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GEOLOGY STUDIES

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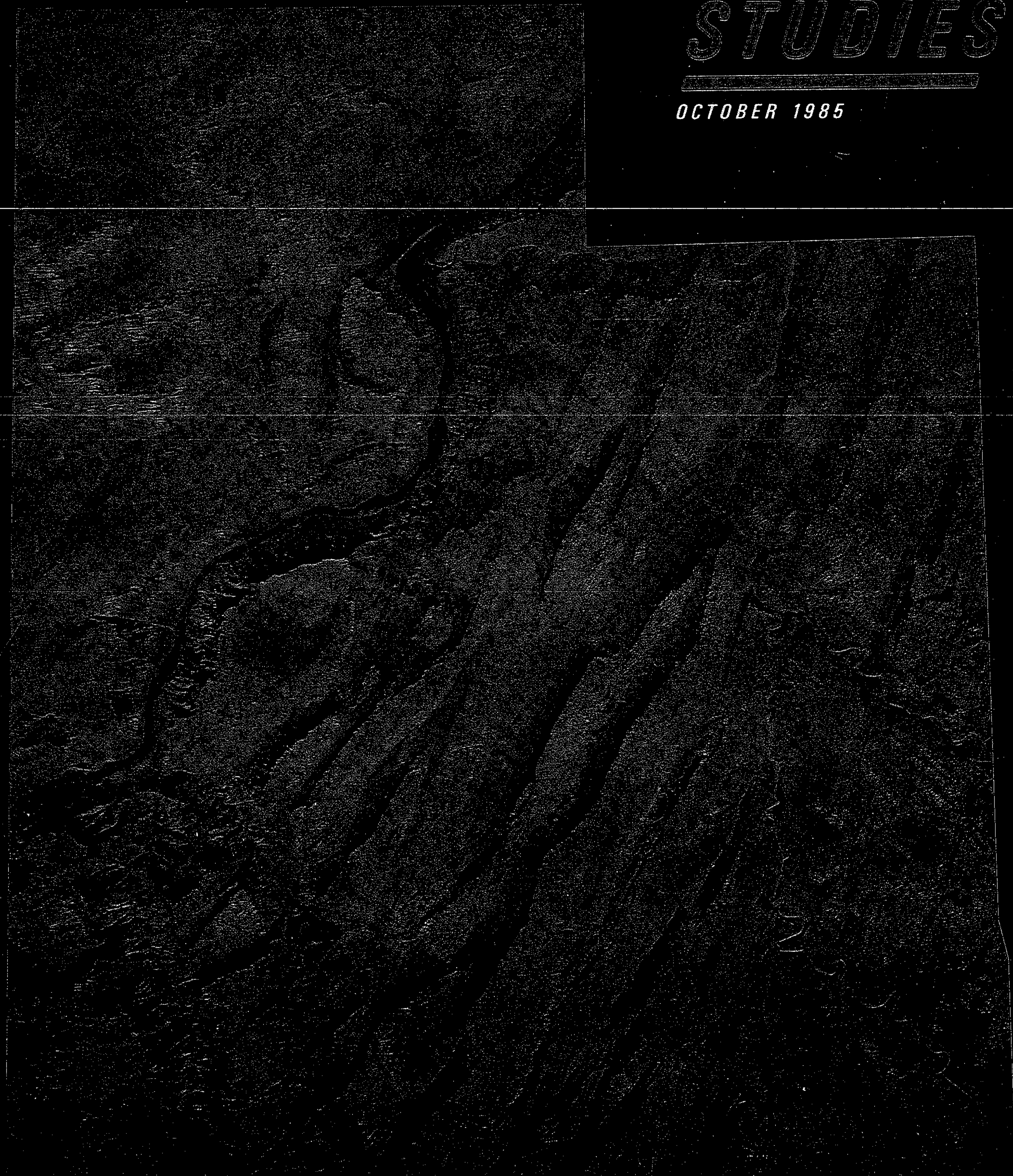

VOLUME 32, PART 1

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CONTENTS

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CONTENTS

Geology of the Scofield $7\frac{1}{2}$-Minute Quadrangle in Carbon, Emery, and Sanpete Counties, Utah*

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ABSTRACT

The Scofield $7\frac{1}{2}$-Minute Quadrangle is located in the northern Wasatch Plateau coalfield.

Field observations were combined with drilling information to produce a surface geologic map at a 1:24,000 scale. Formations exposed include the North Horn, Price River, Castlegate, Blackhawk, Star Point, and Mancos beds, with a total thickness of approximately 3000 feet. A regression is documented as depositional environments of these Upper Cretaceous formations grade upward through shallow marine, deltaic, floodplain, and fluvial complexes.

The Wasatch Plateau was uplifted in middle to late Tertiary time. Igneous dikes of two compositions were intruded along east–west-trending joints. Later, the beds were displaced by numerous north–south-trending faults, which step up from major grabens near Scofield and Electric Lake. This structuring is possibly related to the movement and solution of evaporites at depth. Pleistocene valley glaciers produced cirques, moraines, kettles, and tarns.

LOCATION AND ACCESSIBILITY

The town of Scofield is approximately 110 km southeast of Provo, Utah, via U.S. 50-6. Utah State Highway 96 runs through the eastern edge of the quadrangle and connects the communities of Clear Creek and Scofield to U.S. 50-6 as shown in figure 1. Maintained Forest Service roads in uplands near the Carbon-Emery County boundary, as well as mining roads branching from Utah 96, provide ready access during summer months.

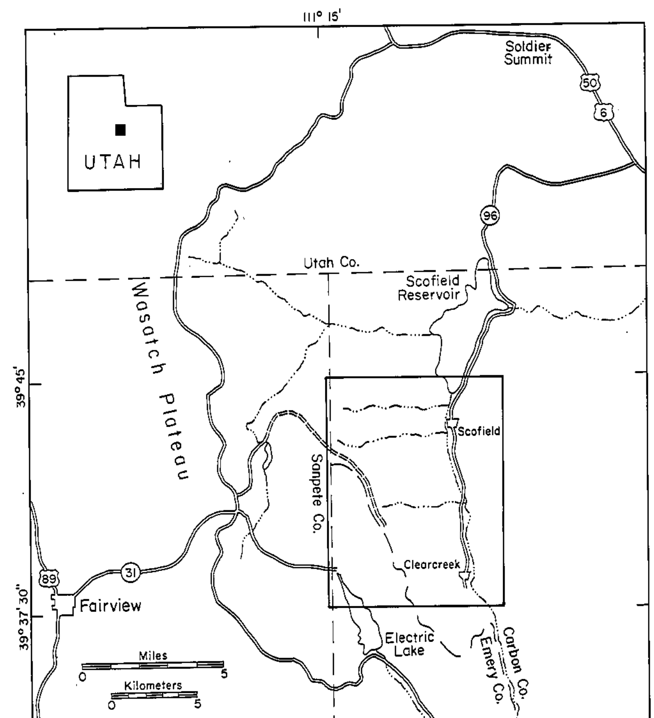

FIGURE 1.—*Index map.*

PREVIOUS WORK

Reconnaissance mapping 1:50,000 of the Scofield Quadrangle by Spieker (1931) included the locations of numerous sections measured in the Scofield area. Walton (1955) described the outcrop and subsurface stratigraphy of the northern Wasatch plateau and included a regional structural contour map of the top of the Ferron Sandstone. Moussa (1965) mapped the geology of the Soldier Summit 15-Minute Quadrangle which borders the northern edge of the Scofield Quadrangle.

Oberhansley (1980) mapped the Fairview Lakes Quadrangle immediately to the west. His geomorphic work documented diverted drainage of the headwaters of Upper Huntington Creek.

*A thesis submitted to the Department of Geology, Brigham Young University, in partial fulfillment of the requirements for the degree of Master of Science, April 1983.

Blanchard (1981) correlated significant coal seams and sandstone units of Pleasant Valley, south of Scofield, with those of the Book Cliffs. This work improved the stratigraphic understanding of the Blackhawk Formation. Blanchard's correlations improved structural understanding of the quadrangle.

FIELD METHODS

Fieldwork began in July and was completed in October 1981. Geologic features were plotted on aerial photographs at a scale of 1:24,000. Fossils were collected and identified by the author to aid in determining the age and paleoenvironment of the strata. Mine maps, where available, were used for control on structure and coal-bed thickness. Data from cores and electric logs were used to provide additional structural and stratigraphic control.

STRATIGRAPHY

Approximately 980 m of Late Cretaceous beds, including the Mancos, Star Point, Blackhawk, Castlegate, Price River, and North Horn Formations, are exposed in the Scofield Quadrangle, as shown in figure 2.

These beds record a significant regression of the Mancos seaway. Depositional environments of these formations grade upward through shallow-marine, deltaic, floodplain, and fluvial complexes.

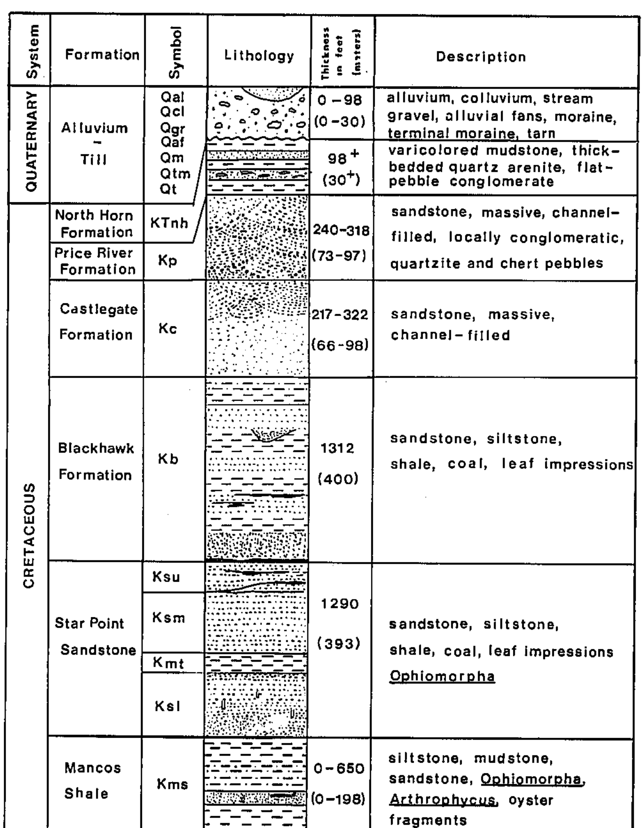

FIGURE 2.—*Columnar section.*

CRETACEOUS SYSTEM

MANCOS SHALE

Previous workers have divided the Mancos in this area into five members, in descending order: the Masuk Shale Member, the Emery Sandstone Member, the Blue Gate Shale Member, the Ferron Sandstone Member, and the Tununk Shale Member.

Upper Mancos beds, a tongue of the Masuk Member, are visible on the western slopes of Pleasant Valley along the western boundary fault. This tongue is the only part of the Masuk and the only part of the Mancos Shale that is exposed in the quadrangle. The best exposures occur along stream banks of Long Canyon and in roadcuts of Boardinghouse, Slaughter House, and Whiskey Canyons.

The Masuk tongue generally forms a covered slope, but the interval can be traced across some slopes because of vegetative banding. This interval is particularly evident where Masuk mudstone layers localize groundwater on the dry south-facing slopes.

Significant thinning of a Masuk tongue takes place between exposures in Boardinghouse Canyon and those in Whiskey Canyon. Thickness of one major mappable Masuk interval, for example, varies from 91 m in Boardinghouse Canyon to 67 m in Whiskey Canyon. Contacts have been drawn to document thinning of Masuk units to the northwest, as suggested in a regional study by Blanchard (1981).

Data from drilling logs in the quadrangle give evidence of numerous thin shaly breaks in the lower Star Point Sandstone and are likely thinner Masuk tongues. The Masuk Shale Member is 198 m thick below the lowermost Star Point Sandstone. Marine Masuk beds complexly intertongue with the littoral Star Point Sandstone, as seen in figure 3. Precise differentiation of beds was not always possible because of poor outcrops.

The lower contact of these transgressive marine Masuk tongues generally is sharp where it rests on an underlying barrier sandstone. The upper contact, however, grades from shale into the overlying littoral sandstones.

A section was measured along a roadcut of Boardinghouse Canyon, section 32, T. 13 S, R. 7 E (appendix 1). Textures vary from mudstone to fine-grained sandstone. Light blue gray siltstones are interbedded with green gray mudstones and buff sandstones. The beds are laminated to thick bedded and show significant bioturbation. Dolomite is the prevalent cement.

Numerous fossils are present. Trace fossils include 8-to-24-mm-wide smooth tubes; 21-to-34-mm-wide large tubes; plug-shaped burrows up to 14 cm deep, *Arthrophycus*, and *Ophiomorpha*.

Oyster fragments, *Trigonia*(?), *Turritella* sp., a 26-mm-long cancellate pelecypod, a 51-mm-long, 38-mm-wide, orthostrophic, conispiral gastropod and a 59-mm-wide, convolute, planispiral gastropod were collected from the section (appendix 1).

Silicified foraminifera were picked and identified from seven units of the measured section. These foraminifera generally correspond with those in the upper Mancos faunas identified by Maxfield (1976).

Flora collected includes stems of *Equisetum* and the silicified, spherical, fruiting structure of a charophyte algae, 0.3 mm across. Peck (1959, p. 120) described occurrences of charophytes in the Blackhawk Formation. Cenozoic charophytes seem to have been limited to fresh and brackish, quiet waters. This evidence suggests that this Masuk tongue was deposited in a lagoonal environment.

The Masuk marine shale is believed to represent the final surges of the regressive Mancos seaway in this area. It is unknown whether these surges were due to eustatic fluctuations or local subsidence.

STAR POINT SANDSTONE

The Star Point Sandstone is Campanian in age and consists of several fine- to medium-grained sandstone units that are separated by partings of siltstone or mudstone.

As originally defined (Spieker and Reeside 1925, p. 443), the lower boundary of the Star Point Sandstone was the base of the Panther Tongue, and the upper boundary was the top of the Spring Canyon Tongue. Young (1955, p. 182) redefined the upper boundary of the Star Point Sandstone, lowering it to the top of the Storrs Tongue. As Young noted, this boundary is impractical in the western Wasatch Plateau where the Spring Canyon, Storrs, and Panther Tongues form a single massive, littoral marine section. Stratigraphic work by Blanchard (1981) suggested that the practical upper boundary of the Star Point Sandstone in the northern Wasatch Plateau is the top of the Spring Canyon Tongue.

The Upper O'Connor coal bed directly overlies the Spring Canyon Tongue according to Blanchard's work, as shown in figure 3. Others who have mined area coals feel that the Upper O'Connor bed correlates with the Castlegate "A" bed at National. I have used Blanchard's correlations and separated the strata in question by mapping an Upper and Lower Star Point Sandstone. Rocks below the base of the Upper O'Connor bed and above the base of the Flat Canyon coal have been mapped as Upper Star Point Sandstone. Beds below the base of the Flat Canyon coal and above the thick Masuk Shale have been mapped as Lower Star Point Sandstone.

The Star Point Sandstone in the Scofield area complexly intertongues with the Blackhawk Formation and the Mancos Shale (see Blanchard 1981, sheet 3). Numerous faults and deep cover make mapping and correlation of outcrops extremely difficult, as can be seen in figure 4. On north-facing slopes even the sandstones are concealed by colluvium and vegetation. The beds that have been mapped as Star Point Sandstone, accordingly, locally may contain thin lower floodplain Blackhawk tongues, as well as shallow marine Mancos tongues near the contact zones. However, the littoral marine Star Point sandstones comprise the most of the mapped interval.

Exposures of Star Point Sandstone occur along the east and west slopes of Pleasant Valley. Units range from thin, laminated, shaly layers to thick-bedded, fine-grained sandstone. Most outcrops are medium yellow brown, but sandstones beneath coal beds are generally bleached to a light yellow gray. These bleached ledges aided early coal exploration and were used by Spieker (1931, p. 25) in his Wasatch Plateau correlations. Parker (1955) and Marley (1979, p. 31) have interpreted these bleached zones as paleosols.

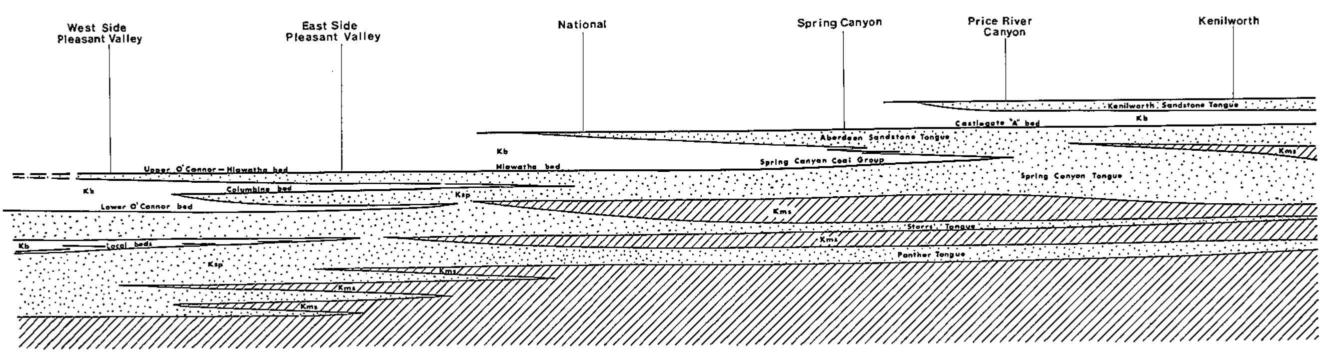

FIGURE 3.—*Diagrammatic cross section showing complex intertonguing of the Blackhawk, Star Point, and Mancos Formations (after Blanchard 1981).*

FIGURE 4.—*This east-facing view of Eccles Canyon Skyline Mine illustrates the deep colluvial and vegetative cover masking the bedrock.*

A section of the Star Point Sandstone was measured in Eccles Canyon. The sands are well sorted and exhibit planar cross-sets, as well as steeply dipping cross-sets.

One persistent sandstone horizon is extremely convoluted. This 50-cm-thick bed might have served as a glide plane for slumped overlying beds.

Nearly 400 m of Star Point Sandstone is exposed along the north flank of Eccles Canyon, SW $\frac{1}{4}$, section 17, T. 13 S, R. 7 E. Electric logs from gas wells in the quadrangle show the Star Point Sandstone to be 393 m thick.

Numerous fossils are present in the Star Point Sandstone. Carbonized leaf-films are frequently visible on sandstone parting planes. Floral elements observed include *Cercidiphyllum* and numerous unidentified leaves and stems.

The Star Point Sandstone is rich in trace fossils. Those observed include *Ophiomorpha, Arenicolites, Thalassinoides, Arthrophycus,* smooth tubes, large tubes, and plug-shaped burrows.

The prominent Star Point exposures along the northern face of Finn Canyon, NW $\frac{1}{4}$, SE $\frac{1}{4}$, section 32, T. 13 S, R. 7 E, are composed of multiple repetitions of laminar to low-angle, east-dipping cross-sets which are bioturbated in the upper third. In one 5-m unit eight repetitions of this sequence can be seen. Escape burrows locally are traceable from one bioturbated zone into the overlying laminar zone. *Ophiomorpha* and 23-mm-wide smooth tubes are common. Some bioturbated zones contain abundant concretions, similar to those seen in the oyster-bearing biomound of unit 28 of the Mancos measured section.

The shelly fauna includes *Pinna, Ostrea, Cucullaea,* and several small unidentified pelycepods.

A 5-cm-thick shale layer between two massive sands yielded several ostracod taxa and the foraminifera *Haplophragmoides rudis*.

Two significant coal horizons occur in the Star Point Sandstone. The Lower O'Connor coal bed underlies the Upper O'Connor coal by 6 to 53 m. It ranges from a feather edge to 9.1 m thick, with significant local variations and splitting. It is generally about 3 m thick across much of the quadrangle.

The Flat Canyon seam underlies the Upper O'Connor bed by 42 to 91 m. It is almost as widespread as the Upper O'Connor seam and ranges from 1.0 to 4.6 m thick. The sandstone wedge between the Flat Canyon and Lower O'Connor coals apparently thins rapidly to the northwest. It is 22 m thick in the NW $\frac{1}{4}$, section 24, T. 13 S, R. 6 E, and thins to a feather edge in the NW $\frac{1}{4}$, section 14, T. 13 S, R. 6 E.

Other coal horizons are localized and rarely reach economic thicknesses. Data from an exploration hole in the south central portion of the quadrangle gave evidence of seven coal seams, each at least 0.6 m thick, below the Upper O'Connor coal seam. The Columbine coal beds lie between the Upper and Lower O'Connor seams, as shown in figure 3.

The Star Point Sandstone consists of a variety of types of deposits. Howard (1966) noted five different facies of the Panther Tongue exposed in the western Book Cliffs and northern Wasatch Plateau. He interpreted these facies as elements of a composite deltaic sequence.

Marley and others (1979) suggested that the uppermost Star Point Sandstone Tongue "represents accretion-ridge barrier sands which were reworked by waves into longshore drift from distributary mouth bar–distributary channel point sources." Such an accumulation is also suggested by the present study for Star Point beds in the Scofield area.

BLACKHAWK FORMATION

The Blackhawk Formation is of Campanian age and was named by Spieker and Reeside (1925, p. 443). At the type section the formation consists of thick sandstones with intervening beds of shale, siltstone, limestone, and coal.

Approximately 75% of the surface of the Scofield Quadrangle consists of Blackhawk beds (fig. 5). Most Blackhawk exposures, however, are contained in two north–south strips that are separated by a belt of Star Point Sandstone outcrops. Most uplands in the quadrangle east of Mud Creek are held up by Blackhawk rocks. Most of the uplands between Mud Creek and Upper Huntington Creek are also capped by Blackhawk rocks. Outcrops of Blackhawk Formation occur along roadcuts and on a few south-facing slopes. The best exposures occur along roadcuts of Boardinghouse Canyon, between the faulted contact in NW $\frac{1}{4}$, NW $\frac{1}{4}$, section 31, T. 13 S, R. 7 E, and the summit in NE $\frac{1}{4}$, NW $\frac{1}{4}$, section 36, T. 13 S, R. 6 E. Portions of the upper Blackhawk Formation are well exposed in a faulted cliff face in the SE $\frac{1}{4}$, SE $\frac{1}{4}$, section 22, T. 13 S, R. 6 E. Generally, Blackhawk bedrock is masked with a thick layer of colluvium.

The Blackhawk Formation is about 400 m thick in the Scofield area. This thickness is partially based upon an electric log of a coal exploration drill hole in section 15, T. 13 S, R. 6 E, which penetrated Price River through Star Point beds. That thickness is also indicated by surface observations throughout the quadrangle.

The lower boundary of the formation is the base of the Upper O'Connor coal seam. The upper boundary was mapped at the first appearance of very light-colored sandstones, at a sharp increase in sediment size, and is usually marked by a change of slope, from gentle below to steeper above.

The lower boundary may be clearly seen at several mine entrances, as, for example, the O'Connor Mine, the Skyline Mine, and the Winter Quarters Mine. Outcrops along the Boardinghouse Canyon road in NW $\frac{1}{4}$, NW $\frac{1}{4}$, section 31, T. 13 S, R. 7 E, also show basal Blackhawk beds. The Upper O'Connor seam is the best marker bed in the quadrangle. The structural contours of figure 5 were drawn using the top of this coal seam as the datum.

The upper boundary of the Blackhawk Formation is only poorly exposed. Slope changes near the contact are most apparent along Winter Quarters and Granger Ridges in the northwest corner of the quadrangle. The light-colored sandstone associated with the boundary is exposed along the skyline road in the NE $\frac{1}{4}$, NW $\frac{1}{4}$, section 23, T. 13 S, R. 6 E. The upward coarsening of sediments shows in NW $\frac{1}{4}$, section 3, T. 14 S, R. 6 E, where grit-sized sandstone marks the boundary at the base of the Castlegate Sandstone. Sandstones change from fine-grained up to grit-sized sandstone at the contact of the Blackhawk Formation and the Castlegate Sandstone in SE $\frac{1}{4}$, NE $\frac{1}{4}$, section 30, T. 12 S, R. 7 E. Where subsurface information is available, the top of the Blackhawk Formation was drawn 405 m above the top of the Upper O'Connor coal seam.

The Blackhawk Formation is mostly sandstone and siltstone with minor amounts of shale, limestone, and coal. The sandstone is mainly fine grained with infrequent medium-grained channel-lag deposits. It ranges from medium orange brown to light yellow gray. The sandstones are very thin bedded to thick bedded. The thicker sandstone sequences commonly form slight ledges. Numerous plant fragments and impressions were found in the sandstone beds, including *Phoenicites* and numerous unidentified leaves, stems, and cones.

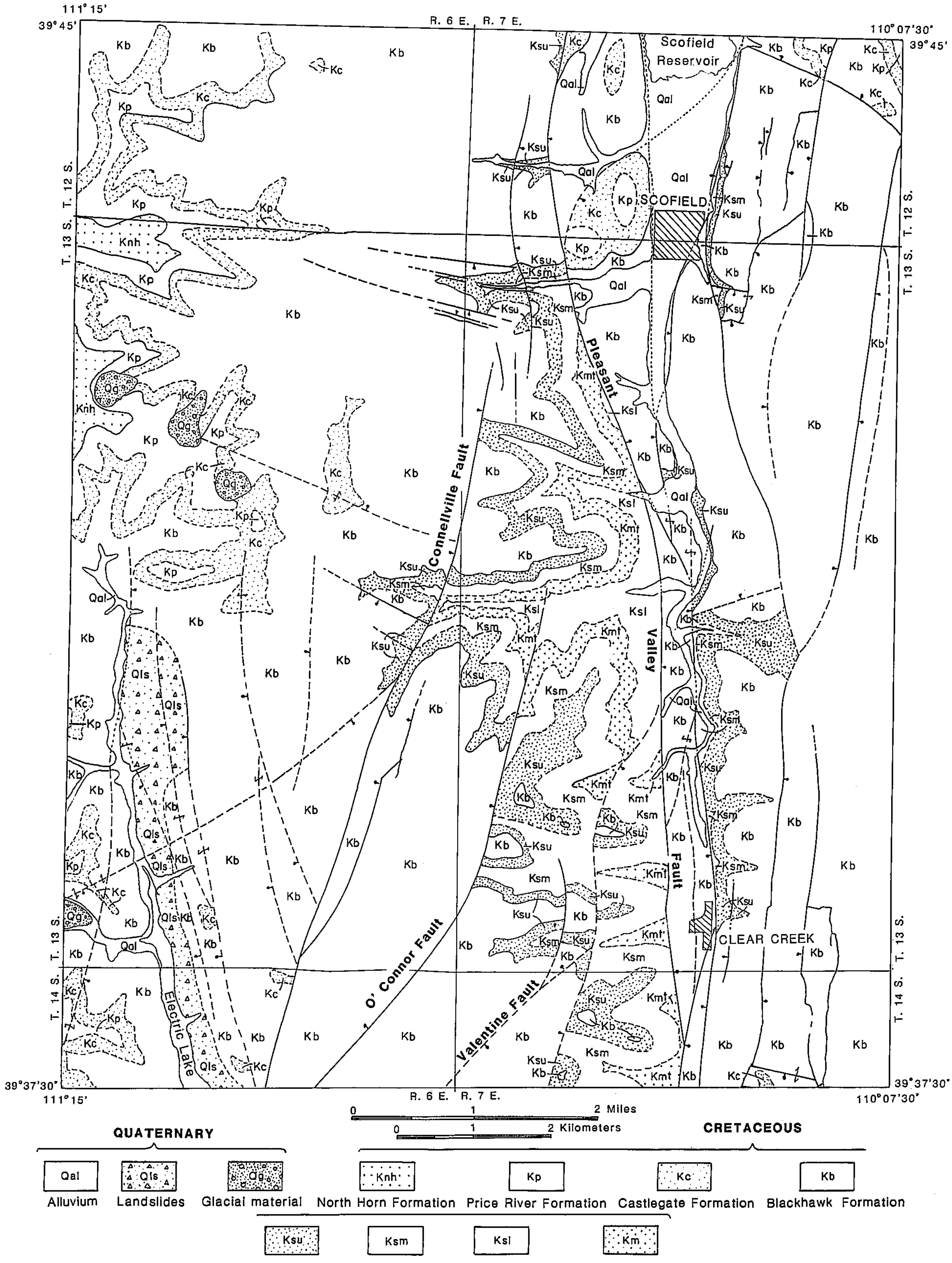

FIGURE 5.—*Surface geology of the Scofield Quadrangle.*

Sandstone beds in the lower Blackhawk are commonly flat-bottomed sheets. Upper Blackhawk sandstones are frequently festoon cross-bedded with convolute laminations. Siltstones and shales are laminated to medium bedded, and are light blue gray to medium olive gray.

Several Blackhawk sections were analyzed from electric logs of exploratory wells that penetrated the entire formation. Clean sandstone comprises approximately half the section. About one-third is siltstone and dirty sandstone, and the remaining one-sixth is composed of shales and mudstones. The percentage of shale and mudstone decreases upward in the Blackhawk Formation, from an average of 23% in the lower third to 11% in the upper third. Marley and others (1979) also noted that Blackhawk sandstone beds coarsen upward in their study interval.

Blackhawk coal beds are the best marker horizons in the study area. Unfortunately the coal beds all vary markedly in thickness and continuity. The Upper O'Connor seam is the most nearly ubiquitous, though it varies from 0.6 to 6.0 m thick (fig. 6). Another widespread coal bed is the Haley or McKinnon seam, which is located about 100 m above the Upper O'Connor seam. It varies from 0 to 3.2 m thick. Other coal seams are more local and only occasionally reach economic thicknesses, as, for example, the 9-m Columbine seam at the Columbine mine.

Stream-channel deposits are abundantly preserved in the Blackhawk Formation. One such channel is well exposed along Utah 96, in a roadcut into the west side of Pleasant Valley, at NE $\frac{1}{4}$, SE $\frac{1}{4}$, section 20, T. 13 S, R. 7 E, as shown in figure 7. The sandstone channel cuts into and has compressed a coally bed. The channel fill is 8 m wide and 70 cm deep, and the stream was flowing to the east. The channel fill is overlain by flat-lying splay sandstones. Another larger fill of an east-flowing channel is exposed along the east side of Pleasant Valley in SE $\frac{1}{4}$, NE $\frac{1}{4}$, section 29, T. 13 S, R. 7 E, about 40 m above the valley floor.

Only one limestone bed was discovered in the Upper Blackhawk in this quadrangle. It is a thin, laminated, light green gray micrite, which crops out along a jeep road in SE $\frac{1}{4}$, SW $\frac{1}{4}$, section 12, T. 13 S, R. 6 E. Only 1.3 m of the unit is visible in outcrop.

The Blackhawk Formation has been interpreted as representing upper and lower delta-plain deposits. Spieker (1931, p. 37) envisioned a broad floodplain of low relief with areas of sandy beach, lowland swamp, forest-covered floodplain, and coastal lagoon. Young (1955, 1975) suggested that lower Blackhawk deposits represent lagoonal and paludal deposits protected by barrier beaches and offshore bars. Upper Blackhawk deposits were seen to represent the regressive upper floodplain.

Parker (1976) collected and studied upper Blackhawk floras and concluded that three sedimentary environments were present, including peat-forming swamps, bottomlands, and point bars. Johnson (1978) concluded that lower Blackhawk sediments accumulated in a shallow-water, wave-modified delta system and that upper Blackhawk sediments accumulated in meandering stream and floodplain environments.

Marley and others (1979) suggested that the lower Blackhawk environment was probably similar to the present Louisiana coast.

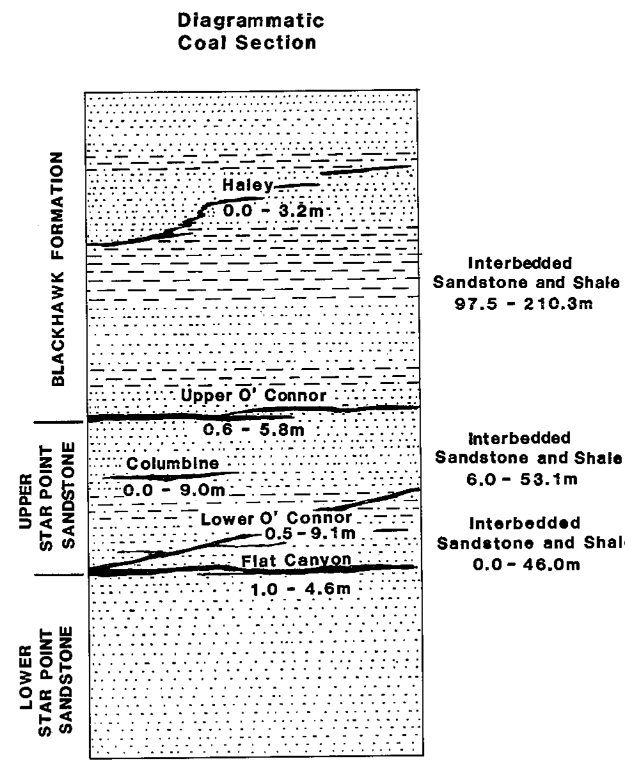

FIGURE 6.—*Diagrammatic coal section.*

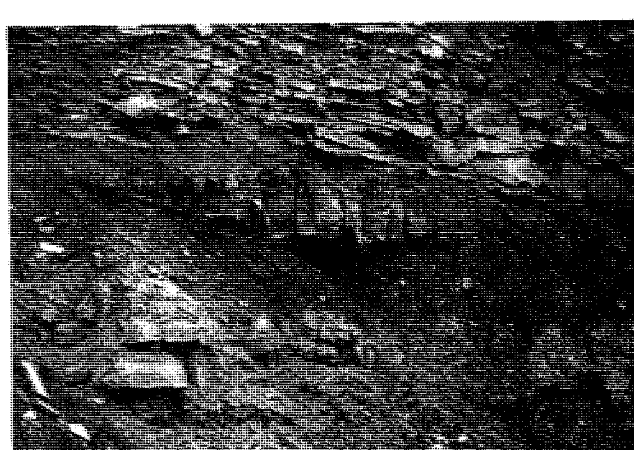

FIGURE 7.—*Channels are common in the lower Blackhawk Formation.*

CASTLEGATE SANDSTONE

The Upper Cretaceous Castlegate Sandstone was originally considered a member of the Price River Formation by Spieker and Reeside (1925, p. 445). Fisher and others (1960) later raised the Castlegate Sandstone to formation rank because of its lateral continuity and distinctive cliff-forming habit.

The Castlegate Sandstone is partially exposed at numerous localities in the study area (fig. 5). Most exposures of Castlegate beds occur in uplands of the northwest quarter of the quadrangle. The formation also caps several downdropped blocks along the upper reaches of Electric Lake, and also armors crests of downdropped blocks in the graben in the northeast quarter of the quadrangle. Castlegate beds are also poorly exposed on a ridge crest in SE $\frac{1}{4}$, SW $\frac{1}{4}$, section 4, T. 14 S, R. 7 E.

Oberhansley (1980) stated that the Castlegate Sandstone is from 66 to 98 m thick in the eastern part of the Fairview Lakes Quadrangle, immediately to the west of this study area. Moussa (1965) reported that the Castlegate Sandstone is 205 m thick in the Soldier Summit 15′ Quadrangle to the northeast.

Poor exposures and the nondistinctive nature of the Castlegate Sandstone prevented independent determination of thickness. I used the topographic expression and the Castlegate thickness established by Oberhansley (1980) in the northeastern edge of the Fairview Lakes Quadrangle to map boundaries in the Scofield area.

The Castlegate Sandstone caps uplands of the northwestern portion of the quadrangle and holds up elongate ridges. This effect is especially evident in sections 26, 27, and 35 of T. 12 S, R. 6 E, where more resistant Castlegate sandstone beds armor the ridges.

The light-colored lower Castlegate sandstone beds can be locally used as marker beds. These beds are especially apparent along the road in SE $\frac{1}{4}$, SW $\frac{1}{4}$, section 14, T. 13 S, R. 6 E, and NE $\frac{1}{4}$, NW $\frac{1}{4}$, section 23, T. 13 S. Here light yellow gray fluvial sandstones of the lower Castlegate Sandstone are readily apparent in occasional outcrops and in the lighter soil they produce.

The increase in grain size of Castlegate over Blackhawk sandstones is sometimes a helpful guide, but the pattern does not always hold true. For example, in exposures along the roads of sections 12, 13, 14, and 23, T. 13 S, R. 6 E, where structural and stratigraphic control is reliable, the lower sandstones of the formation show no significant size increase over underlying units.

The relatively poor outcrops of SE $\frac{1}{4}$, SW $\frac{1}{4}$, section 32, T. 12 S, R. 7 E, show a slight increase of grain size over the Blackhawk sandstones that are mainly medium-grained sand. Castlegate Sandstone in SE $\frac{1}{4}$, NE $\frac{1}{4}$, section 30, T. 12 S, R. 7 E, is medium to very coarse grained. The Castlegate sandstones of SW $\frac{1}{4}$, NW $\frac{1}{4}$, section 3, T. 12 S, R. 6 E, are also medium to very coarse grained. Local differences of texture within the lower Castlegate sandstone are likely due to changing river patterns and variation in stream load during deposition of the unit over the quadrangle.

The lower boundary of the Castlegate Sandstone is only poorly exposed. Nowhere in the quadrangle does the Castlegate Sandstone form the distinctive cliffs that characterize it in the frontal area in the eastern Wasatch Plateau or in the Tavaputs Plateau to the east. The Castlegate–Blackhawk boundary has been mapped at the top of a marked slope change, at the lowest appearance of very light gray sandstones and at a marked increase in grain size. These changes mark a base of the Castlegate Sandstone 405 m above the Upper O'Connor coal bed. Where lower Castlegate beds are covered or nondistinctive, the boundary was drawn 405 m above the top of the Upper O'Connor coal bed.

The upper boundary of the Castlegate Sandstone is marked by a change of slope. It is most apparent where the Price River Formation caps the Castlegate Sandstone in the western third of the quadrangle. Price River beds produce a steeper slope above the Castlegate ridges.

Price River units may be slightly coarser than the Castlegate Sandstone, though this characteristic is not diagnostic. The Castlegate Sandstone–Price River Formation transition can be seen to coarsen upward on Granger Ridge, NW $\frac{1}{4}$, SE $\frac{1}{4}$, section 26, T. 12 S, R. 6 E. Several outcrops show the upward coarsening of the conglomeratic Price River rocks over the fine-grained Castlegate sandstones.

A contact zone is moderately well exposed near the base of a cirque face, in SE $\frac{1}{4}$, section 10, T. 13 S, R. 6 E, where porous, fine-grained Castlegate sandstone grades upward into better cemented, fine-grained Price River sandstone.

The Castlegate Sandstone is light yellow gray to medium yellow brown. It is generally a fine-grained sandstone but occasionally has layers containing very fine pebbles. Minor partings of shale also occur throughout the section. No outcrops were sufficiently exposed to permit measurement of a section. Electric logs and drill data from wells in the quadrangle show the formation to be approximately 80% sandstone, 13% siltstone, and 7% shale.

In all localities where the Castlegate Sandstone crops out, it is in fluvial facies. The fluvial nature of the beds is best shown in striking point-bar deposits in SE $\frac{1}{4}$, SE $\frac{1}{4}$, section 11, T. 13 S, R. 6 E, and NE $\frac{1}{4}$, NW $\frac{1}{4}$, section 23, T. 13 S, R. 6 E. Frost heaving has made cross-bed dip measurements and flow direction inaccurate in these outcrops.

The observed sedimentary textures, structures, and environments of local Castlegate deposits are in agreement with Van de Graaff's conclusion (1972, p. 561) that these deposits belong to the Castlegate fluvial facies. The fluvial beds were deposited in a system of coalescing, low-sinuosity streams, which flowed dominantly toward 60° to 100° east of north.

PRICE RIVER FORMATION

The Upper Cretaceous Price River Formation was named by Spieker and Reeside (1925, p. 445) from exposures in Price River Canyon near Castlegate, Utah. Fisher and others (1960, p. 14) later raised the lower member, the Castlegate Sandstone, to formation rank and restricted the Price River Formation to the ledge- and slope-forming units of the type section.

The formation caps slopes on the Castlegate Sandstone along the west slopes of Upper Huntington Canyon and the highlands of the northwestern portion of the quadrangle. It also caps the hills directly west of the town of Scofield and those carved in beds that have been dropped down by the Fish Creek graben, located in the extreme northeast corner of the quadrangle, sections 27 and 28, T. 12 S, R. 7 E. The best exposures of the Price River Formation appear on cirque facies in section 10, T. 13 S, R. 6 E.

The restricted Price River Formation is 149 m thick in the type locality. Gunderson (1961, p. 21) reported the combined Price River–Castlegate beds to be 122 m thick in the northwestern highlands of the quadrangle. His Price River (nonrestricted) isopachs show the Price River Formation thickens rapidly to 300 m toward the northwest and southwest. He postulated that areas of thinner Price River beds might have been caused by active anticlines during Price River time.

Moussa reported the formation to be 158 m thick where he measured it 8 km northeast of Scofield. This figure varies significantly from the 83 m of Price River Formation beds that Oberhansley (1980) measured in the western part of the Fairview Lakes Quadrangle. On the east side of that quadrangle, Oberhansley reported the formation to range from 66 to 88 m thick, depending on topography.

Partial exposures in the cirques of the northwestern highland showed the Price River Formation to be at least 73 m thick. As with the Castlegate Sandstone, I used the topographic expression and map patterns as established by Oberhansley (1980). According to these topograhic patterns, the Price River Formation ranges in thickness from 73 to 97 m in this quadrangle.

The base of the Price River Formation is located at the base of a steep slope that tops the Castlegate Sandstone ridge. This transition is well expressed on the north ridge crest of Bobs Canyon, NW $\frac{1}{4}$, SE $\frac{1}{4}$, section 3, T. 13 S, R. 6 E. The slope steepens above the light-colored outcrops of the upper Castlegate Sandstone. The slope is also noticeably steeper at the base of the isolated Price River Formation exposure in SE $\frac{1}{4}$, section 15, T. 13 S, R. 6 E.

The Castlegate Sandstone–Price River Formation transition is also marked by a sharp increase in grain size. The Price River base marks the first appearance of conglomerates on Granger Ridge, NW $\frac{1}{4}$, SE $\frac{1}{4}$, section 26, T. 12 S, R. 6 E. Here a paleochannel with a current direction of 195° is filled with conglomerate with a gritty matrix. Nearby a channel with medium-grained sand to medium-sized pebbles shows a paleocurrent direction of 92°.

The upper boundary of the Price River Formation is marked by the first appearance of the characteristic medium red mudstone of the lower North Horn Formation. This transition is best seen in the cirque exposures of SW $\frac{1}{4}$, NW $\frac{1}{4}$, section 10, T. 13 S, R. 6 E, where North Horn mudstones drape over Price River sandstones.

The Price River Formation is composed of very fine- to coarse-grained, light yellow brown sandstones with interbedded mudstone, shale, and siltstone. The whole formation is composed of complexly lenticular deposits of streams which were flowing dominantly in an eastward direction. Pebbles and cobbles of gray quartzite and chert mark channel-lag and point-bar deposits.

The Price River beds exposed in the cirque of the SE $\frac{1}{4}$, section 10, T. 13 S, R. 6 E, are largely well cemented. Cross-beds and slumped convoluted beds are common. Flat-pebble conglomerates appear throughout the formation. A friable, gypsum-cemented, fine-grained sandstone forms a slope at the top of the cirque. Many of the sandstone parting planes show carbonized leaf films. Slope talus yielded a *Phoenicites* leaf.

Spieker (1931, p. 44) envisioned the accumulation of the Price River Formation (nonrestricted) on an area of low relief similar to that concluded for the Blackhawk Formation. He also noted, however, that Price River streams and rivers were much more active and capable of transporting coarser sediments.

Van de Graaff (1972, p. 561) considered the Price River Formation of this area to represent a transitional piedmont-fluvial facies of coalescing braided and low-sinuosity streams that extended eastward from western highlands.

The top of the Price River Formation was considered by Spieker and Reeside (1925, p. 445; Spieker 1931, p. 42) to be an unconformity beneath North Horn beds. The rapid decrease of sediment size from upper Price River to lower North Horn beds, as well as the great variation of the local Price River Formation thickness, supports such a conclusion.

NORTH HORN FORMATION

The North Horn Formation was described by Spieker and Reeside (1925, p. 448) as the lower member of the along the Connellville Fault in section 2, T. 14 S, R. 6 E. Only faults with a throw of at least 3 m were mapped. The faults are nearly vertical and produce a minor graben in Upper Huntington Canyon.

The second set of faults is the Pleasant Valley fault system. They dissect the plateau parallel to Pleasant Valley, and more than 40 faults which belong to this system have been mapped in the quadrangle. The largest is the Pleasant Valley fault which follows the west side of Pleasant Valley. It is visible from Long Canyon, in the south, to Granger Ridge, in the north. It trends nearly north–south in the southern portion of the quadrangle but angles somewhat westward near Green Canyon before straightening to the north near Woods Canyon. As mapped here, the trace is slightly east of Taft's (1907, p. 338) mapped contact. The displacement is approximately 400 m on Granger Ridge and 470 m in Winter Quarters Canyon and Eckles Canyon. Too little is known about the graben blocks to the south to accurately calculate the displacement. One of these faults is visible in figure 11.

The eastern boundary fault of the Pleasant Valley graben parallels Long Canyon (earlier maps show this canyon as Miller Canyon). It is a scissor fault. The eastern block is down in the northern part of the trace relative to the western block, but is up in the southern part. Displacement is as great as 80 m.

Another major fault is the O'Connor Fault, whose trace cuts across Coal and Whiskey Canyons. Near Boardinghouse Canyon it has a displacement of about 130 m. The Valentine Fault of Spieker (1931, p. 56) seems to merge with a fault of the Pleasant Valley system in section 6, T. 14 S, R. 7 E.

The Fish Creek graben (fig. 5) is an anomalous structure that trends northwest–southeast. It angles across the northeast corner of the quadrangle, faulting Castlegate beds against Blackhawk beds. The throw of the southern fault of the graben is about 200 m. It is believed that the Fish Creek graben is younger than the Pleasant Valley fault system.

Walton (1955, p. 410) has suggested that when the grabens began to develop, plastic flowage of underlying Arapian salt would have aided in displacement of the boundary faults. There is some evidence that some of these faults might be Cretaceous growth faults. The T. F. Kearns #1 well in section 13, T. 13 S, R. 6 E, and the Utah Fuel #8 well in section 19, T. 13 S, R. 7 E, are 1.7 km apart. The Connellville Fault separates the two wells. The distance between the top of the Upper O'Connor coal and the top of the Ferron Sandstone is 125 m greater in the downdropped western block than in the eastern block. This suggests either the Ferron had a dip of at least 4° in lower Blackhawk time or else the Connellville Fault was a growth fault with a pre-Blackhawk displacement of 125 m. The post–lower Blackhawk displacement is only 76 m on this fault segment. Faults of the Scofield Quadrangle are a major hindrance to coal mining in the area. Major faults have necessitated tunneling through sandstone walls to rejoin the coal seam. The complex fault system also increases the expenses of estimating coal reserves and preparing a mine plan.

The stresses that developed the faults are apparently still active. Mining equipment was buried near the fault zone in W $\frac{1}{2}$, section 25, T. 13 S, R. 6 E, as the walls burst under only 76 m of cover. North–south-trending fractures rapidly develop in the roof rock of local mines. These fractures frequently necessitate mine regrading and extra roof bolting.

The Wasatch Plateau has experienced subsequent regional tilting, which has been attributed to its position between the Colorado Plateau and the Basin and Range Provinces (Hunt 1956).

GEOMORPHOLOGY

GENERAL STATEMENT

The Scofield Quadrangle is part of the High Plateaus section of the Colorado Plateau. The mean precipitation is 24 to 32 inches, mean minimum temperature in January is 6° to 8° F, and the mean maximum temperature in July is 76° to 80° F.

Geomorphic features show evidence of drainage diversion, glaciation, slumping, and downcutting.

GLACIATION

The end moraine of a large valley glacier is preserved in the mouth of Boulger Canyon, NE $\frac{1}{4}$, SE $\frac{1}{4}$, section 33, and NW $\frac{1}{4}$, SW $\frac{1}{4}$, section 34, T. 13 S, R. 6 E. The end moraine there is nearly 30 m thick and 380 m wide. It is composed of unconsolidated rubble of Blackhawk, Castlegate, Price

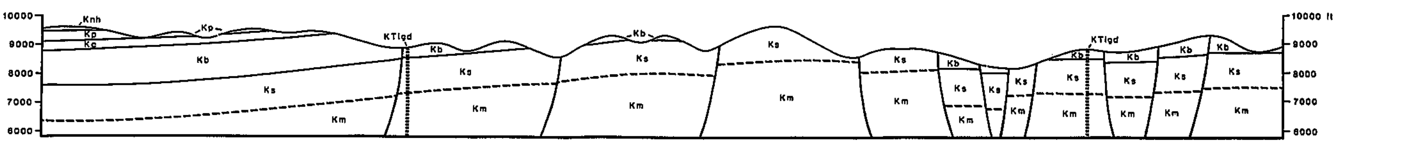

FIGURE 9.—*Northwest-southeast cross section across the Clear Creek structure.*

River, North Horn, and Flagstaff Formations. The debris is unstratified and ranges from silt to angular boulders. Four kettles, created as the glacier melted, have been identified and mapped.

Pleistocene glaciers deposited hummocky morainal debris at the base of cirques in the NW $\frac{1}{4}$ and SE $\frac{1}{4}$, section 10, and NW $\frac{1}{4}$, section 14, T. 13 S, R. 6 E. A series of end moraines marks multiple stages of regressive stages. A prominent tarn remains in the NW $\frac{1}{4}$, SE $\frac{1}{4}$, section 10, T. 13 S, R. 6 E.

Wasatch Plateau glaciation was assigned to the Wisconsin age by Spieker and Billings (1940, p. 1174). Knoll (1977) described similar glacial advances in the Lemhi Range of Idaho. He dated these advances as Pinedale age.

Spieker and Billings (1940, p. 1190) noted the glaciers were almost exclusively restricted to east- and north-facing slopes of the westernmost high ridge of the plateau. They suggested that air currents—affecting precipitation, drifting, accumulation, and melting—must have played an important part in the orientation of the glaciers. Degraff and Zsiray (1978) showed that precipitation was secondary to favorable airflow patterns and slope aspects in the distribution of cirques. The three cirques mapped in the quadrangle formed on northeast-facing slopes (fig. 12).

DIVERTED DRAINAGE

Abundant blocks of Flagstaff Limestone are scattered along the banks of Upper Huntington Creek. Flagstaff debris is seen as high as 50 m above the present stream level in wide stream terraces visible above the valley floor. These terraces are at elevations of 2,646 m (8,680 ft) and 2,667 m (8,750 ft) in the SW $\frac{1}{4}$, section 22, and NW $\frac{1}{4}$, section 27, T. 13 S, R. 6 E, and are visible on both the undisturbed west slope of Upper Huntington Canyon and the unstable east slope. There are presently no Flagstaff Limestone exposures in the headwaters of Upper Hunt-

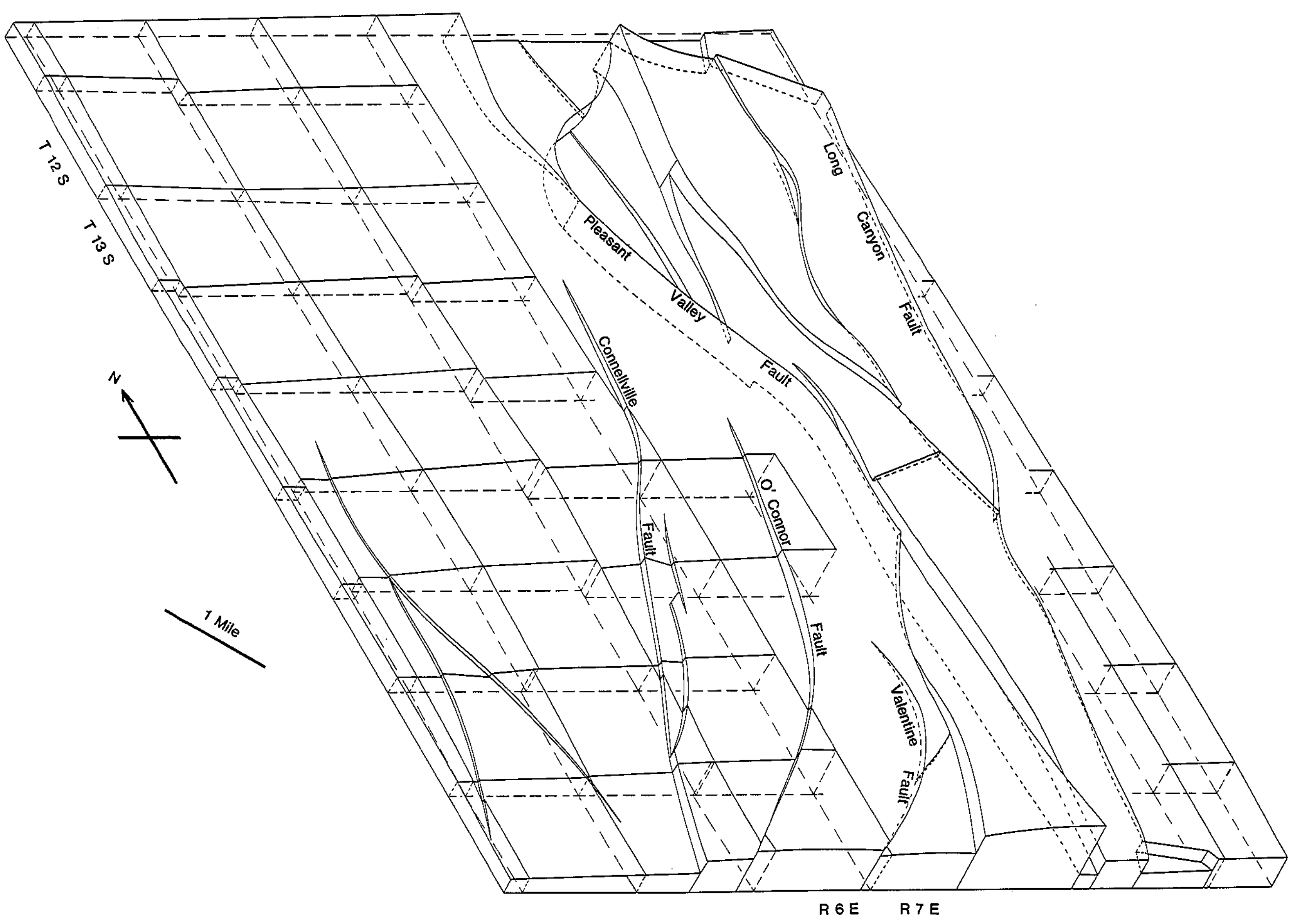

FIGURE 10.—*Isogonal diagram drawn on the top of the Upper O'Connor coal bed.*

FIGURE 11.—*Visible on the northern slope of the mouth of Eccles Canyon, this near vertical fault is part of the Pleasant Valley fault system.*

ington Creek. That Flagstaff rubble was swept in from far to the west is evidence of diverted drainage.

Oberhansley (1980, p. 39) documented barbed drainage east of the Gooseberry Fault. As a result of movement along the East Gooseberry Fault, Gooseberry Creek has captured the headwaters of the Upper Huntington and Flat Canyon Creeks. Prior to capture, Huntington Creek drained Flagstaff outcrops west of the Gooseberry Fault, and debris was brought into Huntington Canyon.

A poorly preserved bone fragment was found in gravels 16 m above the present stream level, at the mouth of Swens Canyon, SW$\frac{1}{4}$, NW$\frac{1}{4}$, section 27, T. 13 S, R. 6 E. It appears to be a fragment of a limb bone of a large Pleistocene mammal and suggests that the stream diversion is at least as old as the Pleistocene.

LANDSLIDES

A landslide zone was identified and mapped along the east slopes of Upper Huntington Canyon in sections 22, 27, and 34, T. 13 S, R. 6 E, and section 3, T. 14 S, R. 6 E (fig. 13). The landslide zone comprises an area of about 2.7 million m^2 (3.3 million sq. yds.) in the quadrangle.

This area was mapped as relatively unstable in a slope instability study of the Wasatch Plateau by Godfrey (1978). These slopes are at angles of over 40%, are underlain by the Blackhawk Formation, and receive 12.6 cm (32 in) of precipitation annually, all adding to their unstable character. Landslides in this zone could be caused by a number of factors. Schroder (1971, p. 5) noted the high incidence of landslides in Cretaceous formations. He attributed it to the high proportion of argillaceous sediments within these beds. The interbedded sandstones, siltstones, and shales of the Blackstone Formation also dip 6° west in the landslide zone, and the landslides also overlie a fault zone.

The crown of the landslide zone intersects a fault in the SE $\frac{1}{4}$, section 22, and NE $\frac{1}{4}$, section 27, T. 13 S, R. 6 E. Fault movement may have initiated sliding or may have offset shale and sandstone beds, increasing hydrostatic pressures in the beds. Such increased hydrostatic pressures could then create planes of weakness.

Eight individual landslide masses have been mapped. The individual rockslides, along the east side of Upper Huntington Canyon in sections 22 and 27, T. 13 S, R. 6 E, may be the area of translation of a much larger block.

The most recent slump is located on the east bank of Electric Lake, NE $\frac{1}{4}$, section 3, T. 14 S, R. 6 E. The distance from the top of the disturbed block to the crown is about 12 m. It appears to have been induced by undercutting by Electric Lake. Such landslides are potentially hazardous to the reservoir.

ECONOMIC GEOLOGY

PETROLEUM AND NATURAL GAS

The Clear Creek anticline has produced significant quantities of high quality methane. The known productive portion of the structure is enclosed by the Connellville and the Pleasant Valley Faults.

Work by Walton in 1950 led him and his partners to obtain leases over the Clear Creek anticline. Byrd-Frost completed the discovery well in October 1951 in section 13, T. 13 S, R. 6 E, and additional wells soon followed. The open flow of the producing wells in the quadrangle varied from 3.5 to 58 million cubic feet of gas per day. A pipeline built to Provo started accepting gas in October 1953 and by mid-July 1954 production had reached 12 billion cubic feet. Edson and others (1954, p. 93) estimated reserves of 700 billion cubic feet of gas. This estimate proved to be overly optimistic in that by September 1982 only 136 BCF had been produced.

The Clear Creek field is a structural trap with strong fracture-controlled intercommunication between wells (Walton 1963, p. 344). Seven producing sandstones have been identified in the Upper Cretaceous Ferron Sandstone. Walton (1955, p. 412) noted that the Ferron Sandstone is cleaner and better sorted at Clear Creek than in the surrounding areas. He suggested that movement during Ferron time may have formed a local offshore bar of cleanly washed sand, surrounded by lagoonal facies containing coal and poorly sorted sands. Average porosities are 12% to 15%, with 15% connate water, and permeabilities are up to 1.0 millidarcy.

Walton (1955, p. 412) wrote that the producing field seems to be sufficiently fault controlled to suggest that migration of gas into the field occurred after development

FIGURE 12.—*Pleistocene glaciers formed cirques in the heads of east-facing valleys.*

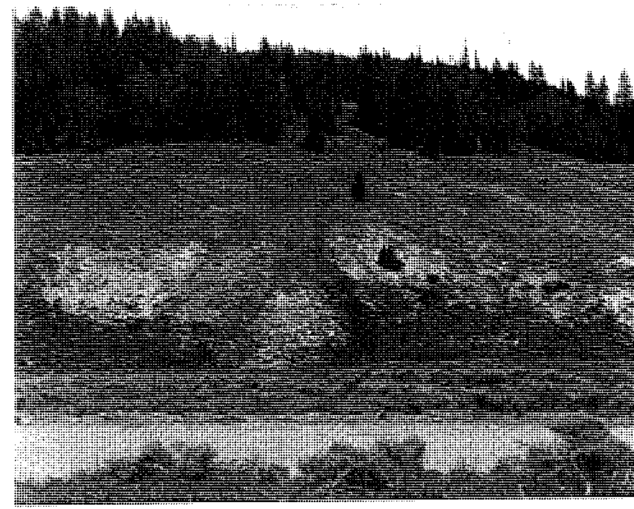

FIGURE 13.—*Numerous landslide masses coalesce in Upper Huntington Canyon.*

of the Pleasant Valley graben. This faulting increased the closure of the structure from perhaps 250 to 550 m.

A well on the apex of the surface anticline, NE $\frac{1}{4}$, section 5, T. 14 S, R. 7 E, tested deeper horizons. Rocks as deep as the Morrison Formation were tested, but only the Ferron Formation produced hydrocarbons.

Present exploration in the quadrangle focuses on deeper horizons and faulted blocks along the flanks of the main Clear Creek structure.

WATER RESOURCES

Water is plentiful in the quadrangle. Streams in the southwest corner flow into Electric Lake, and all other drainages flow into Scofield Reservoir. Five streams in the quadrangle flow year-round: Mud Creek, Flat Canyon Creek, Upper Huntington Creek, and the streams of Winter Quarters Canyon and Eckles Canyon. Mud Creek is the largest of these streams. A measurement in the late summer of 1975 showed it to have a discharge of 0.1 cms (3.7 cfs) (Waddell and others 1978).

Drinking and industrial supplies are obtained through shallow wells into the sandstones of the Blackhawk and Star Point Formations. These wells discharge at a rate of about 3.2 L/s (50 gal/min). Chemical analyses of water from several of these wells show water to have 280 to 482 mg/l dissolved solids, with 20 to 780 ug/l dissolved iron (Waddell and others 1978).

SCENIC AND RECREATIONAL AREAS

More than 65 km^2 (25 mi^2) of the quadrangle is part of the Manti-LaSal National Forest. These lands lie in the western third of the quadrangle. The forest lands are rich in wildlife with deer, elk, moose, bear, bobcat, skunk, beaver, owls, and gophers. The forest is heavily used during the fall big-game hunting season.

Electric Lake provides recreational boating and fishing. Limited facilities are available near the boat ramp on the northwestern shore and on the moraine at the mouth of Boulger Canyon.

Scofield Reservoir also provides recreational boating and fishing. Excellent facilities can be found at a state campground along the east bank of the reservoir, several miles north of Scofield. Private camping and boating facilities are also available along the lake.

The Alpine School District conducts a year-round nature camp 3.2 km (2 mi) south of Scofield. This camp gives students practical experience with botany, zoology, and history.

The appendix to this paper, manuscript pages 36–51, is on file at the Department of Geology, Brigham Young University, where a copy may be obtained.

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