GEOLOGIC MAP OF THE HATCH ROCK QUADRANGLE, SAN JUAN COUNTY, UTAH

By Gordon W. Weir, Chester L. Dodson, and Willard P. Puffet

STRATIGRAPHY

HOLOCENE AND PLEISTOCENE

Lowland eolian and alluvial sand and silt

These deposits are chiefly yellowish-gray to light- and moderate-brown, very fine to fine-grained sand and minor silt. They are mostly derived from the Navajo and Entrada Sandstones, though in the southern part of the quadrangle they include much silt derived from upland deposits. The silty sand is unconsolidated in wind- and water-worked thin sheets, generally less than 10 ft (3 m) thick, that mantle much of the Entrada Sandstone in Dry Valley and form many small patches on the irregular slopes of the Morrison Formation and landslide deposits; it intergrades with alluvium of Hatch Wash and its tributaries. It forms a few small inactive dunes and ramps against cliffs, as much as 20 ft (6 m) high, in the southwestern part of the quadrangle. Patches of silty sand on the Navajo Sandstone are generally not mapped. Along Hatch Wash and its tributaries the alluvium is commonly poorly sorted and contains rare to abundant pebbles derived from the Dakota, Burro Canyon, and Morrison Formations and igneous rocks from the Abajo Mountains, about 6 mi (10 km) southwest of the quadrangle. It is in part crudely stratified and weakly consolidated and probably attains a thickness of 50 ft (15 m) in Hatch Wash.

Upland eolian and alluvial silt and sand

Dark-red to moderate-brown, unconsolidated, very fine sand and silt in structureless thin patches, probably not more than 10 ft (3 m) thick, rest on the Dakota Sandstone on Peters Point and South Canyon Point. The bulk of the material is loess, which covers extensive tracts south and southeast of this quadrangle and forms some of the prime agricultural land of southeastern Utah; the loess was derived from Permian to Jurassic red rocks in desert lands to the west and southwest, probably in the Pleistocene (Huff and Lesure, 1965, p. 44). As is true of other Quaternary deposits in the quadrangle, the material is reworked during torrential rains characteristic of summers in this area. In places much sand derived from the Dakota Sandstone is incorporated in the deposits.

Gravel

On terraces along major streams are irregular deposits composed mostly of pebbles and cobbles of resistant sandstone and chert derived from Upper Jurassic and Cretaceous formations and of diorite porphyry from Tertiary intrusives of the Abajo Mountains. Pebbles of igneous rocks are abundant in gravels near the head of Peters Canyon and Harts Draw; they are less common in the gravels along Hatch Wash and are absent in the gravels along East Canyon Wash. Some deposits near South Canyon Point contain blocks of mudstone, as much as 4 ft (1.2 m) across, derived from the Morrison Formation, probably by reworking of nearby landslide deposits. Most gravels are partly consolidated by the binding of interstitial clay and by caliche, which locally forms a layer several centimeters thick at the basal contact. Caliche fragments and caliche-coated pebbles in the gravels indicate reworking of older deposits. The gravels are as much as 40 ft (12 m) thick. They locally overlap landslide deposits in Peters Canyon and are commonly overlain by thin sheets of eolian and alluvial sand and silt. Although some gravel deposits rest on modern floodplains, most are perched 20–100 ft (6–30 m) above present-day streams and were apparently deposited during periods of greater rainfall in the late Pleistocene.

Landslide deposits

These deposits are irregular hummocky, patchy sheets of mass-moved material made up largely of blocks of sandstone derived from the Burro Canyon Formation and the Dakota Sandstone in a matrix of mudstone of the Brushy Basin Member of the Morrison Formation. They include talus below cliffs near heads of landslides. The deposits, probably as much as 100 ft (30 m) thick, cover the base of the Burro Canyon Formation, much of the Morrison Formation, and locally part of the Entrada Sandstone. Some landslides on north-facing slopes appear fresh and possibly intermittently active, but most landslides belong to a cycle of erosion older than the present. They are cut by modern gullies and locally are so eroded, especially near their toes, that the mudstone matrix is removed and only a rubble of sandstone blocks remain. Most landslide deposits were probably formed in the late Pleistocene.

Talus

On the southwest prong of Rone Bailey Mesa is a cone-shaped mass of blocks and sand from the Slick Rock Member of the Entrada Sandstone. The mass is about 350 ft (105 m) wide, probably as much as 30 ft (9 m) thick and extends about 300 ft (100 m) from base to apex. Elsewhere, talus derived from the Wingate Sandstone is common in patches, too small to show at map scale, on the upper part of the Chinle Formation. Talus from cliffs of the Dakota Sandstone and Burro Canyon Formation is included in the mapped landslide deposits.

PLIOCENE(?)

Old rubble

Scattered heaps of blocks of resistant rocks lie at several levels in places northwest of Lightning Draw and west of Hatch Wash.

Rubble around VABM Bailey on a western point of Rone Bailey Mesa is composed of large blocks, as much as 30 ft (9 m) across, of silicified sandstone from the Burro Canyon Formation and brown conglomeratic sandstone from the Dakota Sandstone mixed with red and bluish-green mudstone from the Brushy Basin Member of the Morrison Formation. The lower part of the rubble is cemented with caliche. This heap is about 250 ft (75 m) across and 30 ft (9 m) thick and rests on a sandstone bed of the Salt Wash Member of the Morrison, about 200 ft (60 m) above the base of the formation at an elevation of 6,620 ft (2,018 m).

On the northwest side of Rone Bailey Mesa is a talus-like, double fan-shaped deposit about 1,200 ft (365 m) wide near the base at an elevation of about 6,070 ft (1,850 m). It is composed mainly of blocks, as much as 6 ft (2 m) across, of gray silicified sandstone from the Burro Canyon Formation, some reddish-gray chert from the Morrison Formation, and dark-brown sandstone probably from the Dakota Sandstone. It rests on a steep (30°) slope cut on the Slick Rock Member of the Entrada Sandstone and apparently was derived from landslide material that once covered Rone Bailey Mesa.

Heaps of rubble, ranging from about 250 to 1,000 ft (75 to 300 m) in length and from about 10 to 30 ft (3 to 9 m) in maximum thickness, are widely scattered on a northeastward-sloping surface cut near the top of the Dewey Bridge Member of the Entrada Sandstone. The surface ranges in elevation from about 5,900 to 6,120 ft (1,800 to 1,865 m), roughly 250 ft (75 m) above nearby Hatch Wash. The material in these low-level rubble deposits is similar to that on the mesa but the largest blocks are smaller, and the deposits include blocks of sandstone from the Salt Wash Member as well as reddish-gray and gray chert from the Tidwell Member of the Morrison Formation. The base of these heaps of rubble is characterized by a layer of caliche as much as 3 ft (1 m) thick.

The deposits of the old rubble are apparently remnants of landslide material that came from cliffs of Cretaceous rocks and slopes of Morrison Formation that were close to Rone Bailey Mesa. The Cretaceous cliffs and Morrison slopes have since retreated about 11 mi (18 km) to the southeast of the mesa. The age of the old rubble is not fixed, but it is probably Tertiary because the deposits appear geomorphically distinct from deposits of Quaternary age.

UPPER CRETACEOUS

Dakota Sandstone

The formation consists of grayish-orange to dark-yellow-brown sandstone, composed chiefly of poorly sorted, subrounded medium grains of quartz. The sandstone contains wispy partings of mudstone and rare to abundant streaks and pockets of dark-gray to black and light-gray to white chert and quartzite pebbles, which average about 0.4 in. (1 cm) but are as much as 3 in. (7.6 cm) in diameter. Most sandstone and conglomerate is in small to medium planar and trough sets of low- to high-angle crossbeds. Some layers of fine-grained sandstone are in planar beds. Iron-stained impressions of plant fragments are common. Mudstone is medium gray to black and generally carbonaceous. The mudstone rarely crops out but appears to be more common in the upper part of the formation. The Dakota attains a maximum thickness of about 180 ft (55 m) on the northern part of South Canyon Point where the overlying Mancos Shale has been stripped away. This is probably near the true maximum thickness of the formation, because in the Montezuma Canyon area, a short distance south of this quadrangle where the overlying Mancos is present, the greatest thickness of the Dakota is 180 ft (55 m, Huff and Lesure, 1965, p. 35).

The base of the Dakota is a regional unconformity characterized by small- to large-scale channeling into the underlying Burro Canyon Formation (Carter, 1957). Local relief is as much as 30 ft (10 m) along 1,000 ft (305 m) of the contact. This contact is generally marked by a basal conglomerate containing large chert pebbles and large pebbles and angular clasts of sandstone, quartzite, conglomerate, white chert, and greenish-gray mudstone from the underlying Burro Canyon Formation. The basal conglomerate is commonly 1–3 ft (30 cm–1 m) thick but is as much as 10 ft (3 m) thick in channels. The conglomerate is well cemented and in many places forms a ledge overhanging bleached, friable sandstone at the top of the Burro Canyon. On the east side of South Canyon Point the basal conglomerate is locally missing, and the basal contact is obscure because of parallelism of bedding and lithologic similarity of sandstone units. In conformance with the regional stratigraphy of the Dakota Sandstone (Peterson and Ryder, 1975, p. 171), the lithologies and sedimentary structures in the Dakota of this quadrangle suggest a transition upward through the formation from deposition in continental, dominantly fluvial, environments to shallow marine environments.

LOWER CRETACEOUS

Burro Canyon Formation

The Burro Canyon Formation consists of sandstone and conglomerate, and lesser mudstone, locally containing nodules and thin beds of limestone. The sandstone and conglomerate are light yellowish brown to light gray and weather slightly darker. The sandstone shows wide ranges in grain size, sorting, and cementation, but much of it consists of medium-grained, moderately sorted, subrounded to subangular clear quartz, colored chert, and white feldspar firmly cemented by silica. Conglomeratic sandstone and conglomerate contain black, brown, red, and grayish-green subangular to rounded pebbles, averaging about 0.5 in. (1.2 cm) but as much as 3 in. (8 cm) in diameter. The pebbles are mostly chert (some containing fragments of Paleozoic bryozoans and corals) and lesser fine-grained sedimentary rocks; locally common are small pebbles of white, weathered feldspar, and green mudstone. Sandstone and conglomerate intergrade laterally and vertically, though in many sections conglomerate is present only at the base of thick sandstone lenses. Most sandstone and conglomerate is in long, thin trough sets of low-angle cross laminae that dip northeasterly. Parting lineation (vague, roughly parallel, low ridges of sand grains) is common on planar beds and ranges generally from N. 30° E. to S. 70° E. Lenses of sandstone and conglomerate in the upper part of the formation are commonly silicified. Mudstone in the Burro Canyon is mostly bright grayish green, grayish brown, and grayish purplish red. Rare lenses, commonly 1 to 3 in. (2.5 to 8 cm) thick and more than 100 ft (30 m) long, of very fine grained limestone are interbedded with the mudstone.

The lower contact of the formation is covered by talus and landslide deposits in this quadrangle. In adjacent areas the contact appears conformable; the rock types of the Morrison and Burro Canyon appear to intergrade and intertongue. Because of poor exposures the thickness of the Burro Canyon in this quadrangle is uncertain; it probably ranges from about 100 to 150 ft (30 to 45 m).

The cross-stratified sandstone and conglomerate of the Burro Canyon Formation were derived from a southerly or southeasterly source and were deposited by meandering or sinuous streams in a warm and relatively wet environment; the mudstone represents mainly overbank deposits; the rare limestone probably represents ephemeral fresh water lakes (Craig, 1981, p. 198–200). The Burro Canyon and the lower part of the overlying Dakota Sandstone form a cliff more than 100 ft (30 m) high that rims the upland along the south edge of the quadrangle.

UPPER JURASSIC

Morrison Formation

The Morrison Formation in this region is divided into three members in descending order, the Brushy Basin, Salt Wash, and Tidwell.

Brushy Basin Member

The Brushy Basin Member is variegated mudstone and minor sandstone, conglomeratic sandstone, and limestone. The mudstone is grayish red, light to medium gray, and less commonly greenish gray. Swelling clays make up a large part of the mudstone and give weathered surfaces a fluffy texture. Some mudstone is silty and very fine sandy. The clay minerals are chiefly montmorillonite and montmorillonite-hydromica mixtures (Craig and Cadigan, 1958, p. 191). The mudstone is in obscure beds, mostly 0.5–4 in. (1.2–10 cm) thick, but generally lacks fissility. Sandstone is dark brown to brownish red, fine grained to silty, in thin lensing planar beds, mostly in the upper part of the member. A few lenses of sandstone are fine to medium grained and characterized by small-scale trough sets of easterly dipping cross laminae. Light-brown to pinkish-gray, very fine grained limestone, in beds less than 1 ft (30 cm) thick, is rare but locally conspicuous. The Brushy Basin forms a gentle to steep slope below cliffs of Cretaceous rock and is almost wholly covered by landslide deposits in this quadrangle.

A zone of lenses of dark-brown-weathering conglomeratic sandstone lies at the base of the Brushy Basin Member. The rock is similar to sandstone in the Salt Wash Member but contains sparse to abundant granules and small pebbles, generally less than 0.3 in. (8 mm) in diameter, of gray, black, red, orange, and green chert. The conglomeratic sandstone is mostly in small-scale trough sets of high-angle, easterly dipping crossbeds. Some conglomeratic units grade laterally to fine-grained sandstone in obscure planar beds. Individual lenses in this zone are as much as 50 ft (15 m) thick and 500 ft (150 m) long. Most lenses are much smaller and are irregularly stratified in a zone as much as 60 ft (18 m) thick. Placing the member contact at the base of the zone of conglomeratic sandstone follows the practice of Craig and others (1955, p. 156). In nearby areas workers have included the conglomeratic sandstone and underlying mudstone in the Brushy Basin, thus placing the member contact at the top of the highest persistent sandstone ledge characteristic of the Salt Wash Member (Huff and Lesure, 1965, p. 27; Shawe and others, 1968 p. A66–A67). More recently, Peterson (1988, p. 45–46) included similar conglomeratic sandstone in the Salt Wash Member.

No complete section of the Brushy Basin is exposed in the quadrangle, but judging by topography the member is 300–350 ft (90–105 m) thick. The Brushy Basin sediments were deposited mostly in mudflat and lacustrine environments and in part in fluvial and overbank floodplain environments (Peterson, 1988, p. 46).

Salt Wash Member

The Salt Wash Member consists of sandstone and mudstone. The sandstone, generally dominant, is mostly very pale orange; it weathers grayish orange to light brown. It is commonly medium grained and moderately sorted, but it ranges from silty and fine grained to conglomeratic. It is composed chiefly of subangular to subrounded, clear quartz with admixtures of fine and medium grains of gray and orange to brown chert, colorless feldspar, dull white material, and green mudstone. Conglomeratic sandstone, most common at the base of lenses of sandstone near the top and bottom of the member, contains stringers and irregular pockets of granules and small pebbles of black, gray, and reddish-brown chert and green mudstone. The sandstone generally is firmly cemented by calcite and interstitial clay. It is dominantly in trough sets of high-angle crossbeds that for the most part dip easterly. Planar beds are also common; many show east-trending parting lineations. The sandstone is mostly in irregular, ledge-forming, compound lenses that commonly range from about 20–50 ft (6–15 m) in thickness and from about 400–1,000 ft (120–300 m) in length along the outcrop. Compound lenses of sandstone near the top of the member are most persistent; some are as much as 100 ft (30 m) thick and appear to be continuous for at least 2–4 mi (3–6 km).

Mudstone in the Salt Wash Member is chiefly grayish red and reddish brown. Thin layers of grayish-green mudstone commonly underlie thick sandstone lenses, and mudstone seams in sandstone are commonly grayish green. Most of the mudstone is silty; some contains abundant very fine sand. The clay minerals are chiefly nonswelling hydromica with hydromica-montmorillonite mixures and minor chlorite (Craig and Cadigan, 1958, p. 189). The mudstone is generally calcareous and firmly cemented, but it is much less resistant than the interstratified sandstone. It crops out poorly in hackly surfaced slopes; it lacks the frothy weathered surfaces common in the overlying Brushy Basin Member. The mudstone is in obscure thin planar beds and laminae. Ripple marks are common. Fissility is uncharacteristic, but some sets of very silty and sandy mudstone split into paper-thin sheets. The base of the Salt Wash Member is the base of the lowest ledge of crossbedded sandstone characteristic of the member. The Salt Wash interfingers with the subjacent Tidwell Member. The two are combined in a single map unit in this quadrangle. The Salt Wash is partly exposed in steep ledgy slopes in the southern part of the quadrangle; much is covered by landslide. The member ranges from about 350 to 425 ft (105 to 130 m) in thickness; some differences are due to the arbitrary nature of the contacts. The Salt Wash was deposited by aggrading braided streams that formed a broad alluvial fan whose head was near the State line in south-central Utah (Craig and others, 1955, p. 137, fig. 21). Dips of sandstone crossbeds in this quadrangle suggest that the flow during deposition of the Salt Wash Member was mainly to the northeast and east.

Tidwell Member

The Tidwell Member (Peterson, 1988, p. 35–42) is the basal part of the Morrison Formation. In this quadrangle, the member consists of mudstone with lesser amounts of sandstone, chert, and limestone. O'Sullivan (1980b, 1981a, b) included these beds in the Salt Wash Member of the Morrison. Earlier usage had referred these beds to the Summerville Formation (Weir and Dodson, 1958a, b, c, d), but the Summerville has been shown to pinch out northwest of this area (O'Sullivan, 1980a). Mudstone in the Tidwell is light brown to dark grayish red and ranges from fairly pure claystone and siltstone to poorly sorted mixtures of fine sand, silt, and clay in thin, fairly continuous beds. Sandstone in the Tidwell is light brown, silty, and fine grained and is in discontinuous thin planar beds. Ripple marks and mudcracks are common. Gray and reddish-gray chert is in lensing beds as thick as 1 ft (30 cm) and in irregular nodules as much as 3 in. (8 cm) across. Bluish-gray, micrograined limestone in planar beds, commonly 1 to 3 in. (2 to 8 cm) thick, is characteristic of the Tidwell in this quadrangle. Locally, limestone is partly replaced by chert. Some limestone grades laterally into calcareous siltstone. The Tidwell forms a conspicuous slope below the ledge-forming, channel-filling sandstone lenses of the Salt Wash. The Tidwell was deposited in shallow quiet water or by sluggish streams (O'Sullivan, 1981a, p. 95).

Largely because of intertonguing with the lower part of the Salt Wash, the Tidwell differs greatly in thickness in short distances. It is only 11 ft (3.4 m) thick on southeastern Rone Bailey Mesa but near the south edge of the quadrangle it attains a thickness of more than 64 ft (20 m) (O'Sullivan, 1980b; O'Sullivan and Pierce, 1983). Together, the Tidwell and Salt Wash Members aggregate about 350–450 ft (105–135 m), more than half the total thickness of about 750–800 ft (225–240 m) of the Morrison Formation in this quadrangle.

The base of the Morrison Formation is a regional unconformity (O'Sullivan, 1984), the J–5 unconformity of Pipiringos and O'Sullivan (1978, p. A25). The unconformity is obscure and has little relief in the Hatch Rock quadangle, but careful tracing of beds by O'Sullivan (1980b, 1981b) has shown that part of the underlying Wanakah Formation has locally been cut out. The contact is recognized most easily as the base of a prominent bed, 0.4–6 ft (12 cm–1.8 m) thick, of gray sandstone containing sparse to abundant coarse to very coarse grains of quartz and chert.

MIDDLE JURASSIC

Wanakah Formation

The Wanakah Formation in this quadrangle consists of a lower layer of red siltstone, a middle layer of light-gray, partly crossbedded sandstone, and a thin upper layer of red siltstone (O'Sullivan, 1980b, 1981b). These layers were previously included in the Summerville Formation (Weir and Dodson, 1958a, b, c, d), but typical Summerville is cut out below an unconformity northwest of this area (O'Sullivan, 1980a). The lower layer of red siltstone, the middle member of the Wanakah of O'Sullivan (1980b), is as much as 37 ft (11 m) thick in the southern part of the quadrangle, but it grades northward into the Slick Rock Member of the Entrada Sandstone between White Rock and Casa Colorado Rock and between Photograph Gap and Rone Bailey Mesa (fig. 1). The middle layer of sandstone, the bed at Black Steer Knoll of O'Sullivan (1980b), is as much as 42 ft (13 m) thick, near Photograph Gap, but it thins irregularly northward to about less than 3 ft (1 m) near the north edge of the quadrangle. The upper layer of red siltstone, the upper member of the Wanakah of O'Sullivan (1980b), is as much as 3 ft (1 m) thick near Lopez Gulch, but it is missing at Casa Colorado Rock and in outcrops to the southeast. It has also been cut out locally between Photograph Gap and Hatch

Wash. Because it is generally thin, the Wanakah Formation is combined with the upper part of the Entrada Sandstone as a map unit in this quadrangle.

Entrada Sandstone

The upper part of the Entrada Sandstone in this quadrangle consists of the Moab Tongue and Slick Rock Member. The lower part is the Dewey Bridge Member.

Moab Tongue

The Moab Tongue (Baker and others, 1927), as redefined by O'Sullivan (1981b), is a thick crossbedded unit without any planar beds, a remnant of a fossil dune field. It is composed of very pale orange, well-sorted, fine grains of quartz and a minor amount of feldspar. It generally forms a sheer cliff above the more rounded cliff of the Slick Rock Member. The Moab Tongue is restricted to the northwestern part of the quadrangle where it ranges from about 75–85 ft (23–26 m) in thickness (O'Sullivan, 1981b). It merges with the Slick Rock Member near Casa Colorado Rock and in outcrops near Rone Bailey Mesa (fig. 1).

Slick Rock Member

The Slick Rock Member of the Entrada Sandstone forms the bulk of the formation. The member consists of sets of crossbeds and thin sets of planar beds representing dune and interdune deposits. It is mostly light orange brown, grading to pale orange or to very pale yellow. Thin dark-brown and pale-red bands locally streak the member; in part the bands coincide with planar beds but they also transect strata. 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 medium and coarse grains are characteristic of the member.

Most of the member is in small- to medium-scale planar and trough sets of westerly dipping, low-angle cross laminae. Planar sets of beds and laminae make up about 10 to 20 percent of the member; they are commonly finer grained and darker than the crossbedded sets. Penecontemporaneous faults, which have offsets of only a few feet and fade out upward in several feet, and contorted beds are common in places near the base of the member. The Slick Rock forms a steep rounded cliff grading to a gentle slope near the base of the member. The base of the member is placed above the highest red siltstone or silty sandstone

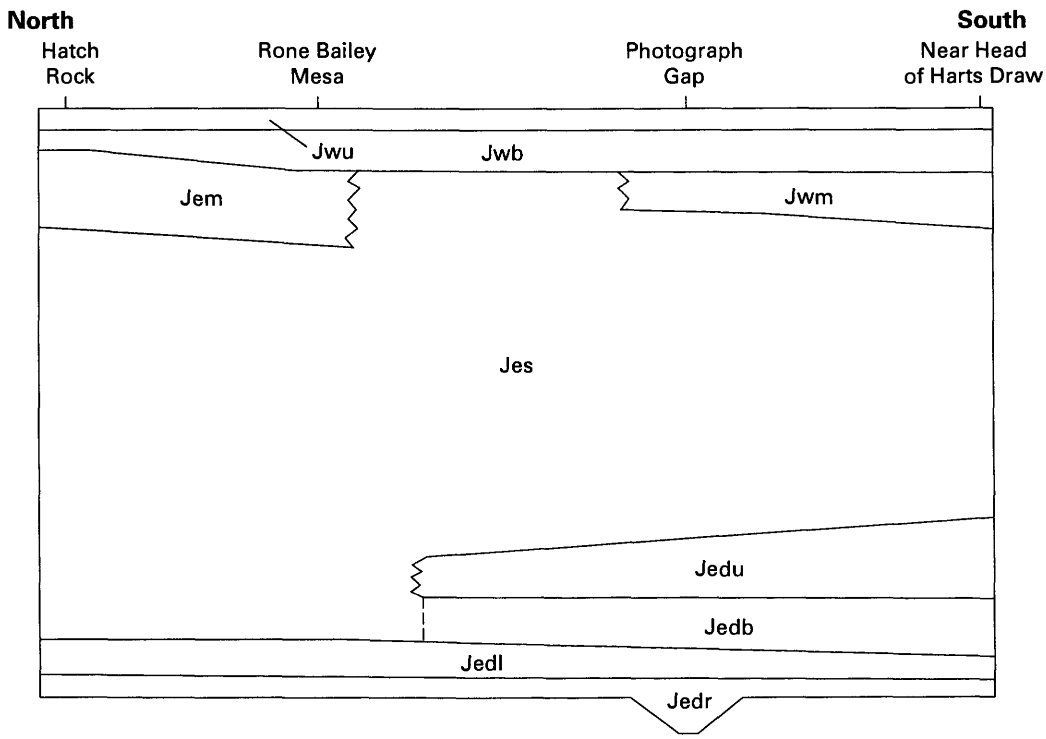

Figure 1. Diagrammatic north-south section from near Hatch Rock to near head of Harts Draw, showing generalized stratigraphic relations of units in the Wanakah Formation and Entrada Sandstone: **Jwu**, upper member of Wanakah Formation; **Jwb**, bed at Black Steer Knoll of O'Sullivan (1980b); **Jwm**, middle member of Wanakah Formation; **Jem**, Moab Tongue of Entrada Sandstone; **Jes**, Slick Rock Member of Entrada Sandstone; **Jedu**, upper red unit of Dewey Bridge Member of Entrada Sandstone; **Jedb**, buff unit of Dewey Bridge Member (vertical dashed line marks arbitrary cutoff); **Jedl**, lower red unit of Dewey Bridge Member; **Jedr**, reworked zone at base of Dewey Bridge Member. Unconformities at top and base of section. No scale. Modified from O'Sullivan (1980b); O'Sullivan and Pierce (1983).

of the basal Dewey Bridge Member of the Entrada. The Slick Rock ranges in thickness from about 305 ft (93 m) at Casa Colorado Rock to about 180 ft (55 m) in outcrops north of Deer Neck Mesa. The differences in thickness are largely due to intergrading with the Wanakah Formation and with the Moab Tongue and the Dewey Bridge Member of the Entrada Sandstone. The combined Wanakah Formation and upper part of the Entrada Sandstone attains a maximum thickness of about 400 ft (120 m) in the western part of the quadrangle and thins generally eastward to about 250 ft (75 m) in outcrops north of Deer Neck Mesa.

Dewey Bridge Member

Throughout much of the Hatch Rock quadrangle the Dewey Bridge Member has a conspicuous four-fold division consisting of alternations of red siltstone and buff sandstone (fig. 1).

The uppermost division of the Dewey Bridge is a layer of pale-reddish-brown, planar-bedded, silty sandstone. North of Lone Cedar Draw and Lopez Gulch it grades northward into buff to light-gray, fine-grained sandstone of the Slick Rock Member of the Entrada Sandstone (O'Sullivan, 1980b, 1981b). Where recognized, the upper red layer ranges from about 30 to 50 ft (9 to 15 m) in thickness.

Below the upper red silty sandstone of the Dewey Bridge Member is a layer of buff to yellowish-gray sandstone, in part in trough sets of crossbeds, in part in obscure planar beds. The buff sandstone is more resistant than the underlying or overlying red divisions and crops out as a prominent rounded ledge where the Dewey Bridge forms the lower part of cliffs of Entrada Sandstone. Elsewhere it forms the floor of much of Dry Valley. The buff sandstone ranges from about 10 to 30 ft (3 to 9 m) in thickness. North of Lone Cedar Draw and Lopez Gulch where the overlying red siltstone has graded into the Slick Rock Member of the Entrada, the buff sandstone also cannot be distinguished from the Slick Rock Member (O'Sullivan, 1980b, 1981b).

Below the buff sandstone is a layer of pale-reddish-brown, silty sandstone in obscure planar beds, locally wavy to contorted. This lower red unit persists over most of the quadrangle and ranges irregularly from about 6 to 30 ft (2 to 10 m). It thins to extinction near the east edge of the quadrangle in outcrops north of Deer Neck Mesa.

At the base is a zone of structureless or planar-bedded, buff to dark-yellowish-brown, fine-grained sandstone, reworked from the underlying Navajo Sandstone. The basal bed contains scattered granules and small pebbles of chert. The zone of reworked sandstone ranges from about 3 to 70 ft (1 to 21 m) in thickness. The zone is thickest near Photograph Gap where it was assigned to the Page Sandstone by O'Sullivan and Pierce (1983), but the sandstone lacks the crossbedding characteristic of the Page and cannot be distinguished from sandstone in the relatively thin reworked zone north and south of Photograph Gap.

In the southern part of the quadrangle, where all four divisions are present, the Dewey Bridge Member ranges from about 70 to 100 ft (21 to 30 m) in thickness. The member was deposited in an environment of mudflats and eolian dunes.

The Dewey Bridge Member of the Entrada Sandstone rests unconformably on the irregular top of the Navajo Sandstone, which is characterized by broad swales and rises. The unconformity, the J–2 unconformity of Pipiringos and O'Sullivan (1978, p. A20–A23), is characterized by scattered granules and small pebbles of chert and extends throughout much of the western interior of the United States.

LOWER JURASSIC

Navajo Sandstone

The Navajo Sandstone is mainly grayish yellow to light grayish orange. Beds of pale-red sandstone are most common near the base but are rare elsewhere in the formation; some are associated with rare thin lenses of limestone. The Navajo is composed of well-sorted, subrounded, very fine grains of quartz and minor feldspar. The rock is generally well cemented by calcite, yet it weathers readily to yield much colluvial sand.

Conspicuous very large to medium-scale trough sets of high-angle crossbeds make up most of the formation. The prevailing dip of these crossbeds is to the southeast. Planar beds and partings and small-scale slump structures are uncommon and are mostly in the basal part of the formation or are associated with sparse nonmarine, yellowish-gray, very fine sandy micrograined limestone. The limestone, commonly in part converted to gray chert, is in lenses as much as 3 ft (1 m) thick and 1,000 ft (300 m) long. The sandstone crossbeds of the Navajo are eolian dune deposits; the rare planar beds of sandstone and limestone are interdune deposits.

The Navajo Sandstone forms a rough rock slope in the northeastern part of the quadrangle. The upper part of the formation forms a broad rock tableland studded with small mesas and knolls along Hatch Wash and in the western part of the quadrangle. The basal part forms a steep cliff, 50 to more than 100 ft (15 to 30 m) high, along the canyons of Harts Draw and its tributaries.

The formation ranges in thickness from about 250 to 400 ft (75 to 120 m) in this quadrangle. It thins generally eastward. Some irregularities in thickness are due to the wavy unconformity at the top of the formation, and some are caused by the indefinite nature of the base of the formation. The base lies in a zone, commonly 50 to 100 ft (15 to 30 m) thick, of layers of light-colored crossbedded sandstone, which are characteristic of the Navajo, alternating with reddish planar beds of siltstone and sandstone, which are characteristic of the underlying Kayenta Formation. The formational contact was mapped at the top of the highest, relatively thick and continuous layer of planar-bedded, reddish sandstone or siltstone, thus placing some Navajo-like units in the Kayenta.

Kayenta Formation

The Kayenta Formation crops out in steep ledgy slopes in the canyon walls of Harts Draw and its tributaries and forms a rough, rocky dip slope southwest of Big Indian Valley in the northeastern part of the quadrangle.

The Kayenta Formation is made up of broad lenses of sandstone and siltstone and minor conglomerate. Sandstone units in the Kayenta are pale red or pinkish brown; they weather dark 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 pale red to dark grayish red.

Most of the Kayenta is sandstone composed of subrounded, very fine to fine grains of quartz and minor feldspar. Siltstone beds are sandy and commonly grade to very fine sandstone. Conglomerate beds have a fine- to medium-grained matrix; the coarser fraction consists chiefly of irregular fragments and subrounded pebbles of red, very fine grained shaly sandstone and gray, calcitic siltstone.

The Kayenta is firmly to moderately well cemented. The chief cement is calcite, but clay binding, iron oxide, and silica are common. Sandstone units in the lower part of the formation are generally more resistant than those in the upper part. Most siltstone units are nonresistant, but some grade into ledge-forming, calcitic siltstone.

Bedding is a distinctive feature of the Kayenta Formation. Sandstone is in broad complex lenses that commonly have an irregular scour surface at the bottom and a relatively planar surface at the top. The sandstone lenses, commonly 3 to 30 ft (1 to 10 m) thick, are made up of many smaller, discontinuous units. These 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). Much of the fine-grained sandstone is streaked with parting lineation. Small-scale slump structures and current ripple marks are sparse. Most conglomerate in the Kayenta is in scour pockets at the base of sandstone lenses. The interbedded siltstone is in small to fairly persistent lenses and commonly grades into planar-bedded, shaly sandstone. Weathering of the complex, irregularly lensing strata yields the characteristic ledgy outcrop of the Kayenta, in contrast to the relatively smooth cliffs of the Wingate Sandstone and Navajo Sandstone.

The Kayenta Formation rests conformably on the Wingate Sandstone. Locally the contact is a diastem marked by a scour surface or a seam of siltstone, but more commonly the contact is arbitrarily placed within an intergrading sequence 10 to 50 ft (3 to 15 m) 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 are like the underlying Wingate. The contact was mapped at the base of the lowest siltstone bed, conspicuous scour surface, or planar-bedded, shaly sandstone. As so drawn, placement of the contact is fairly consistent over small areas, but may differ by several tens of feet between neighboring canyons. The Kayenta ranges in thickness from about 150 to 250 ft (45 to 75 m), thinning irregularly to the east. Regional study suggests that the Kayenta was deposited by braided streams flowing generally to the west from a source area in southwestern Colorado and northwestern New Mexico (Poole, 1961, p. C141).

Wingate Sandstone

The Wingate Sandstone is exposed in sheer cliffs near the west edge of the quadrangle along Harts Draw and its tributaries. Southwest of Big Indian Valley the Wingate forms a cliff and a steep, rough rock slope. The cliff faces are commonly stained dark red to purplish black by coatings of iron and manganese. The cliffs locally have yielded talus blocks that cover the base of the formation and much of the underlying Chinle Formation.

Sandstone of the Wingate 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 are common near the base of the formation. The Wingate is firmly cemented by calcite so that the sandstone generally forms a single massive unit. Bedding is obscure and consists of interlayered crossbedded and planar-bedded strata, which range from about 1 to 60 ft (30 cm to 18 m) in thickness. Medium-scale planar and large-scale trough crossbeds are dominant, but some thin planar-bedded units extend for more than 1,000 ft (300 m). Cosets of crossbedded units are bounded by planar partings. Low-amplitude ripple marks and parting lineations are sparse throughout the formation; mud cracks are common at the base.

The base of the Wingate is an unconformity, the regional J-0 unconformity identified by Pipiringos and O'Sullivan (1978). In the western part of the quadrangle the unconformity is locally indistinct because the basal Wingate seems to intergrade with the underlying Chinle Formation. Lenses of dark-red, horizontally laminated and cross-laminated, fine-grained sandstone are locally interlayered with red mudstone in the upper 30 ft (10 m) of the Chinle Formation. Except for a few seams of red mudstone, these sandstone lenses are similar to the overlying Wingate. The base of the Wingate, however, is characterized by scattered coarse grains of quartz and chert that are lacking in the otherwise similar sandstone of the Chinle. Near Big Indian Valley the contact is sharp and is characterized by the truncation of contorted beds of Chinle and by sandstone of the Wingate in mudcrack fillings that extend as much as 12 in. (30 cm) into the mudstone of the Chinle.

The Wingate Sandstone ranges from about 250 to 350 ft (75 to 105 m) in thickness in the quadrangle. It thins irregularly eastward but some of the variation is probably due to differences in placing of the upper contact. Regional studies indicate that the Wingate was mostly deposited as dune sand by winds blowing from the northwest (Poole, 1962, p. D148).

UPPER TRIASSIC

Chinle Formation

The Chinle Formation crops out on the southwest flank of the Lisbon Valley anticline in the northeastern part of the quadrangle. The formation is about 400 to 440 ft (120 to 135 m) thick and is divided into upper and lower members. The upper member has been referred to the Church Rock Member of the Chinle, but the type Church Rock Member pinches out south of this area (O'Sullivan, 1970). The lower member has generally been referred to the Moss Back Member of the Chinle Formation, but Stewart and others (1972a, p. 4) noted that it was finer grained and possibly younger than the type Moss Back of southeastern Utah. Lupe (1979) has characterized the Chinle of southeastern Utah in terms of three upward-fining fluvial-lacustrine sequences. Lupe's basal sequence is approximately the lower member of this report; the second sequence, the lower part of the upper member; and the third sequence, approximately the top third of the upper member.

Upper member

The upper member of the Chinle Formation crops out along the southwest side of Big Indian Valley and in the canyon of Harts Draw and in Bobbys Hole Canyon near the west edge of the quadrangle. The member forms steep rough slopes studded irregularly with resistant ledges and more or less covered by sandstone debris from the ledges and by rockfalls from the Wingate Sandstone. It ranges in thickness from about 360 to 400 ft (110 to 120 m).

The upper member consists mainly of grayish-red and reddish-brown mudstone and lesser amounts of reddish-gray sandstone and mudstone-pebble conglomerate. Most of the mudstone is impure siltstone that locally grades to fine-grained sandstone and rarely to claystone. Some mudstone shows a faint planar stratification but most appears structureless. Contorted bedding is common near the base and top of the member. Small yellowish-gray and reddish-gray limy concretions, 1 to 3 in. (2 to 8 cm) in diameter, are common. 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. It is composed chiefly of subangular quartz and chert and lesser amounts of feldspar and mica, and variable amounts of mudstone grains. Conglomeratic beds are made up of irregular granules, pebbles, and cobbles of yellowish- and reddish-gray, limy mudstone in a matrix of medium- to coarse-grained sandstone.

The sandstone and conglomerate are interstratified in discontinuous lenses made up of thin to thick, irregular beds. Such lenses are interlayered sporadically with mudstone throughout but are most continuous near the top and near the base of the upper third of the member.

Schultz (1963, pl. 3, sec. 30) studied the clays in sandstone and siltstone of the upper member of the Chinle exposed a few miles east of the Hatch Wash quadrangle. Illite generally makes up more than 50 percent of the clay minerals. Other clay minerals present in varying proportions are kaolinite, mixed-layer illite, mixed-layer illite-montmorillonite, mixed-layer chlorite, and chlorite.

A few beds of limestone, less than 1 ft (30 cm) thick, are interstratified sporadically in mudstone of the upper member. The limestone is unfossiliferous, gray or grayish orange and ranges from micrograined to medium grained. Most limestone is sandy and contains small flattened pellets of mudstone.

Lower member

The lower member of the Chinle Formation crops out along the southwest side of Big Indian Valley. It forms a conspicuous ledge and local benches. The member consists chiefly of light- and medium-gray sandstone and conglomerate and minor interbedded greenish-gray mudstone. Proportions of the different lithologies vary greatly in short distances along the outcrop. The characteristic light- to medium- gray and greenish-grays of these rocks contrast with the reds and browns of the underlying and overlying rocks. The member weathers to form a cliff or steep ledgy slope.

The dominant lithologies of the lower member 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 are mainly clear quartz, gray chert, and yellowish-gray limy mudstone. The most abundant rock is pinkish-gray, poorly to moderately sorted, fine- to medium-grained sandstone, composed chiefly of subangular quartz and feldspar. Most of the sandstone units are feldspathic and many are arkosic. Some units, however, are nearly barren of feldspar and are made up almost entirely of quartz or of grains of calcareous siltstone and limestone. The units made up mostly of quartz tend to be finer grained and micaceous; those made of calcareous siltstone and limestone are mostly coarse grained and pebbly. Carbonaceous material is scattered irregularly in both types of sandstone. Interstitial clay and silt are abundant and are similar to the material making up the interstratified mudstone.

The several varieties of sandstone are commonly interstratified in broad sheet-like beds and in small lenses. The varieties intergrade, though most layers of calcareous grains are discrete. Near the head of Big Indian Valley the member is a single, fairly uniform bed of fine- to medium-grained arkose, but grades a few miles east of the quadrangle into thin lenses of quartzose sandstone and conglomerate interstratified in mudstone. Much sandstone is cross-stratified in small- to medium-scale, thin trough sets of low-angle cross laminae. The cross strata dip mainly to the northwest (Poole, 1961, p. C140–C141). Many sandstone units are made up of irregular lenses of planar beds.

Mudstone in the 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, mostly near the top of the member. Coalified plant debris is locally common to abundant in mudstone, especially near the top of the member. The mudstone is interstratified as lenticles to broad irregular lenses, tens to hundreds of feet long throughout the member but is most abundant in the upper half.

Clays of the lower member of the Chinle Formation in outcrops a few miles southeast of the quadrangle were studied by Schultz (1963, pl. 3, secs. 24, 25, 30). Illite makes up about 50 percent of the clay minerals. Other clay minerals present in various proportions are mixed-layer illite and chlorite. This assemblage of clay minerals differs from that characteristic of the type Moss Back Member in lacking kaolin and having more chlorite. Some sandstone and siltstone in the lower member is tuffaceous. The volcanic material is altered rhyolite tuff, perhaps mixed with altered latitic tuff.

The lower member of the Chinle formation ranges from about 30 to 50 ft (9 to 15 m) in thickness in outcrops along Big Indian Valley and attains a maximum thickness of about 68 ft (21 m) in the subsurface, several miles southwest of the valley (Huber, 1981, fig. 4). Variations in thickness are in part related to scouring at the base of the Chinle Formation. Most variation, however, is related to differences in placing the upper contact of the member in a zone of intertonguing and intergrading lithologies so as to separate gray, mainly coarse-grained rocks below from reddish, mainly fine-grained rocks above. Lateral changes in grain size and color are common and abrupt and may result in differences in placing the upper contact 10 ft (3 m) or more in 100 ft (30 m) along strike. The depositional pattern derived by Huber (1981, fig. 4) from study of drill-hole data of the lower Chinle is of two northwest-trending belts of relatively great thickness. The belts are about 1 to 3 mi (1.6 to 5 km) wide and more than 50 ft (15 m) thick. One belt is along or near the outcrop in Big Indian Valley; a second belt lies about 5 mi (8 km) to the southwest.

The base of the Chinle Formation is a major unconformity of regional extent (Stewart and others, 1972a, p. 14). Beds of the Cutler Formation are truncated northward along Big Indian Valley. The angular discordance ranges from about 1 to 5 degrees. The contact is marked by broad-scale channeling with local relief as much as 10 ft (3 m).

MIDDLE(?) AND LOWER TRIASSIC

Moenkopi Formation

The Moenkopi Formation is not exposed in the Hatch Rock quadrangle but probably underlies much of the western part of the quadrangle. It crops out in Hatch Wash about 5 mi (8 km) northwest of the quadrangle (Weir and Kennedy, 1958) and is fully exposed in canyons about 10 mi (16 km) to the west where it is about 400 ft (120 m) thick (Stewart and others, 1972b, p. 169–170; Huntoon and others, 1982). It is made up chiefly of grayish-red and reddish-brown, micaceous, clayey to sandy siltstone and silty sandstone in thin, planar beds deposited in fluvial environments. Using drill-hole data, Parker (1981, p. 91) gives a thickness range of 0 to 550 ft (0 to 168 m) for the Moenkopi in the Lisbon oil and gas field, whose northern part lies in the Hatch Rock quadrangle. The absence of the Moenkopi along Big Indian Valley may be due to truncation by the pre-Chinle unconformity, or to nondeposition caused by growth of the Lisbon salt anticline in the Triassic, or to a regional northeasterly thinning of the formation against a Mesozoic highland. In the nearest exposures west and northwest of the quadrangle the Moenkopi rests with apparent conformity on the coarser grained rocks of the Cutler Formation (Stewart and others, 1972b, p. 30, 170).

LOWER PERMIAN

Cutler Formation

The Cutler Formation crops out in Big Indian Valley in the northeastern corner of the quadrangle. The lower part of the formation floors the valley; the upper part rises in a steep slope that merges with the cliff formed by the lower member of the Chinle Formation. The Cutler is about 1,300 ft (395 m) thick near the head of Big Indian Valley and thickens south-southeastward along the outcrop to about 1,500 ft (455 m) a few miles east of this quadrangle. Parker (1981, p. 90–91) reports great thicknesses, as much as 5,000 ft (1,525 m), of the Cutler in the subsurface of the Lisbon oil and gas field. The large variation in thickness is ascribed by Parker to the influence of flowage of salt of the Hermosa Formation into the core of the Lisbon anticline during deposition of the Cutler.

The Cutler Formation in Big Indian Valley is an assemblage of red beds consisting of fluvial arkosic sandstone and conglomerate and marine and nonmarine micaceous siltstone and mudstone and minor limestone. Most rocks 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 in the upper part of the formation.

Conglomerate beds make up less than five percent of the formation but they form prominent outcrops in the lower part of the Cutler. The pebbles are as much as 3 in. (8 cm) in diameter and consist of clear and white quartz, pink granite, white gneissic granite, light-gray aplite, gray hornfels and schist, and sandstone and claystone. Sandstone units range from silty and fine grained to very coarse grained. All contain abundant feldspar. Most are micaceous except for light-colored, fine-grained units in the upper part of the formation. Siltstone and mudstone make up more than half the formation and commonly are darker and more micaceous than adjacent sandstone units.

A few thin, discontinuous beds of gray and pale-red, micrograined limestone, commonly less than a foot thick and 10–100 ft (3–30 m) long, are in the lower part of the formation. Most of these limestone beds are sandy and silty, partly converted to gray and red chert, and lack fossils. A few lenses of gray limestone and limy siltstone mostly near the base of the formation contain sparse marine fossils, chiefly brachiopod and crinoid fragments. The base of the Cutler Formation is exposed a few miles east of this quadrangle (Weir, Puffett, and Dodson, 1961). The contact was placed at the top of the highest relatively continuous bed of fossiliferous marine limestone of the Hermosa Formation. Clastic beds above and below this limestone bed are much alike, and thus the contact is arbitrary and probably not regionally consistent.

UPPER AND MIDDLE PENNSYLVANIAN

Hermosa Formation

The Hermosa Formation, not exposed in the quadrangle but shown in part in the cross section, consists of three members. A few miles east of this quadrangle about 900 ft (275 m) of the upper member crops out (Weir, Puffett, and Dodson, 1961; Weir and Puffett, 1981, p. 46–56). The exposed part consists of fissile and nonfissile mudstone, sandstone, and limestone. The buried part of the member is dominantly marine limestone and mudstone. Parker (1981, p. 91) gives a range of thickness of 1,600 to 1,900 ft (490 to 580 m) for the member in the Lisbon oil field. The upper member of the Hermosa Formation is commonly called the Honaker Trail Formation (of Wengerd and Matheny, 1958) by petroleum geologists. Some part of the transitional carbonate-clastic lithology of the upper member of the Hermosa Formation or of the lower part of the Cutler Formation is similar to that assigned to the Rico Formation by Baker (1933, p. 23–29) and by Shawe and others (1968, p. 22) in adjacent areas, but useful criteria for distinguishing a "Rico Formation" in this area are lacking.

The middle part of the Hermosa Formation is the Paradox Member. Drill-hole data show that it consists chiefly of salts interbedded with minor black shale and a relatively thin unit of dolomite, shale, and anhydrite at the top. The Paradox attains a thickness of more than 8,000 ft (2,440 m) in the Lisbon oil field (Parker, 1981, p. 91). This great thickness is the result of flowage of salt from surrounding areas in Permian and Triassic time (Smith and Prather, 1981, p. 56).

Below the Paradox Member are the carbonates and shale of the lower member of the Hermosa Formation (15–170 ft; 4.5–52 m thick) and more than 2,500 ft (760 m) of Lower Pennsylvanian, Mississippian, Devonian, and Cambrian strata (Parker, 1981, p. 91).

STRUCTURE

Most of the Hatch Rock quadrangle is characterized by very gently dipping to flat-lying strata. In the western and southern parts of the quadrangle, dips rarely exceed 3° except near faults. The broad Hatch Rock syncline in the northern part of the quadrangle has a closure of less than 100 ft (30 m). In the southwestern part of the quadrangle is the northeast-trending Shay graben. Maximum stratigraphic separation on the graben faults is about 120 ft (37 m). Separations on the faults in Navajo Sandstone north of the graben, noted by Kitcho (1981, p. 5), are uncertain but probably are less than 30 ft (9 m).

The southwest flank of the Lisbon Valley anticline and associated faults are the major structures in the northeastern part of the quadrangle. The anticline is underlain by a core, more than 8,000 ft (2,440 m) thick, of salts in the Paradox Member of the Hermosa Formation. The trace of the northwest-trending axis of the anticline lies a few miles east of the quadrangle (Weir, Puffett, and Dodson, 1961). Southwesterly dips in the Cutler Formation are as much as 15°; dips in the Mesozoic strata are as much as 11° near Big Indian Valley but decrease to less than 5° within a few miles to the southwest.

A major fault, the Lisbon Valley fault, crosses the northeast corner of the quadrangle. As a single fault it extends to the northwest about 3.5 mi (5.6 km) where it splits into a splay, about 10 mi (16 km) long, of northwest-striking faults (Weir and Kennedy, 1958). The fault extends to the southeast about 8.5 mi (13.6 km) where it divides into a complex more than 15 mi (24 km) long of southeast- and east-striking faults (Weir and Puffett, 1960b; Williams, 1964). The maximum stratigraphic separation on the Lisbon Valley fault in this quadrangle is about 3,000 ft (915 m) where the Dakota Sandstone is downfaulted against the Cutler Formation. The separation is about 5,000 ft (1,525 m) about 8 mi (12.8 km) to the southeast of the quadrangle, where Upper Cretaceous shale abuts Pennsylvanian limestone (Weir, Puffett, and Dodson, 1961). The fault dips about 55° to 85° northeast in this quadrangle; the straight trace of the fault southeast of this quadrangle indicates that high dips are characteristic. According to Parker (1981), seismic and drill-hole data show that the Lisbon Valley fault dies out downward in salts of the Paradox Member of the Hermosa Formation and that a northwest-trending graben in pre-Pennsylvanian strata, not evident in the surface structure, lies about 1 to 2.5 mi (1.6 to 4 km) southwest of the Lisbon Valley fault (fig. 2).

The Lisbon Canyon anticline, whose axis crosses the northeast corner of the quadrangle, is a minor fold on the northeast flank of the Lisbon Valley anticline. Its northwest-trending axis parallels the trace of the Lisbon Valley fault.

ECONOMIC GEOLOGY

The Hatch Rock quadrangle contains significant deposits of uranium and vanadium, copper, potash, and oil and gas.

URANIUM-VANADIUM

Uranium and vanadium ores have been mined from the Cutler Formation (Permian), from the Chinle Formation (Late Triassic), and the Morrison Formation (Late Jurassic). The deposits were mined principally for their uranium content, though vanadium in the Morrison deposits contributed markedly to the value

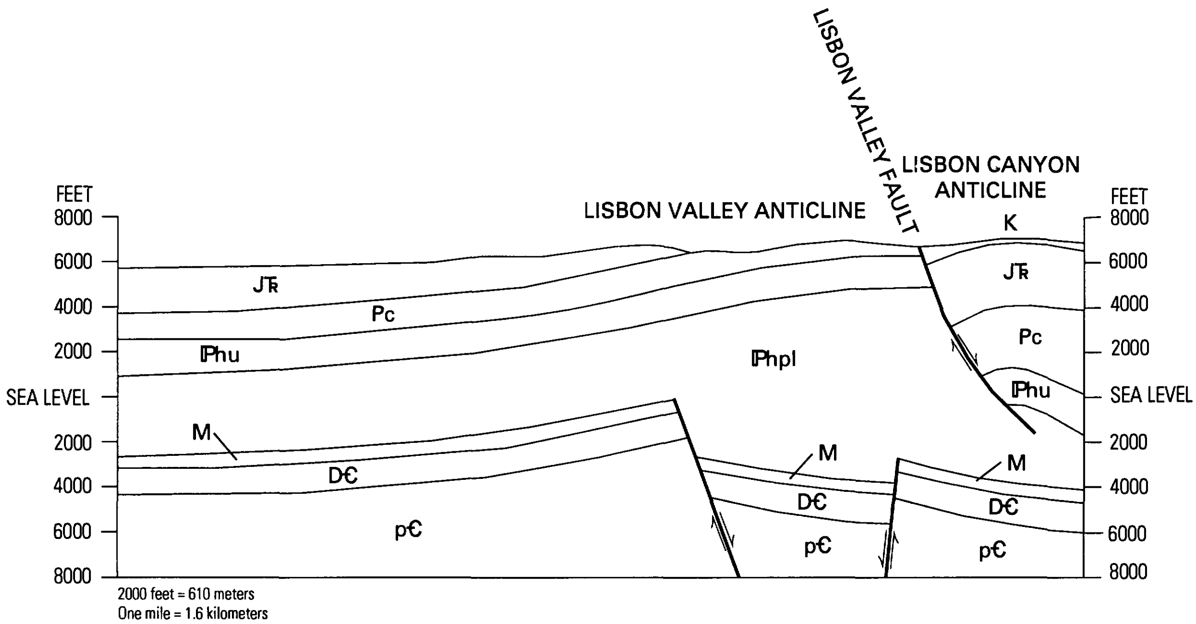

Figure 2. Generalized geology along northeastern part of cross section line *A–A'*, beginning near Hatch Wash, showing inferred relations of surface and subsurface structures. K, Cretaceous formations; JŦR, Jurassic and Triassic formations; Pc, Cutler Formation (Lower Permian); IPhu, upper member of the Hermosa Formation (Upper Pennsylvanian; IPhpl, Paradox Member (chiefly salts) of the Hermosa Formation (Middle Pennysylvanian) and older Pennsylvanian strata; M, Mississippian strata; D€, Devonian and Cambrian strata; p€, Precambrian rocks. No vertical exaggeration. Arrows on faults show relative direction of movement. (Modified from Parker, 1981, fig. 5).

of the ores. In mid-1989 all the uranium-vanadium mines in this quadrangle were inactive or abandoned.

Ore deposits in the Cutler Formation are relatively small. They are in irregular tabular bodies near the top of the formation (Weir and Puffett, 1960a, p. 141–143). The deposits are mostly oxidized. The chief ore minerals are carnotite, tyamunite, bequerelite, uranophane, uraninite, coffinite, and vanadium hydromica. Uranium is most common in iron-oxide coatings of detrital minerals (Campbell, 1981, p. 192).

Large ore deposits are in sandstone, conglomerate, and mudstone in the basal part of the lower member of the Chinle Formation (Weir and Puffett, 1960a, p. 143–144). The deposits are irregular tabular bodies that for the most part are unoxidized. Ore minerals impregnating sediments and replacing carbonaceous material include uraninite, coffinite, and vanadium hydromica.

Small to medium ore deposits are common in relatively thick lenses of sandstone near the top of the Salt Wash Member of the Morrison Formation (Weir and Puffett, 1960a, p. 144, 146). The deposits are oxidized. Fine-grained mixtures of carnotite, tyamunite, vanadium hydromica, and other vanadates impregnate sandstone and replace carbonaceous material. The ore bodies are roughly tabular and elongate and generally include clusters of irregularly curving high-grade layers of ore minerals. The vanadium content of the Morrison ore is relatively high; the vanadium oxide-uranium oxide ratio ranges from about 4:1 to 10:1.

COPPER

Most of the workings of a copper mine, generally known as the Big Indian Mine, lie in the northeast corner of the Hatch Rock quadrangle. Oxidized copper minerals, chiefly azurite and malachite, impregnate carbonaceous sandstone beds in the Dakota Sandstone near the Lisbon Valley fault. The main periods of production were in the 1940's and 1960's. In 1989 the workings were inactive and appeared abandoned.

POTASH

The Lisbon Valley anticline is underlain by a lens of Pennsylvanian salt more than 8,000 ft (2,440 m) thick in the Paradox Member of the Hermosa Formation. Layers consisting mostly of potash minerals, chiefly sylvite and carnallite, are common in the member (Hite and Gere, 1958, p. 224). The potash reserves of the Lisbon Valley anticline are estimated to be large, but the deposits have not been exploited (Hite, 1978). Brines rich in potash salts are being extracted from similar deposits about 30 mi (19 km) northwest of this quadrangle.

OIL AND GAS

The Hatch Rock quadrangle includes the northwestern part of the Lisbon oil and gas field. The oil and gas are trapped in a faulted subsurface anticline (fig. 2) whose axis lies below the southwestern flank of the Lisbon Valley surface anticline (Parker, 1981,

p. 94). Commercial production has been from carbonate rocks of Mississippian age. Oil and gas has also been extracted from Devonian sandstone and limestone and from Pennsylvanian anhydritic dolomite in the Paradox Member of the Hermosa Formation (Parker, 1981, p. 93–94). The field was discovered in 1960; some wells in the quadrangle were active in 1989.

GRAVEL

Many small borrow pits are in gravels along Hatch Wash and its tributaries. Most of the pits are in the relatively young fluvial gravels but a few are in the old rubble. The gravel has been used as dressing on local dirt roads and as highway fill. The pebbles and cobbles are mainly resistant sandstone, quartzite, and chert derived from Cretaceous formations; in the southern part of the quadrangle many pebbles are diorite porphyry from Tertiary intrusives of the Abajo Mountains.

REFERENCES CITED

Baker, A.A., 1933; Geology and oil possibilities of the Moab district, Grand and San Juan Counties, Utah: U.S. Geological Survey Bulletin 841, 95 p.

Baker, A.A., Dobbin, C.E., McKnight, E.T., and Reeside, J.B., Jr., 1927, Notes on the stratigraphy of the Moab region, Utah: American Association of Petroleum Geologists Bulletin, v. 11, p. 785–808.

Campbell, J.A., 1981, Uranium mineralization and depositional facies in the Permian rocks of the northern Paradox Basin, Utah and Colorado, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Denver, Colo., Rocky Mountain Association of Geologists, p. 187–194.

Carter, W.D., 1957, Disconformity between Lower and Upper Cretaceous in western Colorado and eastern Utah: Geological Society of America Bulletin, v. 68, p. 307–314.

Craig, L.C., 1981, Lower Cretaceous rocks, southwestern Colorado and southeastern Utah, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Denver, Colo., Rocky Mountain Association of Geologists, p. 195–200.

Craig, L.C., and Cadigan, R.A., 1958, The Morrison and adjacent formations in the Four Corners area, *in* Sanborn, A.F., ed., Guidebook to the geology of the Paradox Basin: Salt Lake City, Utah, Intermountain Association of Petroleum Geologists 9th field conference, p. 182–192.

Craig, L.C., Holmes, C.N., Cadigan, R.A., Freeman, V.L., Mullens, T.E., and Weir, G.W., 1955, Stratigraphy of the Morrison and related formations, Colorado Plateau region, a preliminary report: U.S. Geological Survey Bulletin 1009–E, p. 125–168.

Hite, R.J., 1978, Geology of the Lisbon Valley potash deposits, San Juan County, Utah: U.S. Geological Survey Open-File Report OF–78–0148, 25 p.

Hite, R.J., and Gere, W.C., 1958, Potash deposits of the Paradox Basin, *in* Sanborn, A.F., ed., Guidebook to the geology of the Paradox Basin: Salt Lake City, Utah, Intermountain Association of Petroleum Geologists 9th field conference, p. 221–225.

Huber, G.C., 1981, Geology of the Lisbon Valley uranium district, southeastern Utah, *in* Epis, R.C., and Callender, J.F., eds., Western Slope Colorado, western Colorado and eastern Utah: New Mexico Geological Society, 32nd field conference, p. 177–182.

Huff, L.C., and Lesure, F.G., 1965, Geology and uranium deposits of Montezuma Canyon area, San Juan County, Utah: U.S. Geological Survey Bulletin 1190, 102 p.

Huntoon, P.W., Billingsley, G.H., Jr., and Breed, W.J., 1982, Geologic map of Canyonlands National Park and vicinity, Utah: Moab, Utah, Canyonlands National History Association, scale 1:62,500.

Kitcho, C.A., 1981, Characteristics of surface faults in the Paradox Basin, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Denver, Colo., Rocky Mountain Association of Geologists, p. 1–21.

Lupe, Robert, 1979, Stratigraphic sections of the Upper Triassic Chinle Formation, San Rafael Swell to the Moab area, Utah: U.S. Geological Survey Oil and Gas Investigations Chart OC–89.

O'Sullivan, R.B., 1970, The upper part of the Upper Triassic Chinle Formation and related rocks, southeastern Utah and adjacent areas: U.S. Geological Survey Professional Paper 644–E, 22 p.

———1980a, Stratigraphic sections of Middle Jurassic San Rafael Group and related rocks from the Green River to the Moab area in east-central Utah: U.S. Geological Survey Miscellaneous Field Studies Map MF–1247.

———1980b, Stratigraphic sections of Middle Jurassic San Rafael Group from Wilson Arch to Bluff in southeastern Utah: U.S. Geological Survey Oil and Gas Investigations Chart OC–102.

———1981a, The Middle Jurassic San Rafael Group and related rocks in east-central Utah, *in* Epis, R.C., and Callender, J.F., eds., Western Slope Colorado, western Colorado and eastern Utah: New Mexico Geological Society Guidebook, 32nd field conference, p. 89–95.

———1981b, Stratigraphic sections of some Jurassic rocks from near Moab, Utah to Slick Rock, Colorado: U.S. Geological Survey Oil and Gas Investigations Chart OC–107.

———1984, The base of the Upper Jurassic Morrison Formation in east-central Utah: U.S. Geological Survey Bulletin 1561, 16 p.

O'Sullivan, R.B., and Pierce, F.W., 1983, Stratigraphic diagram of Middle Jurassic San Rafael Group and associated formations from the San Rafael Swell to Bluff in southeastern Utah: U.S. Geological Survey Oil and Gas Investigations Chart OC–119.

Parker, J.M., 1981, Lisbon Field area, San Juan County, Uath, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Denver, Colo., Rocky Mountain Associa-

tion of Geologists, p. 89–106.
Peterson, Fred, 1988, Stratigraphy and nomenclature of Middle and Upper Jurassic rocks, western Colorado Plateau, Utah and Arizona: U.S. Geological Survey Bulletin 1633–B, p. 13–56.
Peterson, Fred, and Ryder, R.T., 1975, Cretaceous rocks in the Henry Mountains region, Utah and their relation to neighboring regions, *in* Fassett, J.E., ed., Canyonlands Country: Four Corners Geological Society Guidebook, 8th field conference, p. 167–189.
Pipiringos, G.N., and O'Sullivan, R.B., 1978, Principal unconformities in Triassic and Jurassic rocks, Western Interior United States—A preliminary survey: U.S. Geological Survey Professional Paper 1035–A, p. A1–A29.
Poole, F.G., 1961, Stream directions in Triassic rocks of the Colorado Plateau: U.S. Geological Survey Professional Paper 424–C, p. C139–C141.
———1962, Wind directions in late Paleozoic to middle Mesozoic time on the Colorado Plateau, *in* Short papers in geology, hydrology, and topography: U.S. Geological Survey Professional Paper 450–D, p. D147–D151.
Schultz, L.G., 1963, Clay minerals in Triassic rocks of the Colorado Plateau: U.S. Geological Survey Bulletin 1147–C, p. C1–C71.
Shawe, D.R., Simmons, G.C., and Archbold, N.L., 1968, Stratigraphy of Slick Rock district and vicinity, San Miguel and Dolores Counties: U.S. Geological Survey Professional Paper 576–A, 108 p.
Smith, K.T., and Prather, O.E., 1981, Lisbon field—lessons in exploration, *in* Wiegand, D.L., ed., Geology of the Paradox Basin: Denver, Colo., Rocky Mountain Association of Geologists, p. 55–59.
Stewart, J.H., Poole, F.G., and Wilson, R.F., 1972a, Stratigraphy and origin of the Chinle Formation and related Upper Triassic strata, in the Colorado Plateau region, *with a section on* Sedimentary petrology by R.A. Cadigan, *and a section on* Conglomerate studies by William Thordarson, H. F. Albee, and J.H. Stewart: U.S. Geological Survey Professional Paper 690, 336 p.
———1972b, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region, *with a section on* Sedimentary petrology by R.A. Cadigan: U.S. Geological Survey Professional Paper 691, 195 p.
Stewart, J.H., Williams, G.A., Albee, H.F., and Raup, O.B., 1959, Stratigraphy of Triassic and associated formations in part of the Colorado Plateau region, *with a section on* Sedimentary petrology by R.A. Cadigan: U.S. Geological Survey Bulletin 1046–Q, p. 487–586.
Weir, G.W., and Dodson, C.L., 1958a, Preliminary geologic map of the Mount Peale 3 NW quadrangle, San Juan County, Utah: U.S. Geological Survey Mineral Investigations Field Studies Map MF–144, scale 1:24,000.
———1958b, Preliminary geologic map of the Mount Peale 3 NE quadrangle, San Juan County, Utah: U.S. Geological Survey Mineral Investigations Field Studies Map MF–145, scale 1:24,000.
———1958c, Preliminary geologic map of the Mount Peale 3 SW quadrangle, San Juan County, Utah: U.S. Geological Survey Mineral Investigations Field Studies Map MF–146, scale 1:24,000.
———1958d, Preliminary geologic map of the Mount Peale 3 SE quadrangle, San Juan County, Utah: U.S. Geological Survey Mineral Investigations Field Studies Map MF–147, scale 1:24,000.
Weir, G.W., and Kennedy, V.C., 1958, Preliminary geologic map of the Mount Peale 2 SW quadrangle, San Juan County, Utah: U.S. Geological Survey Mineral Investigations Field Studies Map MF–142, scale 1:24,000.
Weir, G.W., and Puffett, W.P., 1960a, Similarities of uranium-vanadium and copper deposits in the Lisbon Valley area, Utah-Colorado, U.S.A.: 21st International Geology Congress Proceedings, Copenhagen, v. 15, p. 133–148.
———1960b, Preliminary geologic map of the Mount Peale 4SE quadrangle, San Juan County, Utah and San Miguel County, Colorado: U.S. Geological Survey Mineral Investigations Field Studies Map MF–149, scale 1:24,000.
———1981, Incomplete manuscript on stratigraphy and structural geology and uranium-vanadium and copper deposits of the Lisbon Valley area, Utah-Colorado: U.S. Geological Survey Open-File Report OF–81–89, 292 p.
Weir, G.W., Puffett, W.P., and Dodson, C.L., 1961, Preliminary geologic map and section of the Mount Peale 4 NW quadrangle, San Juan County, Utah: U.S. Geological Survey Mineral Investigations Field Studies Map MF–151, scale 1:24,000.
Wengerd, S.A., and Matheny, M.L., 1958, Pennsylvanian system of Four Corners region: American Association of Petroleum Geologists Bulletin, v. 42 p. 2048–2106.
Williams, P.L., 1964, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Geologic Investigations Map I–360, scale 1:250,000.

*U.S. G.P.O.:1994-387-030:54