallel to the bedding but are not concordant with the bedding in detail. Boundaries of the ore layers range from sharp to gradational. Locally the ore layers are in ill-defined cone containing many small lenses and spots of sandstone impregnated with ore minerals. These layers commonly range from about 1 to 10 feet in thickness. In plan they range from roughly circular bodies, only a few feet across, to irregularly shaped masses a couple hundred feet across. The layers are at different stratigraphic positions within the ore-bearing sandstone unit, but most of them are near the middle of the unit. A few layers partly overlap other layers.

The Rattlesnake deposit except for its large size is similar to other uranium-vanadium deposits in the Morrison Formation. Although in close proximity to the Lisbon Valley and subsidiary faults and fractures, it is not clearly related to them. Some ore layers have been cut by the faults, although this may reflect only the latest movement on an old fault system above the roll of Salt Wash underlying the nose of the Lisbon Valley anticline. The ore-bearing sandstone is much like ore-bearing sandstones of Dry Valley and Browns Hole. It is thick relative to other sandstone units of the Salt Wash Member nearby but is not as thick as the thicker parts of the ore-bearing sandstones in Dry Valley. The Rattlesnake deposit seems to occupy the relatively thicker part of the ore-bearing unit. Ore bodies within the Rattlesnake deposit do not show a marked preferential orientation, but it seems likely that the deposit trends northeasterly along the projected trend of the thicker part of the ore-bearing sandstone.

Bonanza prospect

The Bonanza prospect is north of Island Mesa about 0.5 mile northeast of State line marker post 82 in Montrose County, Colorado. The workings consist of rim cuts and a short adit in conglomeratic sandstone lens near the base of the Brushy Basin Member of the Morrison Formation. A few streaks of vanadium minerals occur in the adit.

Saint Paul prospect

The Saint Paul prospect is on the north side of Island Mesa about 1.9 miles northeast of State line marker post 82 in Montrose County, Colorado. The workings consist of a rim cut, trenches, and a stub adit. The prospect is in a sandstone lens about 20 feet thick in the lower part of the Brushy Basin Member of the Morrison Formation. The lower one-third of the lens is reddish-gray, fine- to medium-grained sandstone intercalated with thin beds of red sandy siltstone and red mudstone; the upper two-thirds of the lens is dark-brown conglomeratic sandstone containing chert pebbles as much as 2 inches across but averaging about 0.2 to 0.5 inches across. Vanadium minerals occur in dark-greenish-gray and grayish-purple and reddish-brown streaks, a few inches thick, which crosscut beds of fine-grained sandstone in the lower part of the lens. The rock is slightly radioactive, but no uranium minerals were recognized. The host rock in the prospects, which lie near a small fault, are conspicuously jointed but the joints do not apparently affect the mineralized layers. Total production from these workings is estimated to be very small.

Vanadium Wonder group of prospects

The Vanadium Wonder group of prospects is south of Island Mesa in secs. 31 and 32, T. 30 S., R. 26 E. The workings consist of trenches, pits, and rim cuts in sandstone in the upper part of the Salt Wash Member of the Morrison Formation near the fault along the north side of Lower Lisbon Valley. The ore-bearing sandstone ranges from about 10 to 25 feet thick. It is light grayish brown, fine grained, in part horizontally bedded, in part crossbedded, and contains very sparse carbonaceous material. Gray streaks of vanadium hydromica accompanied by spots of malachite occur sparsely in the workings. The sandstone is slightly radioactive but no uranium minerals were recognized. A very small amount of vanadium ore, averaging about 1.38 percent V_2O_5, was shipped from these workings in 1942.

North Side prospects

The North Side prospects are on the south side of Island Mesa in sec. 4, T. 31 S., R. 26 E., San Juan County, Utah. The workings consist of an adit about 70 feet long with a few irregular stopes and a small rim cut. The adit is in a sandstone lens about 15 feet thick in the upper part of the Salt Wash Member of the Morrison Formation. The sandstone is light grayish to light reddish brown, medium grained and is mostly in ripple-marked and current-lineated thin beds. No mineralized rock was seen in place in the adit but a small dump contained carbonaceous sandstone impregnated with vanadium hydromica and carnotite. About 500 feet northwest of the adit is a rim cut in a lens, less than 10 feet thick, of conglomeratic sandstone in the lower part of the Brushy Basin Member of the Morrison Formation. Vanadium hydromica, carnotite, and volborthite are present in this sandstone. The miners report that several truckloads of low-grade ore were shipped from the rim cut.

Mint group of prospects

The Mint group of prospects are on the south side of Island Mesa in secs. 35 and 36, T. 45 N., R. 20 W., San Miguel County, Colorado. The Mint claims were probably staked in 1953, and were prospected with numerous bulldozed pits and rim cuts. Several of the pits contain sandstone impregnated with a dark-greenish-gray mineral, probably vanadium hydromica, sparse volborthite, and very sparse carnotite. The mineral occurrences are in ledge-forming lenses, only a few feet thick, composed of dark-greenish-gray, pebbly, medium-grained sandstone in the lower part of the Brushy Basin Member of the Morrison Formation.

Empire group of mines

The Empire group of mines is on the south side of Island Mesa about 0.6 mile north of McIntyre Canyon in sec. 1, T. 44 N., R. 20 W., and sec. 6, T. 44 N., R. 19 W., San Miguel County, Colorado. The workings consist of rim cuts and three adits, the longest about 300 feet in length and with more than 100 feet of irregular drifts and slopes.

The property was mined in the early 1940's and in the early 1950's. Total production is estimated to be small. The average grade of ore as shown by imcomplete records is about 1.27 percent V_2O_5 and 0.29 percent U_3O_8. the vanadium-uranium ratio was 4.4:1. It was idle when examined in late 1958, and parts of the mines were inaccessible.

The deposits are in the basal part of a complex lens in the upper part of the Salt Wash Member of the Morrison Formation. The lens is about 30 feet thick and consists, in ascending order, of (1) horizontally thin-bedded light-brownish-gray, fine-grained sandstone less than 10 feet thick, (2) a sequence, about 15 feet thick, of greenish- and reddish-gray mudstone intercalated in thin units with fine-grained sandstone, and (3) reddish-brown medium- to coarse-grained sandstone about 10 feet thick. Carbonaceous material is sparse in the ore-bearing sandstone. Vanadium hydromica and carnotite occur mostly in tabular bodies, as much as 2 feet thick, which are apparently localized by marked thinning of the sandstone unit forming the basal part of the lens.

Happy Jack Mine--(McIntyre Canyon)

The Happy Jack mine is on the south side of Island Mesa about 0.8 mile north of McIntyre Canyon in sec 31, T. 45 N., R. 19 W., San Miguel County, Colorado. The workings consist of rim cuts, open pits, and three slightly inclined adits leading to several hundred feet of irregular drifts in an area about 100 feet wide and 250 feet long. The mine is estimated to have produced a small amount of vanadium ore in the early 1940's. The property was idle when examined in the summer of 1957, and part of the underground workings was caved.

The mine is in a sandstone lens bout 90 feet above the base of the Brushy Basin Member of the Morrison Formation. The lens is about 20 feet thick near the mine but thins to only 3 feet within 100 feet to the west of the mine; beyond this point the lens is obscured by landslide. Although the ore-bearing sandstone of the Happy Jack mine is lighologically similar to and at the same stratigraphic level as the ore-bearing sandstone at the nearby Vanadium Queen mine, it appears unlikely that the two deposits are in the same lens. The host rock is chiefly a poorly sorted, pebbly, fine-grained sandstone, composed of quartz with minor feldspar and chert. The pebbles are as much as 10 mm across and are composed of red, gray, and green chert. The sandstone is firmly cemented with calcite and forms a prominent ledge. It is mostly in low-angle crossbeds. Carbonaceous material is abundant as scattered coaly flakes and as coaly and silicified pieces of wood, including a fossil log as much as 25 feet long and more than 12 inches in diameter. The long axes of the large pieces of fossil wood trend nearly due north.

Vanadium hydromica and carnotite occur in spots, streaks, tabular bodies as much as 2 feet thick, and in roll type concentrations. The long axes of the rolls on average trend northerly about the parallel to the trend of the large pieces of fossil wood. These trends and the pattern of the known workings suggest a northerly elongation of the ore deposit.

Vanadium Queen mine

The Vanadium Queen mine is about 0.4 mile north of McIntyre Canyon is secs. 1 and 12, T. 44 N., R. 20 W., San Miguel County, Colorado.

The claims containing the Vanadium Queen mine were located in 1926. The mine has been operated at intermittent intervals since the original discovery. It was apparently inactive when visited in the summer of 1957. Total production was estimated to be small.

The workings consist of several surface cuts and three adits, which are interconnected by more than 500 feet of irregular drifts. Most of the underground workings were inaccessible in 1957 because of caving and flooding.

The mine is about 90 feet above the base of the Brushy Basin Member of the Morrison Formation. The ore-bearing rock is a sequence of lenses of medium-grained and conglomeratic sandstone. The sandstone is light grayish brown or pinkish to greenish gray and weathers darker, commonly with a distinct brownish cast due to limonite or manganese stain. Dominant ore subrounded medium grains of clear quartz, colored chert, and white grains (weathered tuffaceous material?). Pebbles, 2 to 12 mm in diameter, averaging about 4 mm in diameter, occur in pockets and stringers and consist of orange, grayish-green, and yellow-brown chert, and light-gray claystone. The sandstone is poorly sorted, well cemented with calcite, and is mostly horizontally bedded, although in part in low angle crossbeds. Mudstone interbedded with the sandstone is brownish and greenish gray, and contains macerated carbonaceous fossil plants. The claystone above and below the sandstone sequence is generally very light gray, nearly white, and weathers to a fluffy texture.

Mineralized layers occur in the ore-bearing rock in three units which are, in ascending order; (1) dark conglomeratic sandstone, as much as 15 feet thick, which pinches out to the east; (2) about 3 feet higher, is light grayish-brown, medium-grained sandstone in medium to thick beds, which thickens eastward where as the conglomeratic sandstone thins; (3) medium-grained sandstone thin beds about 12 feet above the medium- to thick-bedded sandstone. The underground workings are in the conglomeratic sandstone. The other ore-bearing beds are exploited by open cuts. The ore is tabular bodies, as much as 4 feet thick, and in variously shaped rolls. Gray vanadium hydromica is the dominant ore mineral; carnotite is sparse. The straight adits, orientation of the exposed ore layers, rolls and fossil logs, suggest a northerly to northwesterly trend of the ore zone. A thin lens of claystone near the west portal was bright green, and probably contains a vanadiferous chromiferous clay.

Smokey group of prospects

The Smokey group of prospects are on the north side of McIntyre Canyon in secs. 11 and 12, T. 44 N., R. 20 W., San Miguel County, Colorado. The workings consist of several open pits and a short adit. The deposits are in sandstone in the upper part of the Salt Wash Member of the Morrison Formation within a few hundred of a small fault. The mineralized rock is grayish green and is in patches of thin streaks and spots. Vanadium hydromica is dominant; carnotite, volborthite, and malachite are locally common. The total amount of ore produced from these workings is estimated to be very small.

Yellow Girl mine

The Yellow Girl mine is about 0.5 mile south of McIntyre Canyon in sec. 13, T. 44 S., R. 20 W., San Miguel County, Colorado. The workings consist of several open pits, rim cuts, and two short adits. The mine was active in the early 1940's and in the early 1950's. It was idle and the workings were mostly caved when visited in late 1957. The total amount of ore produced from this mine is estimated to be small.

The mine is in poorly sorted conglomeratic sandstone lens about 70 feet above the base of the Brushy Basin Member of the Morrison Formation. The lens is much obscured by landslide. Vanadium hydromica is the dominant ore mineral; carnotite is common locally. Mine walls in 1944 showed mineralized layers as much as 2 feet thick (R. K. Kirkpatrick, Union Mines Development Corp., written commun., 1945).

Prospect southeast of the Yellow Girl mine

An unidentified prospect is on the east side of a small canyon about 0.5 mile southeast of the Yellow Girl mine in sec. 18, T. 44 N., R. 19 W., San Miguel County, Colorado. A small pit has been dug in vanadium- and uranium-bearing sandstone in the upper part of the Salt Wash Member of the Morrison Formation on the north side of a minor fault.

La Salle Nos. 1 and 2 mine

The La Salle Nos. 1 and 2 mine is on Horse Range Mesa in sec. 30, T. 44 N., R. 19 W., San Miguel County, Colorado. The workings include several open cuts, hundreds of feet long and several tens of feet wide, and a few stub adits. The mine was probably opened in the early 1940's, but was probably much enlarged in the period 1949-1951, when a moderate amount of ore was produced. The mine was idle when visited in late 1958. The average grade of the recorded shipments was about 0.59 percent V_2O_5 and 0.12 percent U_3O_8. The vanadium-uranium ratio of this ore was about 4.9:1. The mine is in a sandstone unit at the top of the Salt Wash Member of the Morrison Formation. The ore-bearing sandstone is fine grained, crossbedded, and contains abundant carbonaceous material. The mineralized sandstone is mostly irregular tabular layers of dark-gray rock impregnated with vanadium hydromica. The only roll exposed trends east-northeast. Carnotite is sparse except in scattered trashy accumulations of carbonaceous material. Malachite is locally common in the workings.

Although here regarded as separate properties in the past this mine, the Buck Horn, Pinto, and Cone mines have been grouped by miners and recorders as the Buck Horn, Cone, or O'Neill group of mines.

Pinto mine

The Pinto mine is on the west rim of Horse Range Mesa in sec. 30,

T. 44 N., R. 19 W., San Miguel County, Colorado. The workings in 1958 consist of small open pits and rim cuts, an adit about 120 feet long leading to irregular drifts and stopes that exploit an area roughly 160 feet in diameter, and a short inclined adit leading to an irregularly stoped area about 100 feet long and 30 feet wide. These workings probably were begun in the early 1940's, and much enlarged in the early 1950's. Total production from this property is estimated to be moderate. Incomplete records indicate that the shipped ore averaged about 1.39 percent V_2O_5 and 0.26 percent U_3O_8. The vanadium-uranium ratio of this ore was 5.2:1.

The mine is in the top ledge-forming sandstone unit of the Salt Wash Member of the Morrison Formation. The ore-bearing sandstone is the same lens that contains the Buck Horn workings. Carbon, as trashy accumulations and limbs, is abundant in the sandstone. Corvusite, carnotite, and pascoite are among the ore minerals; malachite and volborthite also occur in the mine workings (D. R. Shawe, U.S. Geological Survey, written commun., 1956). The ore occurs in irregularly lenticular layers as much as 4 feet thick.

Buck Horn mine

The Buck Horn mine is on the north rim of a small canyon on the west side of Horse Range Mesa in sec. 30, T. 44 N., R. 19 W., San Miguel County, Colorado. The workings consist of rim cuts and several adits leading to several hundred feet of irregular drifts and stopes. The main period of production was in the early 1940's. A small amount of ore was shipped to mills from this property in the early 1950's. The grade of the ore was about 1.68 percent V_2O_5 and 0.23 percent U_3O_8; the vanadium-uranium ratio is 7.3:1.

The mine is in the top ledge-forming sandstone unit of the Salt Wash Member of the Morrison Formation. The ore-bearing sandstone is about 30 to 40 feet thick near the mine and is underlain locally by green mudstone. The chief ore minerals are vanadium hydromica and carnotite. Hewettite and rossite were noted by Kirkpatrick (Union Mines Development Corp., written commun., 1945). Chalcocite in small modules, malachite, azurite, and volborthite are locally common (D. R. Shawe, U.S. Geological Survey, written commun., 1956). The ore occurs mostly in uneven layers, less commonly in rolls.

Cone mine

The Cone mine is on the north side of East Summit in sec. 36, T. 44 N., R. 20 W., San Miguel County, Colorado. The workings consist of rim cuts and an inclined adit collared in the Brushy Basin Member of the Morrison Formation. The stopes are in the top ledge-forming sandstone unit of the Salt Wash Member of the Morrison Formation. Vanadium hydromica is common; carnotite is sparse. The mine is estimated to have produced a small amount of vanadium ore in the early 1940's.

Although here regarded as separate properties, this mine, the Buck Horn, Pinto, and La Salle Nos. 1 and 2 mines have been grouped by other geologists, miners, and recorders as Buck Horn, Cone, or O'Neill group of mines.

NH prospect

The NH prospect is on the north side of East Summit in sec. 36, T. 44 N., R. 20 W., San Miguel County, Colorado. Workings include a small rim cut and an adit about 40 feet long. The prospect is in a sandstone unit, about 15 feet thick, near the top of the Salt Wash Member of the Morrison Formation. The sandstone, is medium grayish brown, fine grained, crossbedded, and contains seams of green and red mudstone. At the portal of the adit the top 12 inches of the underlying red mudstone unit is altered to grayish green. Mineralized rock is mostly in vaguely defined gray layers, only a few inches thick, that conforms roughly to the northwest dip of the crossbeds. A small roll of ore exposed at the portal trends about N. 30° E. Vanadium hydromica is the dominant ore mineral; carnotite is very sparse. A small amount of ore was produced from this prospect in 1950. The average grade of the ore was 1.50 percent V_2O_5 and 0.12 percent U_3O_8; the vanadium-uranium ratio was 12.4:1.

Wild Horse prospect

The Wild Horse prospect is north of East Summit in sec. 36, T. 44 N., R. 20 W., San Miguel County, Colorado. The prospect in 1956, consisted of a small rim cut and trench. The workings are in fine to coarse sandstone that forms the basal unit of the Brushy Basin Member of the Morrison Formation. Sandstone in the trench contains a few streaks of vanadium hydromica and spots of malachite.

Silvertone prospects

The Silvertone prospects are north of East Summit in sec. 25, T. 44 N., R. 20 W., San Miguel County, Colorado. Claims covering the property were established in 1940, and probably the workings were dug in the early 1940's. The workings consist of many small surface cuts, two adits--one caved, the other about 20 feet long--and a shaft about 25 feet deep. The prospects are in the Morrison Formation along a weakly mineralized west-southwest-trending fault that has a maximum displacement of only a few feet. The prospects have a vertical range of about 200 feet. Most are in the upper part of the Salt Wash Member; the highest prospect is in the basal conglomeratic sandstone of the Brushy Basin Member. Sandstone adjacent to the fault is streaked and spotted with a dark-gray mineral probably vanadium hydromica. Spots of malachite and azurite are common. A yellowish-green mineral, probably volborthite, is sparse. Although some of the sandstone is weakly radioactive, no uranium minerals were found. Total production from these prospects was estimated to be very small.

Kuykendall lease

The Kuykendall lease includes a group of claims in San Juan County, Utah, on the north side of East Summit about 2.1 miles south of the junction of Little Indian and McIntyre Canyons in sec. 27, T. 31 S., R. 26 E. Workings consist of a few surface cuts, a stub adit, and an inclined adit, now caved near the portal. A few tons of ore were stockpiled near the adits when the property was visited in late 1958. Total production from this property was estimated to be very small. The prospect explores fine-grained sandstone beds, about 2 feet thick, which are interstratified with green mudstone near the base of the Brushy Basin Member of the Morrison Formation. The sandstone is sparsely mineralized with dark-gray vanadium hydromica and a yellow-green uraniferous mineral. Landslide covers most of the property.

Blue Clay mine

The Blue Clay mine is on the north side of East Summit about 1.5 miles east of Little Indian Canyon in sec. 27, T. 31 S., R. 26 E. The mine, probably developed in the early 1950's, consists of several rim cuts, as long as 150 feet, and inaccessible underground workings. The property was inactive when visited in late 1958. Recorded production through 1957 from this property is very small. The ore received at the mills averaged about 1.42 percent V_2O_5 and 0.24 percent U_3O_8. The vanadium-uranium ratio is 5.9:1.

The workings are in a sandstone unit near the base of the Brushy Basin Member of the Morrison Formation. The sandstone is silty, fine grained and contains seams of grayish-red mudstone. No mineralized rock was seen in place. Slightly radioactive sandstone impregnated sparsely with vanadium hydromica is present in small amounts on a dump. Most of the property is covered with landslide.

State Line prospect

The State Line prospect is just west of the Colorado line in San Juan County, Utah, on the north side of East Summit about 1.8 miles south of the junction of Little Indian and McIntyre Canyons in sec. 26, T. 31 S., R. 26 E. The State Line claim was located in 1949, and has been developed by the digging of a few trenches and an adit about 50 feet long. The property was idle when visited in late 1958. Total recorded production through 1958 is very small. The average grade of the shipped ore was about 2.58 percent V_2O_5 and 0.28 percent U_3O_8. The vanadium-uranium ratio of this ore was 9.2:1.

The prospect is in a gently north dipping sandstone unit in the lower part of the Brushy Basin Member of the Morrison Formation in a small west-trending graben. The ore-bearing sandstone is medium to fine grained, ranges from about 6 to 10 feet in thickness and lies about 35 feet above the base of the member. The ore, mostly dark-gray vanadium minerals, is in streaks, commonly less than 12 inches thick, which parallel the low-angle crossbeds of the host sandstone. The mineralized area is estimated to be about 10 feet wide, 60 feet long, as much as 4 feet thick and apparently trends northeasterly.

Liberty No. 2 mine

The Liberty No. 2 mine is about 1 mile east of Little Indian Canyon on the northwest side of East Summit in sec. 33, T. 31 S., R. 26 E. The workings consist of a rim cut, about 100 feet long, 25 feet wide, and 16 feet deep and an adit estimated to be about 35 feet long. The property was probably developed in the early 1940's. Several sacks of high-grade carnotite ore had been produced prior to 1944 (Kirkpatrick, Union Mines Development Corp., written commun., 1944). The property was idle when examined in September 1958. Total production was estimated to be small.

The mine is in light-brownish-gray, limonite-stained, fine- to medium-grained sandstone of the Brushy Basin Member of the Morrison Formation. The ore-bearing sandstone is about 100 feet above the base of the member. Because it is covered by landslide, its thickness and extent are unknown.

Mineralized rock is confined to the basal part of the sandstone exposed in the open cut and consists of streaks of dark-gray and yellowish-green vanadium minerals and carnotite. A layer of this material exposed in 1953 was about 20 feet long and 8 inches thick. Within the adit the layer increased to more than 12 inches in thickness, but was discontinuous.

Federal prospect

A prospect, thought to be on the Federal claim, is south of Little Indian Canyon on the northwest side of East Summit in sec. 28, T. 31 S., R. 26 E. The working consists of a single rim cut about 60 feet long, 15 feet wide, and as much as 8 feet deep. The property was idle in late 1953. Total production from this mine was estimated to be very small. The deposit is in a poorly exposed sandstone lens in the Brushy Basin Member of the Morrison. The lens is about 10 feet thick and is about 75 feet above the base of the member. The ore-bearing sandstone is medium-grained light brown and grayish purple and tends to weather reddish brown. It is mostly in low-angle cross strata but the upper part is mostly horizontally bedded with much current lineation. Mineralized rock in the rim cut is a single dark-greenish-gray to dark-gray layer, about 10 to 15 inches thick and 15 feet long, impregnated with vanadium hydromica. Carnotite was not recognized and is probably very sparse as the radioactivity of the mineralized layer was very low.

Liberty No. 1 mine

The Liberty No. 1 mine is near Little Indian Canyon on the northwest side of East Summit in sec. 28, T. 31 S., R. 26 E. The mine has two adits and several hundred feet of interconnecting, irregular drifts. The mine was active in the early 1940's, and again in the early 1950's. Total recorded production was small. Average grade of the shipped ore was about 2.20 percent V_2O_5 and 0.25 percent U_3O_8; the vanadium-uranium ratio is 8.8. The property was idle when examined in early 1955.

The deposit is in sandstone in the upper part of the Salt Wash Member of the Morrison Formation. The ore-bearing sandstone is light brown and about 20 feet thick at the mine but more reddish and thinner away from the mine. The ore minerals include vanadium hydromica, carnotite, and a bluish-black vanadium mineral, probably corvusite. Azurite occurs sparsely in the ore zone. Little mineralized rock was exposed in 1955. The mineralized rock is dark gray and occurs in spots, streaks, and irregularly lenticular layers, about a foot thick and a few tens of feet long. Many of the layers of mineralized rock are at least in part parallel to diastems and bedding.

Bench group of claims

The Bench group of claims, also known locally as the Queen Mary group of mines, is on the southeastern part of Three Step Hill in sec. 18, T. 31 S., R. 26 E. The workings consist of several open pits and shallow incline shafts leading to small irregular stopes. Mining on these claims probably began in 1949. Total recorded production is small. The average grade of the ore received at the mills was about 1.30 percent V_2O_5 and 0.23 percent U_3O_8; the vanadium-uranium ratio was 5.7:1. The deposits were studied by O. M. McRae in the summer of 1953, and the following notes are in part based on his report (O. M. McRae, U.S. Atomic Energy Commission, written commun., 1954). The deposits are in the upper part of the Salt Wash Member of the Morrison Formation. They are in the fourth and fifth ledge-forming sandstone units above the base of the member. The ore-bearing sandstones are white to gray, and are composed chiefly of fine grains of quartz and very fine white and black minerals. The ore-bearing sandstones are underlain by 1 to 3 feet of green mudstone, and apparent alteration of red mudstone units that are interstratified with the sandstone units of the Salt Wash Member. McRae noted green copper minerals and abundant orange-red spots of limonite associated with particles of carbonaceous material in the ore-bearing sandstone. The chief ore mineral is carnotite or tyuyamunite. The mineralized layers in the sandstone are uneven and tend to follow undulations in bedding planes. McRae estimated the size of the ore bodies to range from about 5 to 60 feet in width, about 140 to 370 feet in length, and about 1 to 3 feet in thickness.

Lone Star mine

The Lone Star mine is on the northeast side of Three Step Hill north of McIntyre Canyon in sec. 6, T. 31 S., R. 26 E. A prospect pit was reported here by Kirkpatrick (Union Mines Development Corp., written commun., 1944), but active though intermittent mining probably began in 1949. The mine was developed from an inclined shaft, from which side workings were driven. In October 1957, the main stoped area had caved and the operator was attempting to bypass the caved area by sinking another inclined shaft. Extent of the underground workings is not known, but indications from the position of the two inclined shafts suggest the workings extended along the strike of the beds for less than 200 feet. The new inclined shaft had been extended along dip for about 70 feet.

The deposit is in pebbly sandstone about 40 feet above the base of the Brushy Basin Member of the Morrison Formation in a small fault block bordered by older rocks on the west and younger rocks on the east. The ore-bearing bed dips about 10^{o} southwesterly. The chief ore minerals are carnotite and vanadium hydromica. Malachite and azurite are common throughout the deposit. Layers of ore in the caved area were reported to be as much as 4 feet thick and to occur mostly at the base of the ore-bearing sandstone. Some ore was mined from carnotite-rich logs. Total recorded production from this deposit was small. The shipments averaged about 1.19 percent V_2O_5 to 0.36 percent U_3O_8; the vanadium-uranium ratio was 3.3:1.

Peach group of claims

The Peach group of claims are on the north side of West Summit in secs. 9, 10, and 11, T. 31 S., R. 25 E. In 1954, when the western part of these claims were visited only a small prospect pit and dump were noted. Subsequently a mine has been developed on the eastern part of these claims which produced a small amount of ore. Shipments averaged about 0.34 percent U_3O_8 and 1.77 percent V_2O_5; the vanadium uranium ratio is 5.2:1. The deposit is in the lower part of the Brushy Basin Member of the Morrison Formation about 160 feet above the horizon of the ore-bearing sandstone in the Salt Wash Member in the nearby Bee group of claims. The host rock is a light-brown medium-grained thin-bedded sandstone. Vanadium hydromica is abundant; carnotite is common.

Bee group of mines

The Bee group of mines includes many small workings on the Bee, Red Patch, Red Match, and other claims on the north side of West Summit in secs. 8 and 9, T. 31 S., R. 25 E. The workings are in a sandstone unit near the top of the Salt Wash Member of the Morrison Formation. They are mostly small open pits, rim cuts, and irregular adits less than 50 feet long. In the southeastern part of the group an incline leads to an elongate irregularly stoped area about 150 feet long and 5 to 20 feet wide. South of this incline is a shaft said to lead to small stopes about 30 feet below the surface.

The history of these claims is similar to that of the Waterfall group of mines. In the summer of 1942, about 16 tons of vanadium ore was being mined weekly from adits in a mineralized zone about 2 feet thick on the western part of the Bee claim (R. T. Russell, U.S. Geological Survey, written commun., 1942). It is unlikely that this rate of mining was long sustained and the total production from the group in the 1940's is estimated to be small. Production since 1948 is also thought to be small. Incomplete records of production for the period 1948-1956 show that the average grade of ore was 1.64 percent V_2O_5 and 0.23 percent U_3O_8; the vanadium-uranium ratio was 7.1:1. At the time the property was visited in the summer of 1954, the mines were inacitve and in part inaccessible. Little material of ore grade and thickness was visible along the rim and in the accessible workings. Most of the mineralized rock was spotted and streaked with impregnations of vanadium hydromica. Carnotite was very sparse. Although no trends were apparent in the exposed mineralized rock, many of the larger workings in this group are elongated to the southeast suggesting a southeasterly trend to the ore bodies in these deposits.

Waterfall Group of mines

The Waterfall group of mines, as here considered, includes more than 20 mines along the rim and the Jimbo-Bob shaft about 1,600 feet southwest of the rim on the east side of Deerneck Mesa and on the north side of West Summit. The group is conveniently divided into two parts. The northern part includes workings on the Gillman, Roanoke, and Geneva claims in sec. 1, T. 31 S., R. 24 E. and sec. 6, T. 31 S., R. 25 E. and the Jimbo-Bob shaft in secs. 1 and 12, T. 31 S., R. 24 E. The southern part includes workings on the Dime, Logan, and Goodhope claims in secs. 6 and 7, T. 31 S., R. 25 E.

Claims of the Waterfall group were probably originally staked in the late 1910's. Mines in this group probably helped supply a vanadium mill constructed about 1925, in Dry Valley on the northside of Deerneck Mesa. Renewed mining probably accompanied reactivation of the mill in 1930 and 1931, by the International Vanadium Corporation. The period of greatest mining activity was during the early 1940's, when the group produced a large amount of vanadium ore. Except for exploratory work the mines were inactive when examined in 1953 and 1954, and large parts of the underground workings were inaccessible. In the period 1948-1956, only a small amount of ore was produced from mines along the rim. The major producing mine during this latest period was the Jimbo-Bob shaft which was sunk in 1955, and has yielded a moderate amount of ore through 1956. The average grade of recorded shipments from all the Waterfall group is 1.47 percent V_2O_5 and 0.11 percent U_3O_8, the vanadium-uranium ratio 13.4. These figures suggest that ore from the Waterfall group is relatively low in uranium content, but since 1948, when a new price structure for uranium ores was established by the U.S. Atomic Energy Commission, most recorded shipments have contained more than 0.20 percent U_3O_8 and have a vanadium-uranium ratio of about 7:1.

Workings in the northern part of the Waterfall group include many irregular rim cuts, 40 to 300 feet long and 5 to 30 feet wide, and small adits, less than 100 feet long, with small irregular stopes. The largest mine along the rim in the northern part of the group is on the Gillman claim and consists of an adit more than 300 feet long with more than 300 feet of irregular drifts, which are connected by raises and drifts at higher level with more than 100 feet of surface trenches. Production records suggest that the underground workings of the Jimbo-Bob shaft, which was not examined by the authors, were of similar size to those of the large mine on the Gillman claims.

Workings in the southern part of the group include several extensive rim and surface cuts, small adits, and five large mines, four of the large mines are on the Dime claim and one is on the western part of the Goodhope claim. These large mines each are characterized by adits hundreds of feet long, irregular drifts, and stopes also measureable in hundreds of feet.

The ore-bearing sandstone is near the top of the Salt Wash Member of the Morrison Formation and ranges from about 30 to 90 feet and averages about 50 feet in thickness. North of the Dime claim the ore-bearing sandstone at least locally seems to split into two units, each about 20 to 40 feet thick. The intercalated 10 to 30 feet of mudstone, generally covered by landslide, may be several different lenses at about the same horizon, or as seems more likely may be a wedge that thickens northwestward, concomitant with a pinching out of the lower unit and a thinning of the upper unit of the ore-bearing sandstone. The ore-bearing sandstone is dominantly light grayish brown and composed of fine to medium grains of quartz and feldspar with common coarse grains and granules of white chert, possibly weathered tuffaceous material along laminae, and locally containing sparse to abundant greenish-gray mudstone pebbles. Most of the unit is in low-angle crossbeds. High-angle crossbeds are also present. The upper part of the sandstone unit is characterized by thin horizontal beds and laminae, commonly marked with current lineation. Most of the lineations trend about S. 70° E. or S. 45° E. The sandstone is firmly cemented by calcite and forms a prominent ledge. Mudstone, mostly grayish green, is intercalated as partings and thin seams between bedding units of sandstone. Carbonaceous material is sparse to locally abundant as accumulations of limonite-stained coaly fragments and as petrified logs.

Most of the mineralized sandstone consists of slightly wavy dark-gray layers impregnated with vanadium hydromica. Carnotite is generally sparse except around carbonaceous debris and logs. Limonite specks are common throughout the ore-bearing sandstone. Limonite locally impregnates sandstone in layers as much as 2 feet thick above vanadium ore. The vanadium-ore layers pinch and swell, are as much as 10 feet thick, and are more than 100 feet in diameter. The impregnations of vanadium hydromica are generally pervasive in thin layers but where more than 2 feet thick may be streaked and spotty. Rolls are not abundant in the deposits of the Waterfall Group; those measured suggest a southeasterly trend. Where the ore-bearing sandstone is in two units most of the mineralized rock is in the lower part of the upper unit. The mineralized layers are most frequent in low-angle cross-strata, which they crosscut in detail, but they commonly parallel bounding diastems that are marked with mudstone partings. The mineralized layers and associated rolls form ore bodies commonly a few feet thick and several tens of feet across. The ore bodies commonly occur in clusters and in part overlap. Judging from the exposures of ore along the rim in the mines and the sizes of the stopes and the larger clusters of ore bodies in the Waterfall group are commonly 100 to 300 feet long and 50 to 100 feet wide. The clusters of ore bodies are elongated southeast and nearly due east. These clusters of ore bodies rather than ore bodies themselves are rational targets for deep drilling in unexplored ground west of the Waterfall group. A general decrease in the size and frequency of the clusters of ore bodies northwestward was noted in the northern part of the Waterfall group of mines.

Warrior No. 1 prospect

On the north side of Deerneck Mesa is a prospect pit and a small adit on the Warrior No. 1 claim in sec. 3, T. 31 S., R. 24 E. The prospect pit is about 6 feet wide and 20 feet long; the adit was inaccessible, but the size of the dump suggests it is not long. The mineralized sandstone is near the top of the Salt Wash Member of the Morrison Formation. Mineralized sandstone is impregnated spottily with vanadium hydromica and carnotite. No shipments were recorded from this claim. Total production was estimated to be very small.

Wilson mine

The Wilson mine is on the north side of Deerneck Mesa on the Woodrow Wilson and the Woodrow Wilson No. 1 claims in sec. 35, T. 30 S., R. 24 E. An unimproved road leads to the mine from Dry Valley.

The mine workings consist of open cuts along more than 1,000 feet of the rim and many adits, most of which are very irregular and only 10 to 50 feet long. In the western third of the rim cuts is a longer adit about 200 feet long with many irregular stopes. Below the ore-bearing sandstone is more than 500 feet of haulage drifts from which some exploratory raises were cut. The deeper parts of the mine were inaccessible in 1953.

The original claims covering this rim were probably staked in the late 1910's or early 1920's. During the early 1930's, the mine was probably an important supplier of ore for the International Vanadium Corporation about 0.6 mile northwest of the mine in Dry Valley. The mine was active during the early 1940's, and was estimated to have produced a moderate amount of vanadium ore. Since 1949, the mine has been intermittently active and has produced a moderate amount of ore. Average grade of the recorded production is 1.53 percent V_2O_5 and 0.20 U_3O_8; the vanadium-uranium ratio is 7.6:1.

The ore-bearing sandstone is near the top of the Salt Wash Member of the Morrison Formation. Near the mine it is about 50 feet thick and is light gray to grayish brown. It is fine to coarse grained and locally pebbly. It is composed of quartz chert and minor feldspar. Coarse grains of white chert, possibly altered feldspar, are conspicuous especially in sandstone layers impregnated with dark-gray vanadium hydromica. Pebbles occur in ill-defined layers and lenses and include white and gray chert and greenish-gray and minor grayish-red mudstone. The sandstone is, in part, in vague irregular horizontal thin beds commonly marked with current lineation; in part it is in low-angle cross laminae. Carbon is generally sparse but thin lenses of coaly and limonite-stained plant debris are locally conspicuous in both crossbedded and horizontal strata.

Mineralized rock consists principally of irregular vague to sharply defined layers that are impregnated pervasively or in streaks and spots with vanadium hydromica and sparse to common carnotite in the upper part of the ore-bearing sandstone. In an appraisal of the deposit of the Wilson mine, J. C. Standard (U.S. Atomic Energy Commission, written commun., 1953) called attention to two contrasting types of ore bodies. Dominant are tabular bodies which occur in even beds with current lineation of well-sorted sandstone containing little carbonaceous material except along bedding planes. This type of ore body is commonly relatively low in vanadium and uranium but may be extensive. Less common but locally conspicuous are thick irregular bodies associated with irregular accumulations of carbonaceous trash and logs. This type of ore body is generally high in vanadium and uranium and is generally small and erratically distributed, though Standard noted that this type appeared to be associated with the margins of a thick crossbedded sandstone lens. The two types of ore bodies locally intergrade. In places ore layers terninate in C-shaped rolls. No trend to the few rolls seen in the workings accessible in 1953 was apparent, but the overall trend of the long dimension of the mineralized ground and its contained ore bodies was estimated to be slightly south of east.

Prospects southeast of the Wilson mine

Unidentified prospects consisting of open cuts and short adits are in a sandstone unit near the top of the Salt Wash Member of the Morrison Formation on the east side of Deerneck Mesa in sec. 36, T. 30 S., R 24 E. and in sec. 1, T. 31 S., R. 24 E. The ore-bearing sandstone is mostly covered by landslide near these prospects, but though probably thinner it appears generally similar to that exposed near the Wilson mine.

Jack Pot group of mines

The Jack Pot group of mines are on the Sunnyside and Valley View claims, formerly known as the Jack Pot Nos. 3 and 4 claims, on the west side of Deerneck Mesa in secs. 10 and 11, T. 31 S., R. 24 E. The mines include several adits and rim cuts. The northernmost mine is on the Valley View claim and is the largest of the group. It consists of rim cuts and four irregular stub adits in an area about 80 feet long parallel to the rim and about 40 feet wide. About 500, 1,000 and 2,400 feet southeast of the Valley View adits are prospects or small mines consisting of small pits 10 to 30 feet in diameter, rim cuts 50 to 200 feet long, and a few stub adits less than 20 feet long.

The mines and prospects of the Jack Pot group are on claims probably originally staked in the 1920's; they were apparently resurveyed and renamed by the International Vanadium Company in 1931. The Jack Pot group produced a small amount of ore during the vanadium mining perios (R. T. Russell, U.S. Geological Survey, written commun., 1942). Production during the vanadium mining period was estimated to be small. Intermittent mining on these claims was renewed in 1948. At the time the mines and prospects were examined in late 1953, they were idle. Total production of the Jackpot group in the period 1948-1956 was small. Ore shipments averaged 1.30 percent V_2O_5 and 0.18 percent U_3O_8. The vanadium-uranium ratio was 7.2:1.

These deposits are in lenses of sandstone near the top of the Salt Wash Member of the Morrison Formation. The mineralized lenses are generally thinner, and narrower, and probably slightly higher in the Salt Wash than ore-bearing sandstone units that in East Canyon contain the Sunset mine and Frisco group of mines or that on the east side of Deerneck Mesa contain the Waterfall group of mines. The ore-bearing lenses of the Jackpot group of mines range from about 5 to 25 feet in thickness and about 50 to 1,000 feet in length. The thickest point on any of these lenses of sandstone is near the Valley View adits. The sandstone is light-brown, composed of medium to coarse grains of quartz, white chert, and minor feldspar and locally contains sparse small pebbles of red and green chert. Thin horizontal beds are dominant. The sandstone is slightly friable and faces of weathered outcrops commonly have vague vertical ribs.

Mineralized rock is principally patches, streaks, and layers impregnated with vanadium hydromica. On the Valley View claim carnotite is commonly associated with the layers of vanadium hydromica and is locally abundant in and around fossil wood; it is sparse to absent at other workings. The mineable layers of mineralized rock are as much as 3 feet thick and 30 feet long. Rolls are sparse; the few noted trend northeasterly.

Prospect northwest of the Bluebird Group

A rim cut and short adit about 3,000 feet northwest of the Bluebird adits on the south side of Deerneck Mesa in sec. 14, T. 31 S., R. 24 E. is in a sandstone unit near the top of the Salt Wash Member of the Morrison Formation. A few small patches of mineralized rock generally less than 1 foot thick and 2 to 10 feet long are exposed on the face of sandstone rim.

Bluebird group of claims--(East Canyon)

The Bluebird group of claims, as here considered, include the Bluebird, Bluebird Nos. 1 and 2 and Greenfly claims, are east of East Canyon Wash on the south side of Deerneck Mesa in sec. 13, T. 31 S., R. 24 E. The principal workings are on the Bluebird claim and are in the lower part of a sandstone unit near the top of the Salt Wash Member of the Morrison Formation. They consist of aligned irregular small stopes near the base of the ore-bearing sandstone serviced by a haulage adit about 280 feet long driven in mudstone below the ore-bearing sandstone. About 75 feet north of the haulage adit is an irregular adit about 80 feet long driven in the ore-bearing sandstone. About 1,100 feet east of the Bluebird adits is a fairly straight adit about 50 feet long in sandstone near the top of the Salt Wash Member. About 700 feet north of the Bluebird adits is a rim cut in conglomeratic sandstone at the base of the Brushy Basin Member of the Morrison Formation. Vanadium hydromica is the dominant mineral in all these deposits; carnotite is sparse to absent. The main period of mining from the Bluebird claims was in the early 1940's, when a small amount of vanadium ore was produced. Intermittent activity on these claims resulted in shipping a small amount of ore to the mills. Incomplete records indicate that the average grade of this ore was about 1.0 percent V_2O_5 and 0.12 percent U_3O_8; the vanadium-uranium ratio 8.3:1. The ore-bearing sandstone near the Bluebird adits is about 30 feet thick, and contains much carbonaceous plant debris and several silicified logs. The underlying unit is dominantly red mudstone, whose top 1 to 5 feet is altered to greenish-gray. Mineralized rock in rolls, streaks, and wavy layers as much as 2.5 feet thick and 20 to 50 feet long. Boundaries of some of the mineralized layers parallel or are coincident with bedding planes and clay partings along minor diastems in the ore bearing sandstone.

Nipples group of mines

The Nipples group of mines, as here considered, includes three small mines on the east side of East Canyon north of Pine Hallow in secs. 18 and 19, T. 31 S., R. 25 E. The mines consist of several irregular rim cuts and adits on the Nipples, Lonesome, and perhaps other claims. The longest adit is the northernmost working and is more than 200 feet long. The mines produced a small amount of ore in the early 1940's. Mining was resumed intermittently in the early 1950's, and produced a small amount of ore through 1956. The mines were inactive when examined in late 1954. The average grade of the recorded shipments was 1.46 percent V_2O_5 and 0.19 percent U_3O_8; the vanadium-uranium ratio was 7.7:1. Mineralized rock in the accessible workings consisted of nearly horizontal layers commonly about 1 foot thick and 20 to 50 feet long. Vanadium hydromica is abundant; carnotite is very sparse. The mines are in the upper part of the Salt Wash Member of the Morrison Formation, but the central workings are in thin lenses of sandstone below the horizon of the main ore-bearing sandstone of Easy Canyon.

Black Bottom mine

The Black Bottom mine is on the east side of Easy Canyon south of Pine Hollow in sec. 19, T. 31 S., R. 25 E. An unimporved road from East Canyon by way of Pine Hollow provides access to the Black Bottom and nearby mines as far south as the Profit No. 1 incline. The mine was operated during the vanadium-mining period of the early 1940's; most of the production, however, has come from intermittent mining during the period 1948-1956. Total recorded production was small. Shipments averaged about 1.97 percent V_2O_5 and 0.26 percent U_3O_8; the vanadium-uranium ratio was 7.6:1. The workings consist of more than 200 feet of rim cuts and more than 350 feet of irregular drifts in an area about 200 feet long, parallel to the rim, and 140 feet wide. Mineralized rock, consisting of sandstone impregnated with vanadium hydromica and carnotite, is in wavy layers, commonly 1 to 3 feet thick and 5 to 50 feet across. The layers are frequently sharply inflected into C-shaped rolls. The dominant trend of the long arcs of these rolls is southwesterly. Most of the rolls open to the north. The ore-bearing sandstone is near the top of the Salt Wash Member of the Morrison Formation. Most of the mineralized rock is near the base of the sandstone unit, which is about 80 feet thick near the mine but thins markedly to the north. Sandstone of the mineralized zone contains abundant coaly plant material and seams of greenish gray mudstone. The ore-bearing sandstone near the mine is underlain by 1 to 4 feet of greenish-gray mudstone which grades northward into red mudstone.

Profit No. 1 mine

The Profit No. 1 mine is on the east side of East Canyon in sec. 19,

T. 31 S., R. 25 E. The workings consist of an incline leading down about 75 feet to an irregular underground series of drifts and stopes exploring an area roughly 100 feet in diameter. The deposit was discovered by drilling in the summer of 1953.

The mine was open in October 1953, and was active at the time of examination in 1956. A moderate amount of ore averaging about 2.14 percent was produced from the Profit No. 1 claim through 1956. The vanadium-uranium ratio of this ore was 8.6:1. Mineralized rock, consisting of sandstone impregnated with vanadium hydromica and sparse carnotite, occurs in wavy thin layers, small rolls, and lenses as much as 4 feet thick, 15 feet wide, and 30 feet long. No clear trend to the lenses or rolls was perceived. A bright-red mineral, probably hewettite, is locally common in the mineralized rock. The workings are in the lower part of the uppermost sandstone unit of the Salt Wash Member of the Morrison Formation. The sandstone unit is here more than 90 feet thick. Carbonaceous material, chiefly vitreous and resinous coaly plant debris, is common in the ore zone.

Sunset mine

The Sunset mine is on the east side of East Canyon in sec. 30, T. 31 S., R. 25 E. An unimproved road leading from East Canyon by way of Pine Hollow provides access to the Sunset and Humbug, Profit No. 1, and Blackbottom mines.

A small amount of ore was produced from the Sunset claims, also known as the Bluebell claim, during the period of mining for vanadium in the early 1940's. A moderate amount of ore, averaging about 1.82 percent V_2O_5 and 0.29 percent U_3O_8, was recorded for the period 1948-1953. The vanadium-uranium ratio of the shipped ore was 6.4:1. The property was idle when examined in late 1954.

The mine consists of underground workings entered through four closely spaced adits, extensive rim cuts, and several stub adits. The undeground workings were largely inaccessible in late 1954. A sketch map of the workings made in 1944 by R. P. Fischer (U.S. Geological Survey, written commun., 1944) shows that irregular drifts at that time extended more than 130 feet perpendicular to the rim and about 100 feet parallel to the rim. Because most of the production recorded from this mine was subsequent to 1944, the underground workings were undoubtedly much more extensive than these shown on Fischer's map.

The host rock is the uppermost sandstone unit in the Salt Wash Member of the Morrison Formation. The unit ranges from about 30 to 80 feet in thickness and consists of crossbedded light-gray to light-grayish-brown sandstone composed of fine to medium grains of quartz and white chert. It contains seams, partings, and flat pebbles of mudstone, dominantly grayish green but in part grayish red. Carbonaceous material is sparse but locally conspicuous as limonite-stained coaly plant debris and as silicified woody fragments.

Patches of mineralized rock occur along the rim for about 1,000 feet, mostly in the lower part of the host sandstone. The mineralized rock consists principally of nearly horizontal, wavy, and lensing layers of sandstone impregnated with vanadium hydromica and carnotite. Rolls of ore were not seen. Locally, clusters of mudstone pebbles and fragments of fossil plant material are centers of relatively high grade material. Irregular joints are common in the host rock but have no discernible influence on the distribution of ore minerals.

Humbug mine

The Humbug mine in on the east side of East Canyon in sec. 30, T. 31 S., R. 25 E. The workings consist of an incline more than 150 feet long leading downward about 80 feet to about 500 feet of drifts with many irregular stopes. The ore bodies were reportedly discovered by diamond drilling in 1954 and 1955. Mining began soon thereafter and was continuous through 1956. A moderate amount of ore was shipped from the Humbug mine. Average grade of the ore was 2.40 percent V_2O_5 and 0.17 percent U_3O_8; the vanadium-uranium ratio, 13.1:1. Ore occurs in slightly irregular lenses 1 to 4 feet thick and 20 to 40 feet in diameter. No rolls are present. The dominant mineral is vanadium hydromica; carnotite is present but not common. A bright-green clay mineral and sparse gypsum are locally conspicuous. The mine is in the same sandstone unit near the top of the Salt Wash Member of the Morrison Formation as the nearby Sunset mine.

Velvet prospect

The Velvet claim is on the east side of East Canyon in sec. 32, T. 31 S., R. 25 E. The workings consist of more than 120 feet of rim cut and a stub adit in a sandstone lens near the top of the Salt Wash Member of the Morrison Formation. Vanadium hydromica and minor carnotite impregnates sandstone in a few irregular layers commonly about a foot thick and 20 to 50 feet long. Records show that a small amount of ore, averaging 1.30 percent V_2O_5 and 0.19 percent U_3O_8, was produced from the Velvet claim. The vanadium-uranium ratio of the shipped ore was 6.8:1.

Prospects near Sop Canyon

Undeveloped prospects were noted in the course of mapping in Sop Canyon, about 3,000 feet south of Sop Canyon on the west side of East Canyon. J. D. Strobell (U.S. Geological Survey, written commun., 1942) noted mineralized rock in the creek of East Canyon about 4,000 feet south of the Sop Canyon prospect. All these occurrences were of vanadium minerals in thin streaks and patches in the upper part of the Salt Wash Member of the Morrison Formation in sec. 5, T. 32 S., R. 25 E. None of these prospects have recorded production.

Locust and Hopper mine

The Locust and Hopper workings are on the west side of East Canyon in sec. 5, T. 32 S., R. 25 E. The workings are scattered along about 500 feet of outcrop and consist of several rim cuts and stub adits mostly completed in the early 1940's, in sandstone in the upper part of the Salt Wash Member of the Morrison Formation. The mineralized rock is in horizontal lenses as much as 6 feet thick and 60 feet long, but most layers are less than 1.0 foot thick. Vanadium hydromica is dominant; carnotite is sparse to absent, though relatively common in a few remnants of calcified logs. Production from this mine was small. Incomplete records of shipments from the Locust and Hopper claims indicate the average grade of ore was about 1.41 percent V_2O_5 and 0.13 percent U_3O_8. The vanadium-uranium ratio of the recorded shipments was 11:1.

Prospects of South Canyon

About 1,400 feet south of the Frisco group of mines is the northernmost of two small prospects, about 900 feet apart, on the Campground No. 3 claim on the west side of South Canyon. The northernmost workings are in sec. 36, T. 31 S., R. 24 E.; the southern workings are in sec. 1, T. 32 S., R. 24 E. On the east side of South Canyon are two other small prospects. The southernmost prospect is a rim cut on the Campground No. 8 claim in sec. 1, T. 32 S., R. 24 E.; the northern prospect is on the Campground No. 9 claim in sec. 36, T. 31 S., R. 24 E. These prospects are all similar and much like the Rats Nest and Big Lead prospects on the north rim of South Canyon Point. They are in the upper part of Salt Wash Member of the Morrison Formation and contain streaks and patches of mineralized rock, commonly less than a foot thick and less than 10 feet long. Vanadium hydromica is dominant; carnotite is very sparse to absent. The northern prospect on the Campground No. 3 include minor occurrences of vanadium minerals in a sandstone lens below the horizon of the ore-bearing sandstone that contains the ore deposits of the Frisco group of mines.

Frisco group of mines

The Frisco group of mines is on the east side of South Canyon Point in secs. 25 and 36, T. 31 S., R. 24 E. Access to the mines is by truck trails from an unimproved road on the west side of East Canyon.

The rim of the west side of East Canyon was prospected in the 1920's. Old claims were resurveyed and new claims established by the International Vanadium Corp. in 1931. Mining of vanadium ore on these claims was intermittent through the 1930's, and became continuous and substantial during the early 1940's. Incomplete records for the years 1940-43 show that more than 5,500 tons of vanadium ore averaging about 1.6 percent V_2O_5 were shipped from mines of this group. Most of the mines become inactive in 1944, and with few exceptions the mine workings are little changed from early 1944, when they were mapped by Kirkpatrick (Union Mines Development Corp., written commun., 1944). Most of the sustained activity in the postwar years was in the northern part of the group, expecially in the Spider mine, which accounted for more than half of the ore produced from the Frisco group from January 1951 through June 1953. During this period ore shipments averaged about 0.15 percent U_3O_8 and 1.62 percent V_2O_5. The vanadium-uranium ratio was 10.6:1. In September 1953, when the Frisco group was examined for this report all the mines were idle except the Spider mine.

According to miners in the area the limits of the Frisco group were differently placed by different owners and lessees. This report follows the practice of Kirkpatrick (Union Mines Development Corp., written commun., 1944). Twelve separate mines and many prospects scattered along 4,000 feet of rim overlooking East Canyon are included in the group. Names of the workings used in this report are informal though based largely on the usage among miners in the area in 1953. In the northern part of the group is a cluster of four mines in an area about 5,000 feet in diameter. Total length of underground workings in this part of the group is about 800 feet; nearly half of this is in the Spider mine. On the northern part of the Midway claim, about 1,100 feet southwest of the Spider mine, is an adit leading to 350 feet of irregular drifts. The three largest mines are clustered in an area about 600 feet in diameter on the Frisco No. 1 claim, whose center is about 900 feet south of the Midway adit. Total length of the irregular drifts in these workings is estimated to be about 1,600 feet, mostly in the Frisco No. 1 north and Frisco No. 1 central mines. About 100 feet south of the Frisco No. 1 central mine are two small and generally similar workings. Each mine consists of about 100 feet of rim cut about 100 feet apart. The northernmost of these two mines is on the southern part of the Frisco No. 1 claim; the other, on the northern part of the Campground claim. About 500 feet south of this latter mine are workings on the southern part of the Campground claim. They consist of about 150 feet of rim cuts, a few stub adits, and a haulage adit driven in red mudstone below the ore-bearing sandstone leading through a winze to an irregular stoped area, roughly 40 feet in diameter, about 100 feet back of the rim in the lower part of the ore-bearing sandstone. About 400 feet south-southwest of this haulage adit are the southernmost workings included in the Frisco group. They are on the Campground No. 1 claim and consist of about 150 feet of rim cuts and several stub adits.

The Frisco group of mines are in the uppermost relatively continuous sandstone unit in the Salt Wash Member of the Morrison Formation. The sandstone unit is more than 4,000 feet long and on average is about 50 feet thick but ranges from about 30 to 90 feet in thickness. This sandstone is unit 9 of the measured section of the Morrison Formation described from outcrops near the north end of the Frisco group. The top of the ore-bearing sandstone is fairly even and lies about 60 to 90 feet below the base of the Brushy Basin Member of the Morrison. The base of the sandstone is more irregular and ranges from about 290 to 350 feet above the top of the Entrada Sandstone. The ore-bearing sandstone is a compound of many lenses of sandstone, commonly a few tens of feet thick and a few hundreds of feet long, and a minor amount of intercalated mudstone. The sandstone is mostly light grayish brown, composed of medium grains of quartz and white chert, and in trough sets of low- and high-angle cross-strata. Mudstone lenticles and seams in the sandstone are generally bluish to greenish gray. The top 10 to 20 feet of the ore-bearing sandstone contains a high proportion of horizontal beds with abundant current lineation and common ripple marks. Carbonaceous material in the form of abundant coaly grains and flakes, and sparse fragments of wood are irregularly distributed through the ore-bearing sandstone.

Mineralized rock is irregularly distributed through the lower part, mostly the lower 20 feet, of the ore-bearing sandstone. The mineralized rock consists mainly of lenses and slightly wavy, relatively horizontal layers impregnated with dark-gray vanadium hydromica and with sparse carnotite. Locally there are patches of weakly mineralized rock consisting of irregular clusters, a few feet in diameter, of spots, 0.1 to 2 inches across, impregnated with gray vanadium hydromica. Remnants of a few mineralized logs suggest that they contained a much higher carnotite content than characteristic of most of the ore. Ore rolls are more common in the deposits of the Frisco group than in the smaller deposits on the rim of South Canyon Point. The general trend of elongate lenses of ore and rolls was judged to be southwesterly. Rolls measured in the Spider mine show a weak southwesterly trend, nearly at right angles to conspicuous joints in this mine. Most of the mineralized rock visible in the workings in 1953 and 1954 was less than 2 feet thick and was estimated to be below ore grade.

Leftover mine

The Leftover, also formerly known as the South Side, claim is on the north side of South Canyon Point in sec. 26, T. 31 S., R. 24 E. The mine consists of an adit about 135 feet long with subsidiary drifts several tens of feet long. The workings are in a poorly exposed sandstone lens, less than 20 feet thick, near the top of the Salt Wash Member of the Morrison Formation. The horizon of the lens is probably a few tens of feet lower than mineralized lenses along the rim to the west and south. Mineralized rock here consists of an irregular dark-gray layer of sandstone impregnated with vanadium hydromica flecked with yellow minerals of the carnotite. The layer of mineralized sandstone is nearly horizontal, about 100 feet long, more than 30 feet wide, and generally 0.5 to 1.2 feet thick. Production from this deposit, probably mined in the early 1940's, is estimated to be very small.

Bonanza No. 1 mine

The Bonanza No. 1, also known as the Blackfoot, claim is on the north side of South Canyon Point in sec. 27, T. 31 S., R. 24 E. The workings consist of several rim cuts and two adits, about 60 and 80 feet long, about 200 feet apart in a lens of sandstone about 25 feet thick near the top of the Salt Wash Member of the Morrison Formation. Joints are common in the host sandstone and locally occur in thickened portions of layers of mineralized rock. The layers of mineralized rock are as much as 2 feet thick, are discontinuous, and though generally horizontal, locally dip at a low angle to the south. Total production from these workings is estimated to be very small.

Bonanza No. 2 mine

The Bonanza No. 2 workings are on the north side of South Canyon Point in secs. 22 and 27, T. 31 S., R. 24 E. The workings consist of several hundred feet of open cuts, mostly parallel to the rim, and two adits about 130 feet and 55 feet long. The longer adit is about 300 feet north of the shorter adit. Layers of mineralized rock are commonly pod-shaped, as much as 4 feet thick, 30 to 40 feet long and 10 feet wide. The pods of mineralized rock trend southwesterly. Vanadium hydromica is the dominant ore mineral; carnotite is common. The mine was active when examined in 1953, but the workings appeared to be unchanged since they were sketched in early 1944 by Kirkpatrick (Union Mines Development Corp., written commun., 1944). Total production of ore from this property is small. The vanadium uranium ratio of the recorded shipments is 16.1:1.

Rats Nest prospect

A small rim cut and an adit about 50 feet long on the north side of South Canyon Point in sec. 27, T. 31 S., R. 24 E. are believed to be on the Rats Nest claim. The workings are in the lower part of a sandstone lens near the top of the Salt Wash Member of the Morrison Formation. Exposed on the face is a single layer of sandstone weakly impregnated with vanadium hydromica. The layer is as much as 2 feet thick, about 20 feet long, and about 5 feet wide. Production from this prospect is estimated to be very small.

Nonesuch mine

The Nonesuch workings are on the north side of South Canyon Point in sec. 21, T. 31 N., R. 24 E. The workings are a complex of short irregular tunnels and open cuts which explores an area about 300 feet long and 100 feet wide. Mining here was probably confined to the period of vanadium production in the early 1940's. The workings, though in part inaccessible, appear to be virtually unchanged from early 1944 when they were mapped by Kirkpatrick (Union Mines Development Corp., written commun., 1944). A moderate amount of vanadium ore is recorded as from this property. The vanadium-uranium ratio of the recorded shipments was about 10.1:1.

The host rock is a poorly exposed sandstone lens about 20 feet thick near the top of the Salt Wash Member of the Morrison Formation. The sandstone is light grayish brown, composed of fine to medium grains and stringers of coarse grains of quartz and white chert and pockets of gray and brown clay pebbles, and is in thin sets of low- and high-angle crossbeds.

Gray mineralized rock is sandstone impegnated with vanadium hydromica. It is sparsely flecked with canary-yellow and greenish-yellow minerals of the carnotite group. The mineralized layers have sharp to diffuse boundaries and are commonly 1 to 2 feet thick. Most of the mineralized layers presently exposed appear to be below ore grade.

Big Lead prospect

The Big Lead prospect consists of several rim cuts and an adit in a poorly exposed sandstone lens near the top of the Salt Wash Member of the Morrison Formation on the north side of South Canyon Point in secs. 20 and 21, T. 31 S., R. 24 E. Only a few gray patches of rock impregnated with vanadium hydromica are visible in the partly covered cuts; all in the upper part of the lens. An adit, now inaccessible, is about 90 feet long in barren sandstone near the base of the lens according to Kirkpatrick (Union Mined Development Corp., written commun., 1944). Kirkpatrick estimated that the original vanadium ore body in the largest cut was of medium grade and was about 2 to 3 feet thick and 40 feet in diameter.

Claims near northwest corner of South Canyon Point

Two outcrops of sandstone impregnated with vanadium hydromica were noted by Kirkpatrick (Union Mines Development Corp., written commun., 1944), on claims on the east side of Peters Canyon near the northwest corner of South Canyon Point in sec. 30, T. 31 S., R. 24 E. Kirkpatrick described these occurrences as follows: "They are about 500 feet apart in small discontinuous outcrops of sandstone near the top of the Salt Wash Member. Each deposit shows an irregular patch of medium-grade vanadium ore to 12 inches thick and less than 10 feet long."

L. R. Prospect

The L. R. claim is on the east side of Peters Canyon in sec. 31, T. 31 S., R. 24 E. The prospect is in a massive sandstone lens about 30 feet thick near the top of the Salt Wash Member of the Morrison Formation. According to field notes of R. T. Russell (U.S. Geological Survey, written commun., 1942), very low-grade vanadium ore occurs in the middle of the sandstone lens. The vanadium-impregnated sandstone layer lies between two shaly sandstone layers with abundant clay pebbles. Streaks of a green clay mineral occur in the sandstone below the ore layer. No production is recorded from this claim.

Lone Pine prospect

The Lone Pine claim is on the east side of Peters Canyon in sec. 6, T. 32 S., R. 24 E. The prospect is in a sandstone lens near the top of the Salt Wash Member of the Morrison Formation. Very low- to medium-grade vanadium ore occurs in a layer about 2 feet thick (R. T. Russell, U. S. Geological Survey, written commun., 1942). A very small shipment of medium-grade uranium-vanadium ore from the Lone Pine claim is recorded for the period 1950-1955. The vanadium-uranium ratio of this ore is about 8.1:1.

Sunny Day mine

The Sunny Day claim is on the south side of a small unnamed canyon on the east side of Peters Canyon in sec. 6, T. 32 S., R. 24 E. about 3 miles south of Church Rock. The workings consist of a rim cut about 100 feet long and a short adit a few tens of feet long. The size of the workings suggest that the total production was very small. Recorded production in the early 1950's amounted to several tons of low- to medium-grade ore which had a vanadium-uranium ratio of about 9:1. The prospect occurs in the top sandstone lens of the Salt Wash Member of the Morrison Formation. The lens is largely obscured by landslide. The ore minerals include abundant vanadium hydromica and sparse carnotite.

Loya Rae mine

The Loya Rae adits and rim cuts are on the east side of Peters Canyon in sec. 6, T. 32 S., R. 24 E. The Loya Rae mine produced a small amount of vanadium ore in the 1940's, and a small amount of low-grade uranium and medium-grade vanadium ore in the early 1950's. The vanadium-uranium ratio of the post-World War II ore is about 8:1.

The mine is in the upper sandstone lens of the Salt Wash Member of the Morrison Formation. The sandstone is light grayish brown, limonite stained, and medium to very fine grained. Fossil plant material, as coaly fragments and calcified logs, is common. Dark-gray vanadium hydromica is the chief ore mineral, but carnotite is more common here than in most deposits along the rim of Peters Canyon. The ore minerals occur in a northwesterly dipping layer about a foot thick and 80 feet long in the adits.

Morning Star mine

The Morning Star claim, also known as the Deer Trail No. 1 claim, in on the east side of Peters Canyon in sec. 1, T. 32 S., R. 23 E. The workings consist of a short adit with irregular small stopes, and several small rim cuts. An unrecorded very small amount of vanadium ore was probably mined on this claim in the early 1940's. A few tons of low-grade vanadium and uranium ore are recorded as from this property in the early 1950's. The vanadium-uranium ratio of this recorded shipment was 10:1.

The workings are in the top sandstone lens of the Salt Wash Member of the Morrison Formation. The lens, obscured by landslide, is more than 40 feet thick and more than 100 feet long. The sandstone lens is partly underlain by greenish-gray mudstone, partly by grayish-red mudstone. The sandstone is light grayish brown, fine to medium grained with pockets of green and white clay pebbles. Seams of grayish-green mudstone are interbedded with the sandstone. North-striking caliche-filled joints are common.

Dark-gray vanadium hydromica with sparse carnotite impregnates sandstone in layers about 0.2 to 4 feet thick and 20 to 40 feet long. These layers occur discontinuously in the adit and for about 100 feet along the outcrop. The layers are commonly surrounded by limonite-stain. Carbonaceous material is uncommon in the sandstone; some coaly fragments occur in the mudstone seams.

Last Chance mine

The Last Chance mine is on the east rim of Peters Canyon in sec. 12, T. 32 S., R. 23 E. The workings consist of an irregular adit about 50 feet long and several small rim cuts. Probably a very small amount of low-grade vanadium ore was shipped from here in the early 1940's.

The deposit is in the top sandstone lens of the Salt Wash Member of the Morrison Formation. The lens, partly obscured by landslide, is at least 20 feet thick and more than 100 feet long. The sandstone is light grayish brown, and consists of medium grains of clear quartz and feldspar with abundant white grains, probably weathered chert, and contains pockets and stringers of small pebbles or red, gray, and white chert and green and white claystone.

Dark-gray vanadium hydromica impregnates sandstone in wavy bands and streaks a few inches to about a foot thick. No carnotite was seen. A few spots about an inch across of a green clay mineral occur near the vanadium streaks. Sandstone above the vanadium streaks is limonite stained. Fossil wood is common as casts, impressions, and silicified fragments, but little is preserved as coaly material; most of the fossil wood is barren.

Tommie No. 1 prospect

This undeveloped claim is on the east side of Peters Canyon in sec. 12, T. 32 S., R. 23 E. A poorly exposed lens of limonite-stained, light-brown, cross-stratified, medium-grained sandstone near the top of the Salt Wash Member of the Morrison Formation, contains a layer about 0.2 to 1.0 foot thick and about 20 feet long impregnated with vanadium hydromica.

Black Jack prospect

The Black Jack prospect is on the east side of Peters Canyon in sec. 12, T. 32 S., R. 23 E. The workings consist of a small open cut about 40 feet wide and about 120 feet of rim cuts. Probably a very small amount of low- to medium-grade vanadium ore was shipped from here in the 1940's.

The prospect is in the second sandstone lens below the top of Salt Wash Member of the Morrison Formation. The sandstone lens is only partly exposed but is probably about 20 feet thick and a few hundred feet long. The sandstone is light brown, fine to medium grained, and cross-laminated. An interbedded mudstone unit, 1 to 4 feet thick, is greenish gray with common orangeish limonite stain near the base. Mineralized rock occurs both above and below the mudstone layer. The chief ore mineral is vanadium hydromica; carnotite is sparse. These minerals occur in the sandstone in a few wispy gray layers, about 0.1 to 1.0 foot thick and 1 to 2.5 feet long. The lower part of the lens, which is now obscured by waste rock may contain some mineralized rock.

Black Hawk prospect

The Black Hawk prospect is on the east rim of Peters Canyon in sec. 12, T. 32 S., R. 23 E. A small rim cut and a short adit are in a sandstone lens in the upper part of the Salt Wash Member of the Morrison Formation. The lens is obscured by landslide debris but is estimated to be about 20 feet thick and 300 feet long. The sandstone is light brown, fine to medium grained, and composed of quartz with minor clear feldspar. The bedding is mainly horizontal with only a few sets of cross-strata; ripple marks are common. The lens is moderately jointed parallel to the north-trending face of the outcrop. Vanadium hydromica and sparse carnotite form a dark-gray, irregular layer about 0.2 to 2.5 feet thick, about 10 feet wide, and more than 40 feet long in the sandstone. A light-green clay mineral coats a minor joint near the portal of the adit. Although a few tons of low-grade vanadium ore probably were removed from the property, it has no recorded production.

Happy Jack mine--(Peters Canyon)

The Happy Jack mine is on the east rim of Peters Canyon in sec. 13, T. 32 S., R. 23 E. U.S. Highway 160 passes within a few hundred feet of the portals of the old mine.

Claims covering this locality probably were staked during the period of radium production in the early 1920's. The mine was operated by the United States Vanadium Corp. in 1941, and January to February 1942. In March to December 1942 and in 1943, the mine was operated by the Vanadium Corp. of America. In mid-1943, according to Huleatt and others (1943, p. 28) the ore body was nearly mined out and the work of recovering pillars preparatory to caving the workings was awaiting the outcome of a single development drift. In June 1943, the U.S. Bureau of Mines drilled two holes ahead of the drift face, but the drill cores showed no mineralization and, thus, the pulling of pillars and the caving of the mine was begun and completed that year.

The mine may have contributed ore to the International Vanadium Corporation mill in Dry Valley in the early 1930's. The only recorded production is for the period 1941-43, during which more than 10,000 tons of medium-grade vanadium ore was mined. The uranium content of this ore is not recorded, but judging from samples on the dump it was probably of medium grade. The known ore body was virtually mined out in 1943 and no later shipments have been recorded. Total production of the mine ranks this deposit among the largest of the uranium-vanadium deposits in the Morrison Formation of the Lisbon Valley area.

The Happy Jack deposit is in the top sandstone lens of the Salt Wash Member of the Morrison Formation. Landslide debris obscures the outcrop and the workings are inaccessible, but the few exposures available suggest that the lens is about 40 feet thick and probably several hundred feet wide. The sandstone is light brown, medium grained, and cross-stratified in trough sets. Material on the dump indicates that the mineralized sandstone contained abundant carbonaceous material. Logs of two drill holes by the U.S. Bureau of Mines about 400 feet east of the portals suggest that the ore-bearing lens thins and becomes reddish in this direction.

The chief ore mineral is dark-gray vanadium hydromica. Carnotite is common in the dump material but is very sparse in outcrops.

Notes by R. P. Fischer (U.S. Geological Survey, written commun., 1942) suggest that the ore body was an irregular tabular lens ranging from about 1 to 5 feet thick, 150 to 200 feet wide, and 500 feet long. The ore body trended about N. 65° E. to N. 85° E. This trend is similar to the trends noted in the Frisco group of mines and the Sunset mine in East Canyon about 8 miles northeast of the Happy Jack mine.

The Happy Jack deposit differs from most other large deposits in the Salt Wash Member in the Lisbon Valley area in the apparent thinness and discontinuity of the ore-bearing sandstone lens, and in the lack of other known ore bodies approaching it in size nearby.

Rainy Weather prospect

The prospect is on the west side of Peters Canyon in sec. 11, T. 32 S., R. 23 E. Workings consist of a narrow open cut about 100 feet long in a sandstone lens near the top of the Salt Wash Member of the Morrison Formation. The sandstone is light gray, fine to medium grained and conglomeratic. Several mineralized logs occurred in the sandstone. A grayish-brown to greenish-gray layer, about 1 foot thick and 100 feet long, of fine-grained sandstone near the base of the lens is impregnated with vanadium hydromica. Total production is estimated to be very small.

Johnnie prospect

A rim cut and stripped bench believed to be on the Johnnie claim is on the west side of Peters Canyon in sec. 2, T. 32 S., R. 23 E. Several tons of low-grade vanadium-uranium ore were recorded as from the Johnnie claim in the early 1950's. The vanadium-uranium ratio of the ore was about 12:1. Total production is estimated to be very small. A dark-gray layer, about 1 foot thick and 60 feet long, of sandstone impregnated with vanadium hydromica lies near the base of a lens near the top of the Salt Wash Member of the Morrison Formation.

Prospect north of Johnnie claim

A rim cut about 100 feet long is on the west side of Peters Canyon about 1,400 feet north of the Johnnie prospect in sec. 2, T. 32 S., R 23 E. The deposit consists of a few thin streaks of gray vanadium mica impregnating sandstone in a lens near the top of the Salt Wash Member of the Morrison Formation.

Popeye prospect

The Popeye prospect is on the west side of Peters Point in sec. 9, T. 32 S., R. 23 E. The workings consist of several short adits and rim cuts in two sandstone lenses in the upper part of the Salt Wash Member of the Morrison Formation. The ore occurs in dark-gray layers a few inches to about 2 feet thick and a few feet to about 50 feet long. Vanadium hydromica is the chief ore mineral; carnotite is sparse. Some streaks of ore follow sandstone beds containing abundant fine fragments of coaly fossil plant material. The property was mined intermittently in 1941 to 1943 and 1951 to 1955. Total recorded production is small.

Lookout prospect

The Lookout prospect, also known as the Sunrise No. 8, is on the west side of Peters Point in sec. 4, T. 32 S., R. 23 E. Workings consist of several stripped benches, rim cuts, and short adits in a sandstone lens, obscured by landslide, near the top of the Salt Wash Member of the Morrison Formation. Gray streaks of sandstone impregnated with vanadium hydromica and sparse carnotite are only a few inches thick and a few feet long. Estimated production is very small.

Little Joe mine

The Little Joe mine is on the west rim of Peters Point in sec. 9, T. 32 S., R. 23 E., less than 1,000 feet northeast of the Lookout prospect. The workings consist of rim cuts and short adits about 20 feet long at two levels about 25 feet apart. As of October 1954, no further development of the prospect was apparent since J. H. Wells of the Union Mines Development Corp., made a sketch map here in April 1944. Production from these workings is estimated to be very small.

Two separate ore-bearing sandstone lenses, separated by about 23 feet of red mudstone, are near the top of the Salt Wash Member of the Morrison Formation. The lower sandstone lens is only about 6 feet thick and consists of fine- to medium-grained cross-laminated and ripple-marked sandstone. The upper lens is about 11 feet thick and consists of light-brown, fair-sorted, silty, very fine and fine- to medium-grained, cross-stratified sandstone. Both sandstone lenses are mostly covered with landslide, but judging from better exposed nearby lenses of similar thickness, their width is probably only several tens of feet.

Dark-gray vanadium hydromica impregnates fine-grained and silty sandstone in thin layers and streaks about 0.1 to 3 feet thick. Carnotite occurs sparingly in a few of the vanadiferous streaks. The upper sandstone lens contains thin streaks of pale-green clay mineral associated with partings coated with particles of coaly material.

COPPER

History and production

The discovery of copper ore in the Lisbon Valley area is attributed by C. T. Van Winkle, consulting geologist (written commun., May 30, 1923) to Gud

Manville, who in 1881 located the copper deposits in the Big Indian mine near the head of Big Indian Valley. This discovery was probably made during a short but intense period of prospecting for silver reported by Tanner (1937):

> "What was perhaps the first big prospecting rush of the Moab area occurred in the fall of 1880, according to an account written by the late Frank Silvey. 'A prospector from Nevada, on his way to Rico, picked up a piece of ore that looked good to him near Lisbon Springs.' Silvey wrote, 'Upon reaching Rico he had it assayed and it ran high in silver values. This caused a stampede into Lisbon Valley of some three hundred men who prospected for several weeks but could not find this rich lead. Finally becoming disgusted, they nearly all left and went back to Rico. Later on this piece of silver ore was thought to have been dropped out of a prospector's pack. It came, perhaps, from some distant silver mine as a specimen."

Old claim notices at many of the copper prospects indicate that the search for copper has been sporadic since the first discovery; interest in the deposits is renewed when copper prices are relatively high. Because of the copper potential of the area, the Big Indian mining district was organized on June 19, 1892 (Butler and others, 1920, p. 146). As the name is now commonly used, the "Big Indian mining district" includes all the uranium-vanadium deposits as well as the copper deposits near Big Indian Wash and Lisbon Valley.

Early exploration and development was largely confined to two properties, the Blackbird (also formerly known as the "Pioneer" or "Lisbon") mine, which lies near the head of Lower Lisbon Valley, and the Big Indian mine, which lies near the head of Big Indian Valley. Records of early activities at the Blackbird mine are scanty. A small tonnage of sorted ore, probably from this mine, was transported by burro from Lisbon Valley to Placerville, Colorado, in 1908 (Heikes, V. C., 1909, p. 566-567). In 1913 the property was idle but had been developed by several surface trenches and an inclined shaft about 100 feet deep (Butler and others, 1920, p. 615). Total production from the mine prior to 1950 was probably only a few hundreds tons of closely sorted ore. During the late 1950's the property was exploited by an open-pit operation. An estimated several thousands tons of ore, probably averaging about 2 percent copper, was shipped to a smelter near Salt Lake city, Utah. Operations were suspended in 1958.

At the Big Indian copper mine an inclined shaft had been sunk 300 feet by 1900. Processing mills to up-grade the ore were constructed in 1916, 1925, and 1943. Probably the only sustained mining and milling operation at the property was from 1942 to 1946, when the Ohio Copper Company of Utah mined and treated more than 150,000 tons of ore averaging about 1.5 percent Cu. In 1947 the concentrating plant was dismantled. The ores contained small amounts of silver and traces of gold.

Geologic habits of the ore deposits

Copper occurs in both sedimentary and igneous rocks in the Lisbon Valley area. The deposits in the sedimentary rocks are more numerous and generally larger than those in the igneous rocks.

Copper deposits in sedimentary rocks

The formations containing copper deposits range in age from Pennsylvanian to Late Cretaceous. Most of the deposits, including the two largest ones (the Big Indian and Blackbird), are in the Dakota Sandstone of Late Cretaceous age. Small deposits are in the Hermosa Formation of Pennsylvanian age, the Cutler Formation of Permian age, the Kayenta Formation of Late Triassic age, and the Burro Canyon Formation of early Cretaceous age.

Copper minerals are common to rare in some uranium-vanadium deposits in sedimentary rocks in the area. Copper minerals occur in uranium-vanadium deposits in the Cutler Formation (Permian), the Chinle Formation (Late Triassic), and the Morrison Formation (Late Jurassic). Manganese ore from the Entrada Sandstone (Late Jurrassic) also contains small amounts of copper, but copper minerals have not been identified in the ore.

The sedimentary rocks containing the copper deposits are mostly sandstone of continental or marginal marine origin. All deposits in the Cutler and Kayenta Formations and several in the Hermosa Formation are in arkosic sandstone. In the Burro Canyon Formation the host rock is chiefly silicified quartzose sandstone. In the Dakota Sandstone the host rock is composed mainly of quartz and chert. The host sandstones are generally light gray to brown. They range from fine to coarse grained and fair to poor sorted. The host sandstones are generally firmly cemented by calcite; the copper-bearing sandstone of the Burro Canyon Formation is very firmly cemented by silica. Copper minerals occur also in small amounts in rocks other than sandstone--in coal of the Dakota Sandstone and in limestone of the Hermosa Formation.

Carbonaceous material is common in many of the host sandstones. Plant debris is scattered through the Dakota Sandstone, the principal host formation. The debris locally forms small pockets of impure coal, and the main copper-bearing sandstone bed in the Dakota at the Blackbird mine is underlain by a thin bed of shaly coal. In the sandstone of the Hermosa Formation the copper is associated with iron-stained Calamites fragments. The Cutler, Kayenta, and Burro Canyon Formations lack carbonaceous debris, but some copper-bearing sandstone of the Cutler Formation at the Woods mine and of the Burro Canyon Formation at the Big Indian mine are cemented and stained by a hard, black, combustible asphaltic substance, probably dried petroleum. Copper minerals in uranium-vanadium deposits in the Chinle and Morrison Formations also commonly occur in sandstone containing carbonaceous plant material.

The copper deposits with few exceptions are close to faults. Most deposits, including the largest ones, are adjacent to the faults of the central part of the Lisbon Valley fault system. Many small deposits are scattered along faults that bound the McIntyre graben. The major faults generally contain only small amounts of copper. Minor fractures, subparallel to the major faults, are commonly filled with copper minerals; this type of occurrence accounts for most of the copper in deposits in limestone and in small deposits in sandstone. The larger deposits, however, consist of copper minerals in tabular bodies, parallel to the bedding of the host sandstone. The copper minerals are disseminated throughout the sandstone, coating sand grains, and filling interstices and minute cracks. In the Dakota Sandstone and Hermosa Formation they also replace carbonized wood. The deposits are elongate, parallel to the faults, and are as much as a few thousand feet long and several hundreds of feet wide and range from a few inches to more than 10 feet in thickness. The edges of the deposits away from the faults are poorly defined. Patches of weakly mineralized rock are scattered irregularly around the main part of the deposit.

The Big Indian deposit and the Blackbird deposit are of possible future economic interest. Together they account for practically all the known production and reserves of copper ore averaging more than 1 percent Cu in the Lisbon Valley area. Most of the other copper deposits described in this section have little economic potential, but some of these minor occurrences, such as the Woods and Lucky Strike properties, are of geologic interest, for they give clues to the origin of the copper ores.

Copper deposits in igneous rocks

Copper sulfides and carbonates occur sporadically in altered diorite porphyry of Tertiary age in an area about 500 feet in diameter at the head of Lackey Creek on South Mountain. The diorite porphyry is fractured, argillized, and silicified so that most phenocrysts are destroyed. Many fractures show slickensides, but no faults were identified. Much of the porphyry is hematite-stained and veined on a small scale by quartz and calcite. Some open fractures are lined by coarse crystals of grayish-orange calciet or by small, acicular crystals of quartz. This altered and fractured rock is probably part of the shatter zone of the South Mountain stock (Hunt, 1958, p. 346); it also resembles some of the vent breccias in North Mountain (Hunt, 1958, p. 331).

The copper minerals occur chiefly as discontinuous fracture fillings, commonly less than an inch thick, and also as irregular nodules and linings of small voids in coarsely brecciated rock, and as small pods, less than 3 inches in diameter, in relatively massive rock. The copper minerals are younger than most of the rock alteration, in part contemporaneous or younger than the quartz crystals, and older than the grayish-orange calcite.

These copper deposits appear to be too low in grade to have economic potential. Somewhat similar deposits in the igneous rocks of North Mountain, however, have been worked on a small scale in the past for their gold and silver content (Hill, 1913; C. B. Hunt, 1958, p. 355-358).

Mineralogy

As presently known, all the copper deposits are oxidized. The most common copper minerals are carbonates, sulfates, and oxides. The richer parts of the deposits generally contain the sulfides chalcocite and covellite. Chalcopyrite occurs sparsely in some deposits in sedimentary rock and, along with bornite, is fairly common in the deposits in igneous rock.

Few gangue minerals were deposited with the copper minerals in sedimentary rocks. Barite is locally abundant in a few of the ore deposits in sedimentary rocks and is apparently older than the copper minerals. Calcite is common in the ores and is probably a redistribution of the original cement. Pyrite occurs in the ore zone at the Big Indian mine but has not been recognized in other deposits. The former presence of pyrite, however, is suggested by widespread limonite-stain in several of the ore-bearing formations.

Gangue minerals deposited with copper minerals in igneous rock include quartz and calcite. The copper sulfides are partly contemporaneous with the quartz and older than the calcite.

Radioactive minerals and vanadium minerals were found in only three deposits: The Lucky Strike, Woods and Big Indian mines. An extremely fine-grained, yellow radioactive mineral of the carnotite group coats silicified fracture surfaces at the Lucky Strike mine. The radioactive mineral is associated with copper vanadates, malachite, and chalcocite. In the lower workings of the Lucky Strike mine gray vanadium hydromica impregnates sandstone along irregular joints. Vanadium hydromica also locally impregnates sandstone at the Woods and Big Indian mines; the gray vanadiferous sandstone is anomalously radioactive, but no uranium mineral was identified. Copper minerals, as noted below, also occur sparsely in some uranium-vanadium deposits.

The following copper minerals have been identified in the Lisbon Valley Area:

Sulfides

Chalcopyrite ($CuFeS_2$) occurs as nodules surrounded and replaced by sulfides, carbonates, and oxides of copper at the Big Indian mine (Dakota Sandstone), the Woods property (Cutler Formation) and the Twin Logs claims (diorite porphyry). It is generally criss-crossed with veinlets of tenorite, cuprite and an extremely fine grained unidentified black copper mineral. Chalcopyrite in ore from the Twin Logs claim is partly surrounded and replaced by bornite.

Chalcopyrite is also found in sparse amounts in some uranium mines in the Chinle Formation, and probably formed contemporaneously with uranium oxides (Laverty and Gross, 1956, p. 199).

Bornite (Cu_5FeS_4) is the only copper mineral found in the igneous rock (the Twin Logs claims) not also found in sedimentary formations. It is closely associated with and partly replaces chalcopyrite.

Chalcocite (Cu_2S orthorhombic), the most common copper sulfide, occurs as isolated lenticles less than 0.5 cm in diameter, as disseminated fine to coarse grains, as fracture fillings as much as an inch thick, and particularly in the Blackbird deposit, as tabular masses as much as 3 inches thick and 12 inches in diameter. In the larger masses it surrounds and partly replaces grains of the host rock, fills voids, and replaces cement.

In the igneous rocks of the Twin Logs deposit chalcocite occurs as nodules less than 1 inch in diameter and as thin rims around masses of bornite and chalcopyrite. Chalcocite is the only sulfide present in some deposits. Where it occurs with chalcopyrite, the chalcocite appears to be the younger mineral, but otherwise it appears to be the oldest mineral in most deposits.

Digenite (Cu_2S, isometric) occurs at the Blackbird mine and the Woods property closely associated and intimately mixed with chalcocite. Digenite replaced and was replaced by chalcocite.

Covellite (CuS) occurs sparsely as an oxidation product of chalcocite. Although not distinguishable in most hand specimens, it has been identified in all polished sections of the ores that contain chalcocite.

Carbonates

Malachite ($Cu_2(OH)_2CO_3$), the most abundant and widespread copper mineral in the area, occurs generally as a thin film on clastic grains and as coatings on fracture surfaces. Less commonly, it forms tiny rosettes of radiating crystals on fracture surfaces. At the Woods property sparsely disseminated malachite replaces biotite along cleavage planes.

Malachite is the most common copper mineral in uranium-vanadium deposits in the Cutler, Chinle, and Morrison Formations.

Azurite ($Cu_3(OH)^2(CO_3)^2$) is common in areas containing copper sulfides. It generally forms discrete spots within the host rock, as if grains of sulfide were altered with little migration of copper. Ore from the Blackbird mine contains thin, veinlike fillings of azurite in fractured quartz grains near chalcocite.

Azurite occurs sparsely in a few uranium-vanadium deposits in the Cutler, Chinle, and Morrison Formations.

Oxides

Cuprite (Cu_2O) occurs in narrow veinlets with tenorite that cut copper sulfides in ore from the Twin Logs claims, and surrounds native copper in ore from the Big Indian mine. Fischer (1937, p. 916) reported finding cuprite at the Blackbird mine.

Tenorite (CuO) occurs with cuprite in ores from the Twin Logs claims and sparsely in the Blackbird mine.

Sulfates

Brochantite ($CuSO_4.3Cu(OH)_2$) was found only in the Lucky Strike property where it occurs as a green film on fracture surfaces and less commonly as interstitial fillings.

Antlerite ($3CuO.SO_32H_2O$) was tentatively identified in samples containing brochantite from the Lucky Strike deposit.

Chalcanthite ($CuSo_4.5H_2O$) occurs as blue efflorescences on coaly beds underlying sulfide ore at the Blackbird mine. The mineral commonly occurs as masses of needlelike crystals several millimeters long.

The type of sulfate deposited is probably due to the pH and concentration of cupric sulfate solution (Anderson, 1955, p. 332); evaporation of cupric sulfate solution results in the crystallization of chalcanthite, neutralization of concentrated cupric sulfate solution yields antlerite, and the neutralization of dilute cupric sulfate forms brochantite.

Other copper minerals

Native copper (Cu) occurs sparsely, mostly as angular grains surrounded by cuprite, in the Big Indian, Blackbird, and Lucky Strike mines and in the Kayenta prospect. At the Big Indian mine it also occurs rarely as thin sheets lining fractures. Disseminated grains in the Kayenta prospect are rounded and perhaps are replacements of detrital grains.

Native copper was found in only one uranium-vanadium deposit, the Standard mine in the Chinle Formation. It forms impregnations in the sandstone at the Chinle-Cutler contact and small curved plates in mudstone.

Volborthite ($(Cu_2(VO_4)_2 \cdot 3H_2O(?))$) or calciovolborthite ($((Cu, Ca)_2 (VO_4)(OH))$) forms tiny rosettes of green and yellowish-green crystals on fracture surfaces at the Lucky Strike mine, and impregnates sandstone at the Big Indian mine.

(Volborthite has also been tentatively identified in a few uranium-vanadium deposits in the Cutler Formation and in some of the uranium-vanadium deposits in the Salt Wash Member of the Morrison Formation south of McIntyre Canyon.)

Comparison with other copper deposits

Sedimentary host rocks

Many small copper deposits, generally similar to those in the Lisbon Valley area, occur around the La Sal Mountains. These deposits are briefly described by Fisher (1936, 1937), Butler and others (1920, p. 615-616, Dane (1935, p. 178-179), Finch W. I., (1954, p. 4), Withington (1955), Shoemaker (1955, 1956b), and Witkind (1964, p. 103-104). Virtually all the deposits are fissure fillings or impregnations in sandstone near faults. Host sandstones range in age from Late Triassic (Chinle Formation) to Late Cretaceous (Dakota Sandstone). The larger deposits, including the economically significant Cashin mine near Paradox Valley, Colorado, are along small faults in the Wingate Sandstone of Late Triasssic age. Malachite is probably the most abundant mineral, for all the deposits are to some degree oxidized. Sulfides are locally common and include chalcocite, chalcopyrite, covellite, and in the Cashin and other copper deposits near Paradox Valley, Colorado, bornite and enargite. Though some copper ores contain silver, silver minerals are sparse; probably most of the silver is in copper sulfides. Radioactive minerals are rare in these copper deposits, though copper minerals occur sporadically in uranium-vanadium deposits in the same general area. An exceptional occurrence of radioactive pyrobitumen near native silver in sandstone of the Chinle Formation in the Cashin mine (Carter and Gualtieri, 1957c, p. 94) suggests that the uranium-vanadium and copper deposits of the region may be interrelated.

Copper deposits in sedimentary rocks, mostly unaltered continental sandstone, are widespread on the Colorado Plateau and in the southwestern United States in general (Finch, J. W., 1933; Fischer, 1936, 1937). Like the deposits in Lisbon Valley most of these deposits are stratiform, and consist of copper oxides, carbonates, and chalcocite.

Igneous host rocks

Many small deposits of copper, silver, and gold in the northern part of the La Sal Mountains resemble the copper deposits in altered diorite porphyry at the head of Lackey Creek on South Mountain (Hill, 1913; Hunt, C. B., 1958, p. 355-358). The chief value of the deposits in the northern La Sal is their gold content, which is probably mostly in pyrite, but copper carbonates, chrysocolla, chalcopyrite, bornite, and chalcocite are present in notable amounts at most prospects. The deposits are in sheared, altered porphyries in sheeted zones around the stock of North Mountain. Veinlets of quartz and calcite cut the host rocks but are not generally abundant. Chalcopyrite and pyrite occur locally in narrow veins in the explosion breccias of volcanic vents (Hunt, 1958, p. 331). Radioactivity is high in a few of these deposits, but according to Hunt (1958, p. 338, 356) it is related to the potash-rich younger igneous rocks rather than to hydrothermal solutions that deposited iron, gold, and copper.

Similar gold fissure deposits with associated copper minerals, chiefly carbonates and chalcopyrite, occur in altered porphyries in some other laccolithic centers of the Colorado Plateau--the Henry Mountains, Utah (Hunt and others, 1953, p. 217-220), the Abajo Mountains, Utah (Gregory, 1938, p. 108-110; Witkind, 1964, p. 101-103), and the Ute Mountains, Colorado (Ekren and Houser, 1965, p. 66).

Origin of copper deposits in the Lisbon Valley area

Previous theories

Copper deposits in sedimentary rocks

Butler and others (1920, p. 154-158), considering the Big Indian mine and similar deposits in sandstone, suggested that such ores were formed by circulating meteoric waters that collected the metal disseminated throughout the sedimentary rocks and deposited them on contact with carbonaceous material, earlier sulfides, or other precipitating agents. The circulation was controlled mainly by the geologic structure and locally was artesian. Most minerals now seen are the result of surface alteration. The deposits probably began to form in the Tertiary and may in places still be forming.

The copper ores in sedimentary rocks of Lisbon Valley area were classed with the "red beds" type of copper mineralization by Fischer (1937). He suggested that the metals in this type of deposits are syngenetic, and were perhaps concentrated from surface waters by organisms such as bacteria; the minerals of these deposits are, however, epigenetic.

J. W. Finch (1933), in a general discussion of the "red beds" type of copper deposit, suggested that the copper was deposited from solutions and as detritus derived from areas containing copper outcrops; the copper was deeply buried and reduced to sulfides by hydrogen sulfide given off in the coalification of plant debris; much later, the deposits were weathered, oxidized, and in part reconcentrated with the formation of epigenetic minerals.

Copper deposits in igneous rocks

The copper deposits in the igneous rocks of the La Sal Mountains are of hydrothermal origin, the last phase in the igneous history of the mountains (Hunt, C. B., 1958, p. 338, 355). The content of copper, lead, and zinc increases slightly from older to younger porphyries as a result of differentiation, and in places increases tremendously in hydrothermally altered porphyries. It decreases generally away from the stocks. The ore deposits in the La Sal Mountains are younger than the volcanic phase of North Mountains. Gases, which continued to rise after the magma had solidified, argillized the porphyries, and deposited the ore minerals. The copper deposits are thus probably Tertiary, but their precise age involves the more general problem of the age of the igneous rocks.

Hypogene hypothesis

Any hypothesis of the origin of the copper deposits in the Lisbon Valley area must account for all the deposits in the sedimentary rocks as a single class, for they are all similar in geologic habit and mineralogy. The close association of the copper ores with faults in the sedimentary rocks indicates that they are structurally controlled and thus epigenetic. Their wide stratigraphic range in formations ranging in age from Triassic to Cretaceous argues against an originally syngenetic origin for these deposits, because the host rocks differ not only in age but in depositional history, environment, and source areas, and to a lesser degree in rock type. The common association of the copper ores with carbonaceous material implies that this material was an important factor in localizing the ores, but its chemical influence may have been effective long after its original deposition.

The field evidence does not show clearly whether the solutions that deposited the copper were ascending, descending, or laterally moving. The Dakota Sandstone, the chief sedimentary host rock, is not copper-bearing away from faults even though it is more of less carbonaceous everywhere; it is an unlikely source for all the copper in the area. The presence of hydrothermal copper fissure veins at the Cashin mine, Colorado, and at other localities around the La Sal Mountains (Fischer, 1936) suggests that a basement source is most likely and that the solutions were ascending (hypogene).

The occurrence of hydrothermal copper deposits in fissure igneous rocks of the La Sal Mountains and the arc-like distribution of copper deposits in sedimentary rocks (including the Cashin mine and similar vein deposits) around the mountains suggest that all the copper deposits in the area may be related to the hydrothermal phase in the history of the igneous intrusions. The mineralogy of the deposits in the sedimentary rocks and in the igneous rocks are much alike except for the restriction of bornite to the igneous rocks. The host igneous rocks are, however, altered and contain quartz and calcite as epigenetic gangue minerals; the sedimentary host rocks are virtually unaltered and generally contain no epigenetic gangue minerals. These differences in habit may be largely the result of temperature differences in the two types of deposits. Any hydrothermal solutions moving outward from the La Sal igneous centers and upwards along the Lisbon Valley fault system would be greatly diluted by connate water within the sedimentary rocks so that the ore deposits would be of the low-temperature (telethermal) type.

The precipitation of the copper within carbonaceous-rich sedimentary rocks, such as the Dakota Sandstone, was probably caused by hydrogen sulfide engendered by anaerobic bacteria from fossil plant material (Jensen, 1958) or during coalification of the plant material. The presence of pyrobitumen, probably dried petroleum, with copper minerals locally in the Cutler and Burro Canyon Formations suggests that hydrogen sulphide derived from underlying petroliferous Paleozoic rocks may have precipitated some copper in formations lacking fossil plant debris.

Suggestions for prospecting

The Dakota Sandstone has yielded most of the copper ore mined in the Lisbon Valley area, has most of the known small reserves of ore in the area and is the recommended target for future exploration. In times of high copper prices or when there is need for siliceous copper ores as flux, additional reserves of copper ore with a cutoff grade of 1 percent Cu could probably be developed by shallow drilling in the Dakota around the Big Indian and Blackbird mines.

The most favorable part of the area in which new discoveries of copper deposits in the Dakota Sandstone may be sought is along Lisbon Valley. For a distance of about 7 miles the Dakota Sandstone forms the hanging wall of the Lisbon Valley fault but is covered by alluvium. The structural and stratigraphic relations are similar to those at the Big Indian and Blackbird mines. A few scattered occurrences of copper minerals in Paleozoic rocks on the footwall side of the fault suggest that copper-bearing solutions passed through this part of the fault system.

Mines and prospects

Big Indian copper mine

The major workings of the Big Indian copper mine are a few hundred feet northeast of the Lisbon Valley road at the head of Big Indian Valley, mostly in the NW1/4, sec. 34, T. 29 S., R. 24 E., San Juan County, Utah. A long history of exploration at the Big Indian mine has resulted in several widely separated surface cuts, trenches, small open pits, and some underground workings. The sandstone rim was cut back in several places in the central part of the mineralized area. Open-pit mining obliterated most of the early undergound workings.

The copper deposits at the Big Indian mine are in sandstone strata of Cretaceous age that form the southwest limb of a gently northwest plunging anticline and are downfaulted adjacent to the Cutler Formation of Permian age along the Lisbon Valley fault. Most of the copper ore is disseminated in a sandstone bed about 20 feet thick at the base of the Dakota Sandstone (Upper Cretaceous). The grade of the ore diminishes irregularly away from the fault. The area of mineralized rock is about 3,000 feet long parallel to the fault and as much as 800 feet wide. Outcrops of the Burro Canyon Formation (Lower Cretaceous) also contain copper minerals but the ore appears to be of lower grade and less persistent than ores in the Dakota.

Most of the outcrops are of the lower 60 feet of the Dakota Sandstone, which consists mainly of crossbedded, lenticular, light- to dark-brown sandstone and conglomerate with interbedded gray and brownish-gray mudstone, dark-gray carbonaceous shale, and lenses of impure coal. Carbonaceous and iron-stained plant impressions are common. A coarse basal conglomerate locally marks the unconformity between the Dakota and the underlying Burro Canyon.

The Burro Canyon Formation crops out on the lower slopes near the mine, and consists mainly of crossbedded, very light gray and light- to dark-brown sandstone and conglomerate, bluish-gray limestone, and green and purplish-red mudstone. Logs of diamond drill holes on the property indicate the Burro Canyon is here about 250 feet thick.

Malachite and azurite are the most abundant copper minerals. These were probably derived from the sulfides chalcocite, chalcopyrite, and covellite which occur sparsely. Native copper occurs as scattered grains commonly surrounded by cuprite and as thin sheets lining fractures; it reportedly caused grinding problems in the local milling operations in the period 1943-1946. Silver has been recovered in small quantities from the ore but no silver minerals have been identified. Pyrite is generally sparse, though Butler and others (1920, p. 615) found nodules of quartz grains cemented by pyrite and a mixture of covellite and chalcocite. Limonite and a purplish-black maganiferous mineral stain the host rocks locally. Some sandstone in a small prospect in the Burro Canyon Formation below the main workings is impregnated with a black and brownish-black pyrobitumen, probably "dead oil." The pyrobitumen is flecked with an apple-green mineral, tentatively identified as a copper vanadate (volborthite?) and is slightly radioactive though no uranium minerals were found. The deposit as a whole is not abnormally radioactive (Gott and Erickson, 1952, p. 5, 13).

The Lisbon Valley fault trends northwesterly across the property, dips generally about 55° to the northeast, and has here a stratigraphic displacement of about 3,000 feet. The Cutler Formation on the southwest side of the fault dips generally 10° to 15° SW. The red beds of the Cutler are unmineralized but are bleached as much as 15 feet from the fault. On the northeast side of the fault Cretaceous beds mostly dip 10° to 20° SW, but close to the fault, owing to drag, they dip northeasterly. The Cretaceous rocks are all slightly mineralized along the fault plane.

Some old underground workings, now inaccessible, are reported to have explored for copper along the Lisbon Valley fault. An incline, whose location is now uncertain, was 185 feet or more long and cut into weakly mineralized rock (probably the Burro Canyon Formation) in the wall near the fault (Joralemon, 1952, p. 250). A vertical shaft in the Burro Canyon Formation about 2,500 feet north of the open-pit area probably intersected the fault at depth of about 100 feet; silicified conglomeratic sandstone containing a small amount of copper carbonates is scattered on the dump near the shaft. The available evidence does not suggest that the fault contains material of commercial grade or thickness.

Philadelphia prospects

The Philadelphia prospects are on the dip slope southwest of Lisbon Valley about 1.5 miles northeast of Big Indian Rock.

The property, previously called the Independence claims, has been developed by six shafts, three adits, and several shallow prospect pits. These workings explore a mineralized fault zone about 2,500 feet long, extending northeasterly from a few hundred feet southeast of the center of sec. 18 to the NW1/4 sec. 17, T. 30 S., R. 25 E., San Juan County, Utah. The deepest shaft, near the southwest end of the zone, is about 50 feet deep; other shafts are less than 30 feet deep. Near the central part of the mineralized zone, a drift connects three closely-spaced shafts. None of the shafts were accessible in 1959. The size of the dumps near the workings suggests that little if any of the mined rock had been shipped from the area.

The prospects explore a fracture zone in micrograined fossiliferous gray limestone bed about 9 feet thick, which forms a dip slope near the top of the Hermosa Formation of Pennsylvanian age. The beds strike northwesterly and dip about 8° southwesterly at the crest of the slope and steepen to 14° downslope.

The zone of fracturing strikes northeasterly, is nearly vertical, and ranges in width from about 3 feet at the southwest end of the zone to about 50 feet near the crest of the dip slope. Erosion has removed the limestone bed at the crest of the slope and a few tens of feet further north of the crest the fractures die out in sandstone. The zone of fracturing is in effect a normal fault having a displacement of only a few feet downward on the northwest side of the zone. Within the limestone bed the zone of fracturing is characterized by brecciated limestone cemented by coarsely crystalline white to gray calcite, having crystal faces ranging in size from a few millimeters to nearly half an inch. Within the underlying sandstone thin discontinuous veinlets of white calcite mark the fractures. Veinlets of calcite also extend several inches outward from the fracture zone and are parallel to the bedding in the limestone.

The copper minerals are confined mainly to the crystalline calcite in the fractures in the limestone and are apparently later than the calcite. Near the crest of the slope copper minerals form small tabular concentrations parallel to the bedding in the upper 3 feet of the sandstone; these mineralized layers are more calcareous than the barren sandstone. Copper minerals are also sparsely distributed in unfractured limestone.

The most widespread copper mineral is malachite. Chalcocite is common, as nodules nearly an inch in diameter, generally masked by a thin film of malachite and covellite. Small nodules and thin streaks of chalcopyrite, partly altered to cuprite and tenorite, occur sparsely. Azurite is present in minor amounts. Some limonite stain may represent original pyrite.

Copper Queen

The Copper Queen prospect is on the southwest side of Lisbon Valley about 1 mile northwest of the mouth of Lisbon Canyon.

The workings consist of several shallow bulldozer trenches and one small prospect pit.

The rock exposed in the workings is micaceous sandstone and some limestone of the Hermosa Formation of Pennsylvanian age. The beds strike N. 55° E. and dip 8° SE. The surface trace of the Lisbon Valley fault is a few tens of feet east of the prospect.

Malachite and azurite are disseminated in light-brown to light-gray, fine- to very fine-grained micaceous sandstone. Nodules of malachite and azurite as much as 1 inch in diameter, shome having sulfide cores, occur locally. Some of the limestone has spots of radiating malachite crystals.

Western Star

The Western Star prospect is on the southwest side of Lisbon Valley, southwest from the mouth of Lisbon Canyon at the base of a cliff which rises to form a prominent cuesta. Workings consist of two adits, each about 20 feet long, and several surface cuts, trenches, and pits.

The Western Star prospects lie on the southwest side of the Lisbon Valley fault and are in faulted sandstone, shale, and limestone of the Hermosa Formation of Pennsylvanian age. Fossilized carbonaceous plant fragments are common in the sandstone and fusulinids are common in the limestone. The beds strike N. 79° E. and dip 17° SE.

Malachite and, less commonly, azurite occur as coatings on bedding and fault planes, as disseminations in sandstone, and locally as replacements of carbonaceous material. A semiquantitative spectrographic analysis of a selected sample of copper-bearing material showed copper in excess of 10 percent, about 30 ppm vanadium, about 150 ppm lead, and about 300 ppm silver.

Blackbird

The Blackbird mine is in northwest Lower Lisbon Valley, and 1 mile south of Lisbon Canyon on an elongate small hill just northeast and parallel to the Lisbon Valley road.

The Blackbird property contains an open pit, several trenches, prospect pits, adits, and shafts, and an inclined shaft which is the main underground working. The open-pit mining operation in 1957-1958 removed part of the hill east and northeast of the portal of the main inclined shaft.

The main shaft is said to have been sunk about 140 feet with an inclination of about 45° (Sample, R. D., U.S. Geological Survey, 1950, written commun.); in 1957 it was inaccessible below 110 feet due to sloughed rock and flooding. Drifts extend from both sides of the shaft at 79 and also reportedly at 120 feet below the portal. The upper drift extends 37 feet northwest and nearly 40 feet southeast from the shaft.

The Blackbird workings are mainly in the Dakota Sandstone (Upper Cretaceous); a few small prospects are in the sparsely mineralized Burro Canyon Formation (Lower Cretaceous). The beds strike northeasterly and dip 11° to 45° southwest. A branch of the Lisbon Valley fault is concealed beneath the alluvium a few hundred feet southwest of the mine. Near the mine along this fault, which strikes northwesterly and dips steeply to the northeast, Cretaceous rocks of the northeast block are dropped against Triassic rocks of the southwest block. Displacement on the fault decreases to the southeast. The ore-bearing beds dip most steeply near this fault. Several minor northwest-trending faults, which offset the beds only a few tens of feet and trend parallel to the branch of the Lisbon Valley fault, cut the beds northeast of the shaft portal.

The Dakota Sandstone here is dominantly medium-grained sandstone with some conglomerate. Locally carbonaceous fossil plant material is scattered through the sandstone. About 70 feet above the base of the Dakota is a lens of carbonaceous shale and coal, ranging from 5 to 10 feet thick.

The most widespread ore minerals are malachite and azurite. Malachite as grain coatings, grain-crack fillings and interstitial fillings is widespread, whereas azurite is mostly found only near visible chalcocite or in scattered, small button-like nodules, some of which have a minute core of chalcocite or cuprite. Intermixed chalcocite and covellite in places form fracture fillings more than an inch thick and locally are concentrated along the bedding in sandstone in wispy layers and in pods as much as several inches long and more than an inch thick.

In the underground workings efflorescences of chalcanthite on the coaly layer are common. Native copper (Fischer, 1937, p. 916) and cuprite are among the less common minerals in this deposit. Although the ore-bearing beds are somewhat limonite-stained, pyrite and chalcopyrite are rare.

The highest concentration of copper minerals is in the sandstone overlying the lens of carbonaceous shale and coal and is best exposed in the main inclined shaft and connecting drifts. The sandstone contains scattered to abundant sooty, carbonaceous plant material. A mixture of chalcocite and covellite forms thin wispy lenses, a fraction of an inch to about an inch thick and several inches long, in the sandstone immediately above the carbonaceous shale. A few nearly vertical fractures less than an inch wide are also filled with these sulfides; these mineralized fractures extend from the top of the upper coal to the top of the mine workings, a distance of more than 3 feet. A mixture of malachite and azurite is concentrated in the sandstone above the coal and shale and gradually decreases in concentration upward. Small button-like nodules of chalcocite, a fraction of an inch in diameter, are scattered sporadically through the copper-carbonate sandstone ore. The upper limit of well-mineralized rock is not sharp. The richer copper ore forms a lens that thins markedly to the northwest and to the southeast.

Copper carbonates are widely distributed in the Dakota Sandstone, but outcrops east of the shaft are generally of much lower concentration than in the main inclined shaft. Locally copper sulfides fill narrow fractures in the copper-carbonate-bearing sandstone. The area containing visible copper minerals extends northwest of the inclined 400 feet, southeast 1,200 to 1,500 feet, and to the northeast 500 to 700 feet. Average thickness of the mineralized zone in the Dakota Sandstone is estimated to be 10 to 20 feet.

The underlying Burro Canyon Formation and the overlying Mancos Shale crop out in a few places on the property. The Burro Canyon here is partly a noncarbonaceous sandstone, which contains a few occurrences of copper carbonates; but the ore-bearing potential of the Burro Canyon is small compared to that of the Dakota. The Mancos here is a greenish-brown, fossiliferous, limy shale; it is barren.

Samples of the rock containing copper minerals range widely in copper content. R. D. Sample (U.S. Geological Survey, 1950, written commun.) reported nine channel samples totaling 56.6 feet ranging from 1.84 to 5.78 percent Cu; two channel samples in the coal seam totaling 9.9 feet assayed

1.46 and 1.66 percent Cu. He also reported a 24-foot sample cut parallel to the bedding in an incline southeast of the main inclined shaft assayed 1.51 percent Cu. The ore contains a trace amount of silver associated with the copper sulfides.

Prospect in Kayenta Formation

This unnamed prospect is on the east slope of the hill southwest of the Lisbon Valley road in northwest Lower Lisbon Valley. The workings are 650 feet S. 27° W. from the main incline on the Blackbird copper property. No road leads to the prospect. Workings include a 10-foot long adit and two small trenches. The total length of outcrop explored is about 60 feet.

The prospect is about 30 feet below the top of the Kayenta Formation (Upper Triassic?). The beds strike N. 75° E. and dip 40° SE. The bedrock is thin-bedded, well-cemented, fine-grained, cross-stratified sandstone overlying silty mudstone.

Malachite and minor amounts of azurite and native copper are disseminated in sandstone within a stratigraphic interval of about 10 feet; a few specks of malachite are in the underlying mudstone. These copper minerals occur along the strike of the beds for about 100 feet. In the area containing copper minerals the host rock is much lighter colored than normal, possibly because of bleaching by ore solutions.

Woods property

The Woods property is near the base of a steep slope on the west side of a prominent hill in the NE1/4 sec. 35, T. 30 S., R. 25 E. Workings consist of two northeast-trending adits, 120 and 140 feet long, driven subparallel to each other and about 200 feet apart in a north-south direction. A small open cut lies along a fault between the two adits.

The adits cut across a normal fault that separates the Cutler Formation (Permian) from the downthrown Wingate Sandstone (Upper Triassic) and Kayenta Formation (Upper Triassic?). The fault, a southeastern branch of the main Lisbon Valley fault system, forms the southwest boundary of the graben in Lower Lisbon Valley.

Near the adits the Cutler Formation consists mainly of maroon to gray, crossbedded, arkosic and micaceous sandstone. In the north adit lenses of red mudstone are exposed; in the south adit the sandstone contains numerous small mudstone pellets. Sandstone near the south adit is flecked with black carbonaceous material, which appears amorphous, breaks with a conchoidal fracture, and has a vitreous luster. In thin section it fills the interstitial areas between grains and apparently was deposited as a fluid. A fragment of rock containing this material will support a flame. The black pyrobitumen is probably a residue of petroleum. The area of sandstone containing the dried oil as a cement is estimated to be only a few hundred square feet.

The gray to buff rocks of the Wingate and Kayenta on the eastern, downthrown side of the fault, are lighter colored than the rocks of the Cutler. In the south adit the rocks are fine-grained, crossbedded sandstone. In the north adit the strata east of the fault are alternating shale and fine-grained sandstone, which are contorted along numerous small faults.

Barite in masses as much as 6 inches thick fills fractures along the main fault at the surface. Calcite in these fractures is mostly later than the barite. Malachite occurs sparsely along the fault at the surface and is later than the barite.

In the south adit malachite and sparse azurite are disseminated in sandstone of the Cutler Formation and commonly coat tiny limonite-stained pellets. The malachite occurs as interstitial fillings and as partial replacements along cleavage planes in biotite. Some of the copper materials seem to have formed earlier than the pyrobitumen. A gray vanadium mineral, probably vanadium hydromica, colors a radioactive layer above a thin layer of copper carbonate in sandstone of the Cutler in a short drift south from the south adit.

In the north adit a thin vein, about an inch wide, of chalcopyrite, chalcocite, cuprite, and copper carbonates with calcite and barite gangue lies in a zone of minor fractures about 20 feet east of the main fault. The copper minerals are, for the most part, later than the barite. A small drag fold in a thin vein of copper minerals adjacent to a small fracture suggests some movement on the fault after formation of the vein. Copper carbonates are sparsely disseminated in the Wingate Sandstone and locally are concentrated at contacts between sandstone and shale.

Lookout Point

The Lookout Point prospect is on a small hill about 1,200 feet north of the Patterson Ranch in the northwest part of the southwest side of Lower Lisbon Valley. The Lookout Point property, probably first developed in the early 1900's has been mined by cutting back a rim. Several truckloads of hand-sorted ore containing 10 percent copper reportedly were shipped from this prospect prior to 1943 (Sample, R. D., U.S. Geological Survey, 1950, written commun.). When the property was visited in October 1958, recent mining activity had removed several hundred tons of rock from a rim cut.

The prospect is in the lower part of the Dakota Sandstone (Upper Cretaceous). These rocks are downfaulted along a major branch of the Lisbon Valley fault whose surface trace is obscured in the alluvial-filled flats a few hundred feet west of the property. Ore consists of malachite and azurite with some chalcocite in well-cemented conglomeratic sandstone overlying carbonaceous mudstone. Fracture surfaces are coated with copper carbonates. In the surrounding area copper carbonates in sandstone are exposed in road cuts and small surface pits.

Lucky Star

The Lucky Star prospect is on the lower slope of Three Step Hill about one-quarter mile northwest of McIntyre Canyon. No roads lead to the property. Workings include a trench, about 20 feet long, which leads to an adit, about 30 feet long; both trend S. 35° E.

The adit has been driven along a normal fault that dips about 50° NE and strikes S. 35° E. Silicified and conglomeratic sandstone of the upper part of the Burro Canyon Formation (Lower Cretaceous) forms the hanging wall of the fault; reddish-brown sandstone and siltstone of the Salt Wash Member of the Morrison Formation forms the footwall. The broken rock and gouge along the fault is mostly made up of bleached rock of the Salt Wash Member and is generally about 2 feet thick. Beds on either side of the fault dip gently away from the fault. The stratigraphic displacement on the fault here is about 700 feet.

The ore minerals are malachite and azurite and less commonly chalcocite. The ore minerals are confined mainly to fractures in sandstone of the Burro Canyon Formation.

Lucky Strike

The Lucky Strike copper mine lies on the lower part of Three Step Hill near the head of McIntyre Canyon. In 1953 workings consisted of two adits and several surface cuts. About 1955 some of the surface cuts were extended; the upper adit was modified to an open cut; a winze was sunk; and a short sublevel was driven near the northwest end of the lower or main adit.

The main adit is in the Burro Canyon Formation (Early Cretaceous) and parallels to a northwest-trending, steeply northeast dipping normal fault that has displaced the Burro Canyon Formation down against the Salt Wash Member of the Morrison Formation. This fault is a part of the Lisbon Valley fault system and is the southern boundary of McIntyre graben. Northwest of the Lucky Strike mine many small copper prospects, including the Lucky Star and the Woods property, lie along this same fault. Copper minerals also occur sparsely at several localities on the fault southeast of the Lucky Strike mine.

The ore-bearing unit in the Burro Canyon Formation is brown conglomeratic sandstone with interbedded greenish-gray sandstone overlain by brownish-gray limestone. The regional dip of the beds near the mine is southerly to southeasterly, but at the mine the beds dip only 2°-4° NE, possibly due to local drag along the fault.

The major fault is exposed near the portal of the main adit, in the south crosscut, and possibly in the bottom of the winze. The adit explores a zone of minor normal faults which are subparallel to the main fault. Sandstone along the zone of minor faults locally is intensely silicified.

The most conspicuous ore minerals are brochantite and volborthite (or calciovolborthite), which coat fracture surfaces and locally form well-developed crystals. Brochantite is also disseminated in sandstone several feet away from fractured rock. Chalcocite impregnates sandstone near the northeast face of the adit and forms a veinlet in a small fault near the northeast face of the sublevel. Tiny blades of native copper occur locally with brochantite and volborthite.

In the sublevel a dark-gray vanadium mineral, presumably vanadium hydromica, locally impregnates sandstone along bedding planes and irregular joints.

Most of the mineralized sandstone in the main adit and sublevel is anomalously radioactive, and some samples reportedly contain more than 0.1

percent U_3O_8. Commonly, no distinct uranium mineral can be recognized although many samples containing brochantite and volborthite also contain minute grains of a radioactive yellow mineral of the carnotite group. The highest radioactivity measured was of sandstone impregnated with chalcocite without other visible minerals. Probably some uranium occurs as an impurity in copper minerals.

Uranium and vanadium were first noted in these prospects by R. K. Kirkpatrick (Union Mines Development Corp., written commun., 1944). He assumed that the uranium and vanadium were derived from a nearby carnotite deposit in the Salt Wash Member of the Morrison Formation on the footwall side of the fault. The Salt Wash Member close to the Lucky Strike mine is not uraniferous, although a few small carnotite prospects lie about one-half mile to the southeast and also about 1 mile to the southwest. The intimate association of copper, vanadium, and uranium in the Lucky Strike mine suggests that all these metals were deposited from the same mineralizing solution.

Lone Wolf

The Lone Wolf copper prospect is on the northeast side of Lower Lisbon Valley a few hundred feet west of the center of sec. 4, T. 31 S., R. 26 E., San Juan County, Utah. Development consists only of a pit about 5 feet square. The pit explores a northwest-trending, nearly vertical normal fault that separates the Burro Canyon Formation on the southwest side of the fault from the Salt Wash Member of the Morrison Formation on the northeast side.

Malachite, the only copper mineral seen, coats fracture surface and impregnates the sandstone of the Burro Canyon Formation (Lower Cretaceous). The sandstone is very fine grained and firmly cemented with silica. Some malachite on fracture surfaces has been slickensided. Some gypsum occurs in the fault zone within 100 feet of the prospect.

Twin Logs group of claims

The Twin Logs group of claims, also known as the HBC group of claims, are near the head of Lackey Creek on the south slope of South Mountain at an elevation of about 10,000 feet. Access to the property is by jeep trail that connects with Utah 46 about 2.5 miles west of La Sal, Utah.

On the east side of the creek are two open cuts, a shaft about 25 feet deep, two adits, each about 30 or 40 feet long, and one with a winze about 20 feet deep. On the west side of the creek are three small open cuts. All the workings are in a fairly small area about 1,000 feet in diameter.

The bedrock near the prospects east of Lackey Creek is a breccia of igneous rock cemented by quartz and calcite. The igneous rock is so argillized and silicified and in places hematite-stained that the original characteristics of the rock are difficult to determine. According to Hunt, C. B., (1958, pl. 39) the brecciated and altered rock is part of the South Mountain stock that is composed mainly of diorite porphyry of Tertiary age. Sedimentary rocks, questionably assigned to the Cutler Formation of Permian age, crop out a few hundred yards east of the prospects. Monzonite porphyry, containing large phenocrysts of zoned plagioclase in an iron-stained, very fine grained groundmass crops out several hundred feet north of the prospects.

The most abundant and widespread ore minerals are the copper carbonates, malachite and azurite. Much less common though locally dominant are the sulfides chalcocite, bornite, and chalcopyrite. Cuprite, tenorite, and chrysocolla and the copper carbonates are commonly found with the sulfides. Malachite, azurite, and chrysocolla occur generally as a diffuse stain and as disseminated minute grains. The sulfides occur chiefly as grains and irregular modular replacements as much as an inch across and in places as veinlets as much as one-half inch wide.

Most of the copper minerals occur in highly brecciated rock, though a few small pockets of copper sulfides were found in relatively unbrecciated igneous rock in the streambed between the prospects. The brecciated rock commonly contains vugs, which are partly filled with quartz crystals, commonly less than a quarter of an inch long and a sixteenth of an inch in diameter. The tiny quartz crystals are frequently coated with a thin film or, more rarely, small crystals of calcite.

The copper minerals for the most part are clearly later than the brecciation of the host rock. A few specimens contain angular fragments of copper sulfides scattered through a breccia of altered diorite cemented with quartz. These specimens suggest either that some of the brecciation is post-ore, or, as seems more probable, that the copper minerals completely replaced some fragments of the igneous rock.

Silver occurs in small amounts in the Twin Logs ores, but gold, the metal of chief interest in the La Sal Mountains (Hunt, C. B., 1958, p. 356), was not found in the few specimens analyzed. The ores are not radioactive.

Other copper occurrences

The Cutler Formation (Permian) contains several small, low-grade occurrences of copper carbonates, generally not close to faults. Small nodules of malachite occur in a sandstone bed about 1,000 feet south of the Lisbon Valley fault in the NW1/4 sec. 36, T. 29 1/2 S., R. 24 E., San Juan County, Utah. A similar occurrence probably in the same sandstone bed was noted in the SW1/4 of sec. 36. Malachite, yellow-green volborthite(?) and gray vanadium hydromica streak sandstone near the base of the formation along a gully in SW1/4 sec. 20, T. 30 S., R. 25 E., San Juan County, Utah. Copper carbonates and vanadates, sulfates and native copper are sparse to common in the uranium-vanadium deposits in the Cutler Formation along Big Indian Valley.

Isolated occurrences of chalcocite and copper carbonates were observed in the upper part of the Chinle Formation (Late Triassic) in the SE1/4 sec. 24, T. 30 S., R. 24 E. and in the SW1/4 sec. 35, T. 30 S., R. 25 E., San Juan County, Utah. Many uranium deposits in the lower part of Chinle contain sparse copper minerals. Commonly the copper minerals are widely separated small concentrations of the copper sulfides, chalcocite and chalcopyrite. Generally the sulfides have small rims and halos of oxidized copper minerals. At the Standard Big Buck uranium mine native copper occurs both above and below the unconformity between the Chinle Formation and the Cutler Formation, but seems to be mostly concentrated at the top of the Cutler. Generally the copper minerals occur within the uranium ore bodies within the Chinle Formation. The sparsity of the copper minerals compared to the widespread and abundant uranium minerals in these deposits obscures age relations. In the Mi

Vida mine, however, chalcopyrite was both contemporaneous and later than uraninite (Gross, 1956, p. 647; Laverty and Gross, 1956, p. 199.).

Copper minerals have been found in several of the uranium-vanadium mines in the Salt Wash Member of the Morrison Formation of Late Jurassic age in the area south of McIntyre Canyon. The mines containing copper include the Buckhorn, Pinto, Silvertone, and the La Salle Nos. 1 and 2. The Red Devil mine in the Salt Wash Member on the west flank of the La Sal Mountains contains bluish copper minerals that impregnate a silicified and carbonized fossil log.

A few small occurrences of copper minerals are in the Brushy Basin Member of the Morrison Formation along the northeast side of Lower Lisbon Valley. The Mint claims and the North Side mine, prospects for uranium-vanadium ore, are near these occurrences. At the North Side mine the copper minerals are in a conglomerate in the Brushy Basin Member whereas the uranium-vanadium minerals are in sandstone in the Salt Wash Member. At the Mint claims both copper and ruanium-vanadium minerals are in the Brushy Basin, but the copper and uranium-vanadium minerals are not closely associated.

Copper minerals, chiefly malachite and azurite, occur sparsely in sandstone of the Burro Canyon Formation (Early Cretaceous) along or near the Lisbon Valley fault and subsidiary faults. A few of these occurrences have been prospected by pits, trenches, and short adits. An isolated occurrence of copper carbonates and chalcocite(?) was noted in steeply dipping, fractured sandstone of the Burro Canyon in the SE1/4 sec. 31, T. 27 S., R. 24 E., San Juan County, Utah, on the hogback on the west side of South Mountain.

The Dakota Sandstone (Late Cretaceous) frequently contains sparse copper carbonates where it is cut by the Lisbon Valley fault. A few occurrences have been explored by small trenches; these prospects resemble the Lone Wolf and Lone Star prospects.

MANGANESE

Small deposits of manganese minerals occur in sandstone in fractured ground near Muleshoe Wash and near the head of Big Indian Wash, San Juan County, Utah. These deposits were probably first prospected about the turn of the century and were further developed during World Wars I and II. The size of workings and neighboring dumps near Muleshoe Wash suggests that some material may have been shipped from these deposits during the war periods. The only recorded production, however, is a single shipment of ore from mines near Muleshoe Wash to the U.S. General Services Administration in Deming, New Mexico, in 1954. The shipment consisted of 35 long tons (dry weight) of ore averaging 32.1 percent manganese (A. L. Ransome, U.S. Bureau of Mines, 1958, written commun.).

Deposits near Muleshoe Wash

Little can be added to the excellent descriptions of the manganese deposits near Muleshoe Wash given by Baker and others (1952, p. 128-131), who examined these occurrences in 1940. The deposits are all on the southeastern part of Flat Iron Mesa, whose surface is near the top of the Navajo Sandstone. The beds dip gently to the northeast and are cut by several near-vertical, minor faults that make up northwestern part of the Lisbon Valley fault system. Displacements on these faults are less than 20 feet, mostly downward to the northeast. Traces of many of the faults are conspicuous because of the dark-purplish manganese stain in rocks adjacent to the fault planes.

The manganese-stained rock has been prospected by numerous shallow pits and trenches. Most of the workings are in deposits in the W1/2 sec. 19, T. 28 S., R. 23 E. and the E1/2 of sec. 24, T. 28 S., R. 22 E., San Juan County, Utah, and probably these deposits, known as the Black Beauty group of claims, yielded the ore shipped in 1954. The workings consist of several bulldozed trenches and short adits and a shaft, estimated to be about 20 feet deep. Most of the ore is in irregular blanket-like pods, a few tens to a few hundreds of feet across and less than a foot thick, adjacent to the faults. Some manganese ore is in small veins and groups of veins a few inches to about a few feet wide, along faults and paralleling joints. The ore consists of purplish-black and brownish-black oxides, chiefly pyrolusite with admixed limonite, and veinlets and crusts of calcite. The manganese oxides fill open spaces along the faults and joints; in the blanket-like pods they are mostly interstitial, but in part, replace sand grains. The bulk of the mineralized material is in light-colored, crossbedded quartzose sandstone of the lower member of the Entrada Sandstone of Late Jurassic age, immediately above the detrital chert that marks the unconformity separating the Entrada from the underlying Navajo Sandstone of Late Triassic(?) and Jurassic age. The two formations are here nearly lithologically identical. The faults and the unconformity rather than the lithologic details seem to be the principal controlling factors in the shape of the deposits. Along most of the faults the manganese stain dies out within 10 to 20 feet below the top of the Navajo Sandstone. Some thin blanket-like pods of manganese minerals impregnate a limestone bed near the top of the Navajo in the NW1/4 of sec. 30, T. 28 S., R. 23 E; these occurrences, which are more than 0.5 mile from the nearest fault, are smaller and lower in grade than the deposits on the Black Beauty claims.

More detailed descriptions of these deposits are published in Baker and others (1952, p. 128-131).

Deposits near Big Indian Wash

Two manganese prospects are on either side and within 10 feet of the Lisbon Valley fault in the northwest end of Big Indian Valley. The Locus No. 1 prospect is in sec. 35, T. 29 S., R. 24 E. on the hanging wall side of the fault in quartzose sandstone of the Burro Canyon Formation (Early Cretaceous). The other unnamed(?) prospect is about 500 feet southeast of the Locus No. 1 on the footwall side of the fault in arkosic sandstone of the Cutler Formation (Permian).

Shallow pits have exposed most of the mineralized rock in both deposits. The deposits are each about 10 feet in diameter and about 5 feet thick. Neither deposit extends to the fault. Manganese oxides fill the voids between sand grains of the mineralized rock, which even in selected hand samples probably contains less than 15 perctent manganese. Some limonite and calcite occurs with the manganese minerals.

Comparisons and origin

The manganese deposits of the Lisbon Valley area are much alike, though they occur in host rocks of widely different ages. They are in unaltered sandstone and with few exceptions close to one of the faults of the Lisbon Valley fault system. Their similarity suggests that all these deposits are due to a single time and process of mineralization.

The manganese deposits in the Lisbon Valley area resemble the copper deposits and, to a lesser extent, the uranium-vanadium deposits in the area. They all commonly occur in sandstone; the host rocks, except for the addition of ore minerals, are relatively unaltered, and introduced gangue minerals are sparse. The manganese deposits resemble the copper deposits in their close association with faults, but differ in this respect from the uranium-vanadium deposits. Though most of the manganese ore is in tabular bodies, similar to many ore bodies in the copper and uranium-vanadium deposits, some manganese ore has a distinctive vein-like habit. Carbonaceous material, a common constituent of many copper deposits and most uranium-vanadium deposits, is lacking in the rocks containing the manganese ores. All the ores--manganese, copper, and uranium-vanadium--seem to have been deposited from relatively low temperature solutions. They are probably all related to a similar, possibly to the same, mineralizing process.

The relative ages of the different kinds of deposits may be hypothesized from their relations to the Lisbon Valley fault system. Thus, the Rattlesnake uranium-vanadium deposit is cut by a fault and is not elongated along it. The Big Indian and Blackbird copper deposits are elongated along the faults and are clearly mostly post-fault deposits, although a little copper ore is brecciated near the faults. Many of the manganese deposits on Flat Iron Mesa are vein accumulations along faults and the ore is not brecciated. These relations suggest that the uranium-vanadium deposits are oldest, the copper deposits somewhat younger and the manganese deposits the youngest.

The association of the manganese deposits with the Lisbon Valley fault system suggests that these deposits are all interrelated. The stratigraphic range of the deposits implies that they are not syngenetic. We are inclined to view these deposits as a late stage in the mineralization of the area. They were apparently deposited from relatively cool water circulating along the Lisbon Valley fault system, probably normal ground-water contaminated with manganese perhaps derived from ascending solutions similar to those inferred for the copper deposits in the area. The localization of the deposits mainly in the lower member of the Entrada Sandstone and in the Navajo Sandstone is not easily explained, for these units are rarely ore bearing elsewhere on the Colorado Plateau. Baker and others (1952, p. 129) thought that the character of the ore near Muleshoe Wash suggested a surficial deposit formed at the outcrop by evaporation of manganese-bearing solutions.

Suggestions for prospecting

All the manganese deposits in the Lisbon Valley area are small, and there is little point in looking for more deposits of this size. Though some activity at these deposits is to be expected in times of high manganese prices, deposits in the Little Grand district near Green River, Utah, about 40 miles northwest of Moab offer more opportunities for small-scale manganese production (Baker and others, 1952, p. 77-118; Bowman, 1960).

GOLD

Prior to World War I gold was mined from quartz veins in igneous rock and placer deposits in tills and gravels in the northern La Sal Mountains, a few miles north of the Lisbon Valley area (Hill, 1913; Hunt, C. B., 1958, p. 355-359). The quartz veins are most abundant in sheeted zones around the North La Sal stock and in fissures in the stock. Copper minerals and pyrite are the most abundant ore minerals. The gold is probably mostly in the pyrite (Hunt, C. B., 1958, p. 356). The deposits described by Hill and Hunt are similar to the copper deposits of South Mountains, but spectrographic analyses of specimens of the South Mountain ores revealed no gold. Caved adits in pyritized diorite porphyry on the north side of Gold Basin in the Middle Mountain group of intrusions are said to be prospects for gold, but there is no record of any gold production from within the Lisbon Valley area.

Most of the gold production, whose total value Hill estimated to be less than $5,000, was from the placer mines. Comparison of the locations of the placer mines shown by Hill (1913, p. 107) with the map of the surficial deposits by Richmond (1955) shows that most mines were in till of pre-Wisconsin age. These auriferous tills were derived from the central part of the North Mountain group and lie on Wilson and Bald Mesas, several miles west of their source area. Hunt also reported a few gold prospects in younger outwash and till on the north side of the mountains.

The gold in the placers occurs as small wires or flakes and probably in sulfides in quartz stringers in fragments of porphyry. The free gold is not much waterworn and apparently is disseminated throughout the older till. The placer ores were difficult to process, in part because there is little water for sluicing on the mesa tops. Only the free gold was recovered; gold in the quartz stringers in the porphyry fragments was lost.

Some older till lying along the north boundary of the Lisbon Valley area north of Mill Creek is probably derived from the North Mountain group and offers opportunities for gold prospecting similar to those of Wilson and Bald Mesas. Most older tills in the Lisbon Valley area, however, are derived from the Middle and South Mountain groups of the La Sals, which are apparently less metalliferous than the North Mountain group.

NONMETALLIC DEPOSITS

Because the Lisbon Valley area is far from large industrial markets, interest in the nonmetallic deposits has been centered on those that can be used locally. Road building is the main enterprise requiring significant amounts of nonmetallic material. Other than road-metal, nonmetallic materials in the area that may be of future interest include limestone, building stone, barite, and potash. Of these, only potash shows promise of being utilized on a large scale.

Gravel and sand

Most borrow pits in the area are in younger gravels close to main roads. large quarries are near the Moab airport, near the junction of the Lisbon Valley road and Utah 46, and near U.S. 160 south of Church Rock.

Most of the material shown as younger gravel on the geologic maps is probably suitable--after screening--for road building. Promising localities for future gravel quarries are in Spanish Valley and on the fan of South Mountain near La Sal. Gravels are not present in the southeastern part of the Lisbon Valley area, and are thin and patchy in the southwestern part of the area. Some deposits of older gravel, older rubble, and older moraine are probably suitable as road metal, but most of these deposits are far from good roads.

Thin deposits of sand are widespread in the area, but they contain much silt and clay, and generally are unsuitable for construction purposes. Fairly pure sands are in old dunes near cliffs of Navajo Sandstone in eastern Spanish Valley and near cliffs of Entrada Sandstone in Dry Valley. These dune sands are well sorted, fine to very fine grained, and fairly free of silt and clay.

Limestone

In the Lisbon Valley area limestone occurs in many formations and is abundant in the lower part of the upper member of the Hermosa Formation. Limestone also occurs in thin lenses in the Cutler Formation, Navajo Sandstone, Summerville Formation, Morrison Formation, Burro Canyon Formation, and Mancos Shale; in these formations the limestone is commonly silty or sandy and may be partly silicified. On the west side of Peters Canyon a few small pits in a clayey limestone bed, about 1 foot thick, at the top of the Summerville suggests an attempt to develop a local source of lime. Limestone of the Hermosa Formation offer more commercial potential, for some fairly pure limestone units, more than 30 feet thick, are accessible on dip slopes on the southwest flank of the Lisbon Valley anticline. However, limestone of the Lisbon Valley area is not likely to be developed before exploitation of similar Paleozoic limestone close to U.S. Highway 160 near Moab (Baker, 1933, pl. 1).

Building stone

Building stone has been used only for a few rude huts in the Lisbon Valley area. In Moab a few old buildings were partly built of roughly trimmed rock apparently quarried from the Kayenta Formation. Beds in the Kayenta probably are one of the most easily worked rocks in the area, but the mudstone pellets common in these sandstone beds detract from the appearance and durability of the stone. Gray silicified sandstone in the Burro Canyon Formation north of the Rattlesnake mine is probably the most durable rock in the area, but it is not consistent in lithologic character and thickness for more than a few hundred feet.

Clays

No clay deposits in this area have been utilized, although several formations have a high clay content. Most of the clay-bearing rocks contain a large proportion of silt and commonly an admixture of very fine sand; units of nearly pure claystone are rare. The purest clay-stone noted in the area is in seams, a few inches thick, of tan plastic clay underlying coal beds in the Dakota Sandstone, as in the Blackbird copper mine. Thick seams of this type of claystone were not found.

Barite

Thin veins, a few inches thick and a few tens to a few hundreds of feet long, of white, fibrous barite are common along northwest-trending joints and faults in the Glen Canyon Group on the hill between the Woods copper property and the Blackbird copper mine in Lower Lisbon Valley. As presently known these veins do not contain significant reserves of barite.

Potash

Potash has been considered a potential resource of eastern Utah since 1924, when potassium salts were recognized in samples from a well on the Salt Valley anticline near Crescent Junction, Utah, about 30 miles north of Moab (Lang, 1926, p. 38-39). Subsequent drilling by private companies and by the Government found potassium salts in other localities near Moab and Crescent on the Salt Valley anticline and on other salt anticlines in the Paradox basin (Dane, 1935, p. 175-176; Dyer, 1945). The first mining of potash deposits in the Paradox basin was begun in early 1965 by the Texas Gulf Sulphur Company on the Cane Creek salt anticline about 7 miles southwest of Moab (Merritt, 1966).

The presence of potash deposits on the Lisbon Valley salt anticline was established by potash exploration drilling program of the Superior Oil Company in 1958 and 1959 on the southwest flank of the anticline (Hite, 1963, p. 519-520).

The potash deposits are interstratified with salt in the Paradox Member of the Hermosa Formation of Pennsylvanian age. The Paradox Member was deposited in a subsiding shallow basin that was restricted by tectonic, sedimentary, and dynamic barriers (Wengerd and Strickland, 1954, p. 2186; Herman and Barkell, 1957, p. 868-869). Deposition of potassium salts was confined to the deep and dessicated part of the basin.

According to Hite and Gere (1958, p. 224) the mineralogy of the Paradox basin salt deposits is relatively simple. The chief minerals of the potash deposits of the Paradox basin are sylvite (KCl) and carnallite ($MgCl_2KCl.6H_2O$). Only sylvite forms beds of economic significance. The Paradox sylvite is commonly milky white to colorless and occurs as crystalline intergrowths with halite in a unit near the top of the halite unit in a cyclothem.

The Lisbon Valley area is near the center of the potash deposition in the Paradox basin and the chances of finding mineable potash deposits along salt-cored structures appear good. Here as elsewhere in the basin, the economics of mining depend not only on thickness, grade, and depth, but also on the effects of deformation and salt flowage on the potash deposits. In this area subsurface deformation is probably greatest near Lisbon Valley and in Spanish Valley and may generally be expected to decrease away from these localities.

FUELS

Oil and gas

The search for oil in southeastern Utah began before the turn of the century (Lupton, 1914), but except for temporary production of oil from the Rico Formation of Permian age near Mexican Hat (Woodruff, 1912) no commercial discovery of oil or gas was made in southeastern Utah till after World War II. Drilling activity in and near the Lisbon Valley area prior to 1930 is reviewed briefly by Baker (1933, p. 80-83, 85-92). Most of the early wells were located on anticlinal structures underlain by thickened salt of the Paradox Member of the Hermosa Formation (Pennsylvanian). Many of these wells penetrated oil-stained rock in the basal part of the upper member and in the Paradox Member of the Hermosa Formation. Among these wells was the Union Oil Co. No. 1 Utah State drilled in 1927 near the crest of the Lisbon Valley anticline in sec. 16, T. 30 S., R. 25 E. The driller's log of this well noted a show of oil in sandstone and several pockets of gas in shale in the Paradox Member (Baker, 1933, p. 92).

In 1954 discovery of oil in the Paradox Member of the Hermosa in the Desert Creek field, about 60 miles south of the Lisbon Valley area (Lauth, 1958), stimulated exploration throughout the Paradox basin. By 1960 several major new fields in the Hermosa Formation had been established in southeastern Utah (Intermountain Assoc. Petroleum Geologists, 1958, p. 230-289).

In 1957 the Pure Oil Co. No. 1 Big Flat well, about 20 miles northwest of the Lisbon Valley area, confirmed the presence of commercial amounts of oil in beds of Mississippian age and gave renewed impetus to deep drilling in the Paradox basin (Carlton, 1958; Parker, 1960).

Oil and gas in commercial quantities were discovered in the Lisbon Valley area in late 1959. The following notes are drawn mainly from Budd (1960, 1961), Preston and Campbell (1960) and Kunkel and Schick (1963). The discovery well, the Pure Oil Co. No. 1 U.S.A. (earlier known as the Northwest Lisbon No. 1) is on the southwest flank of the Lisbon Valley anticline in the NW1/4, sec. 10, T. 30 S., R. 24 E. The well was completed in Devonian rocks on January 5, 1960, with an initial flow potential of 586 barrels of oil per day. This is the first well in Utah to yield commercial amounts of oil from rocks of Devonian age. On drill stem tests the well produced oil and gas from limestone and dolomite of Mississippian and Devonian age and from sandstone of Devonian age. The carbonates mainly yielded gas; the sandstone yielded 44° gravity oil with a 65° pour point. The petroleum trap is a combination of structure and stratigraphy--an exceptionally porous section on a subsurface faulted structural high that lies southwest of the surface trace of the axis of the Lisbon Valley salt anticline.

As of early 1962 eighteen wells had been completed in the area of the Pure Oil Company No. 1A discovery well. This area is generally known as the Northwest Lisbon or the Lisbon field. Nine of the wells produce from Mississippian carbonates, three from Mississippian carbonates and Devonian sandstone; two from Mississippian and Devonian carbonates; one from the Paradox Member of the Hermosa Formation, and three are dry holes (Kunkel and Schick 1963, p. 437). In addition, the Pure Oil Company No. 1 USA-Big Indian well, about 2 miles north of the Northwest Lisbon field, and the Pubco 2-21-F

Federal well, about 3 miles southeast of the Northwest Lisbon field, produce gas from Mississippian carbonates and probably were new field discoveries rather than extensions of the Northwest Lisbon field.

Another new field, the McIntyre Canyon or Southeast Lisbon field, was discovered in 1960 by the Pure Oil Co. on the north side of McIntyre graben. The discovery well is the SE Lisbon-U.S.A. No. 1 well in the NW1/4, sec. 5, T. 44 N., R. 19 W., San Miguel County, Colorado, less than a mile east of the Lisbon Valley area (Four Corners Geol. Soc., 1960, p. 153). The well flowed 605 thousand cubic feet per day from rocks of Mississippian age. Several offset wells are believed to have extended this gas field within the Lisbon Valley area in late 1960.

The wells presently drilled in and near the Lisbon Valley area show that oil and gas are to be found in porous Devonian and Mississippian beds on subsurface structural highs near salt anticlines. Oil shows have also been noted in carbonates of Cambrian age (Parker, 1961, p. 173). The extent of the potentially oil- and gas-bearing units in the region and details of the subsurface structural highs are not fully understood. Neff (1960) suggested that all the salt anticlines are bounded on one or both sides by subsurface structural highs in Mississippian rocks.

Future deep tests of the pre-Pennsylvanian rocks will probably be along the flanks of the Lisbon Valley anticline and the McIntyre graben in the central and eastern parts of the area. The thickened roll of salt underlying Spanish Valley and extending southeastward to Pine Ridge may offer similar exploration possibilities. The latter salt roll is intruded by the South Mountain group of the La Sal Mountain intrusions, but Heylmun (1960) emphasized that the metamorphic effects by the laccolithic-type intrusions are small and do not preclude the possibility of commercial amounts of oil in the intruded rocks. Hunt, C. B., (1942) pointed out that the domes over igneous stocks may form post-intrusive structural traps for oil and gas.

Many shows of oil and gas have been reported from wells in the Hermosa Formation in and near the Lisbon Valley area, but production has been small. Oil and gas have been produced from the Paradox Member of the Hermosa in the Northwest Lisbon field (Budd, 1961; Kunkel and Schick, 1963, p. 437) and in the Big Flat field, about 20 miles northwest of the Lisbon Valley area (Parker, 1960). Hite (1960) reported that many shows of oil and gas are in shale-anhydrite marker beds in the saline facies of the Paradox Member. As these beds have an inherently low permeability, sustained production of oil and gas most likely will be found only in fractured zones in the salt anticlines. Hite also pointed out that limestone beds peripheral to cyclothemic salt beds probably contain organic buildups similar to the reef-like character of productive limestone beds in extreme southeastern Utah.

Formations younger than the Hermosa Formation in the Lisbon Valley area are mostly continental deposits and are unlikely source rocks for petroleum. Oil-stained sandstone has been recovered from several test holes for uranium in the Morrison Formation in several holes on the northwest side of the Lisbon Valley fault and one hole about a mile southeast of the Rattlesnake mine in the upper part of the Morrison or lower part of the Burro Canyon Formation had a strong flow of combustible gas and water with a small amount of tar-like substance. This gas and petroliferous material probably migrated along faults from deeply buried marine Paleozoic rocks into the younger rocks. Some Tertiary structures, however, as for example the Lisbon Canyon anticline, may provide structural traps for oil and gas in Mesozoic rocks.

Coal

A lens of bituminous coal, more than 30 feet long and as much as 7 feet thick, in the Dakota Sandstone of Late Cretaceous age, is exposed in the underground workings of the Blackbird copper mine. The coal is bony, commonly coated with copper sulfates, and highly fractured. Coal from this copper mine is said to have been used by local ranchers in Lower Lisbon Valley, but because of its impurities and fracturing this coal is unsuitable as a general purpose fuel.

A thin coal bed in the lower part of the Dakota Sandstone was noted on the west side of South Canyon Point and on Middle Mesa near Bullhorn Wash. At these localities the impure coal is about a foot thick and grades into carbonaceous shale. Coal has been mined from the Dakota Sandstone nearby in southwestern Colorado (Landis, 1959, p. 154-157) and southeastern Utah (Gregory, 1938, p. 110-111) but no potentially commercial deposits of coal are inferred for the Dakota in the Lisbon Valley area. Although other formations in the area locally contain abundant carbonaceous material, none contain layers of coal.

WATER

Water is an important commodity in the Lisbon Valley area. The lack of large dependable supplies of potable water is an important factor in controlling settlement of the area. Mill Creek and Pack Creek have continuous though greatly variable flow throughout the year. Records of discharges of these streams at gaged sites are given by Sumsion (1971, p. 16-18). Pack Creek is diverted by ditch to irrigated fields north of the Grand County Airport so that the creek bed near the edge of the mapped area is dry except during infrequent heavy rains. Many of the minor streams heading in the La Sal Mountains, such as Brumley Creek, have continuous flow except in the driest of summers and are a significant source of water for stock grazing on the mountain slopes.

Springs are not numerous in the Lisbon Valley area outside of the La Sal Mountains. Most of the springs in the mesa lands are intermittent and discharge ground water from the saturated sandstone at or near the base of the Burro Canyon Formation. Lisbon Spring in Lisbon Canyon, an important source of potable water in the southeastern part of the Lisbon Valley area, is partly a spring of this type, but the discharge here is increased by flow along a minor fault and associated fractured rock. Minor springs were also noted during mapping of mesa rims in the Entrada Sandstone and the Salt Wash Member of the Morrison Formation along mesa rims and more rarely in sandstones of the Glen Canyon Group in canyons in the western part of the area. In the La Sal Mountains springs are numerous; the larger springs are in sandstone units of Mesozoic age.

Groundwater has been little utilized in the Lisbon Valley area. Some stock-watering ponds and mining camps in the southern part of the area are supplied by wells in the Entrada and Navajo Sandstones. Some mining camps and ranches north of Lisbon Valley and south of La Sal are supplied by wells in sandstone beds of the Burro Canyon Formation. Artesian water supplied by large recharge areas in the La Sal Mountains can be expected in all permeable beds, especially the surficial units and the Burro Canyon Formation, on the southwest and west flanks of the South Mountain group of intrusives. The most economically significant ground-water resources of the area are probably those of Spanaish Valley (Sumsion, 1971).

The principal aquifer here is the Quaternary unconsolidated valley fill, which averages about 70 feet in thickness and attains a maximum thickness of about 360 feet. Fractured fine-grained sandstone of the Wingate and Navajo Sandstones on the east side of Spanish Valley are also locally important aquifers (Sumsion, 1971, p. 13-14).

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