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UNITED STATES DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SEDIMENTARY FEATURES OF THE BLACKHAWK FORMATION (CRETACEOUS) AT SUNNYSIDE, CARBON COUNTY, UTAH

By John O. Maberry II 1935-

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ABSTRACT

The Blackhawk Formation at Sunnyside, Utah, was deposited along the western margin of the Western Interior Cretaceous sea during southeastward withdrawal of the sea. Sand was the dominant type of land-derived sediment deposited in the Sunnyside district during the regressive phases. Sand bodies prograded seaward in response to changing sediment supply from a source west of Sunnyside. Where conditions were favorable for the accumulation of vegetable material, peat deposits formed and were later changed to bituminous coal by diagenesis. Studies of the coal bed show that the coals were formed from accumulation of small, low-growing plants and plant debris that was transported into the area of accumulation. Remains of large plants in the coals are rare.

Trace fossils, which are tracks, trails and burrows formed by organisms and preserved in the rock, are extremely abundant in the Blackhawk rocks. These biogenic sedimentary structures are common in Cretaceous deposits throughout the western United States. Trace fossil distribution in the rocks is controlled by the depositional environment preferred

by their creators. A study of the trace fossils of a locality allows a more precise determination of the conditions during deposition of the sediments. Water depth, bottom conditions, salinity, current velocity and amount of suspended nutrients in the water are some of the environmental factors that may be reconstructed by studying trace fossils.

The Blackhawk Formation at Sunnyside comprises two members, the Kenilworth Member and the Sunnyside Member. Field studies show that the formation may be further subdivided in the Sunnyside district, according to the precepts of units of mappable thickness and similar lithologic characteristics. The Blackhawk pinches out eastward and northward into the Mancos Shale, and names for submembers become meaningless. Names are of value in the region of interest, however, because of the prominence of the named units.

Coal mining is the main industry of the Book Cliffs region. Mines of the Sunnyside district are plagued by coal mine bumps, which are sudden, catastrophic releases of stress in the coal. Bumps cause loss of life, property damage, and loss of profit to mining companies. Bumps occur when shear stress built up in the coal exceeds the shear strength of the coal. Differential overburden pressure, faulting and tectonic activity, and lithology and structure of roof rocks are factors which influence bumps. Petroleum and natural gas (methane), which occur locally in pockets in the roof rocks above coal beds, may be diagenetic products of organic-rich sediments.

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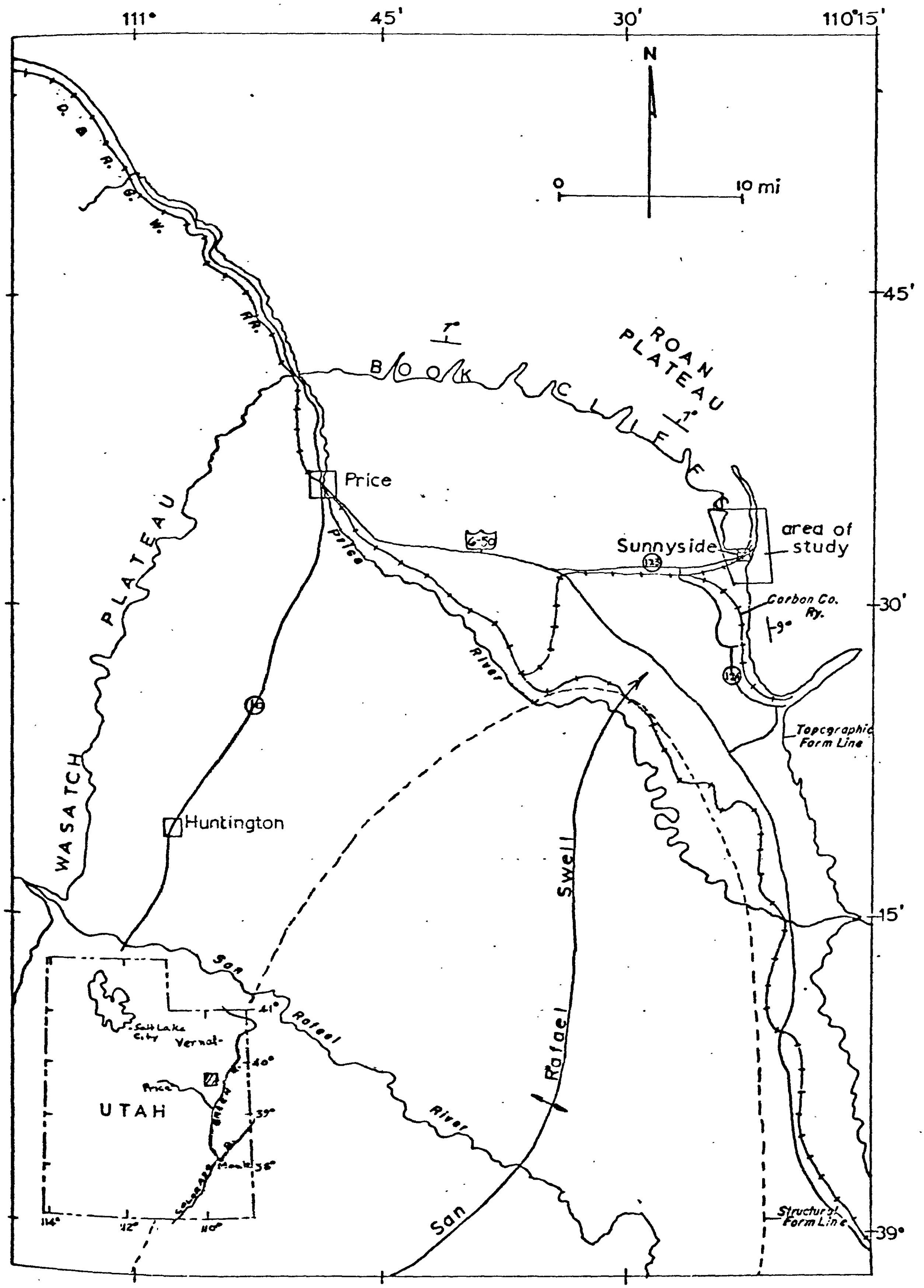
INTRODUCTION

The study was undertaken to determine the depositional environment of the Upper Cretaceous Blackhawk Formation at Sunnyside, Utah. Within the formation is a thick, extensively-mined coal bed that is the basis for the economy of the region. Parallel goals of the investigation were: to ascertain the relationship of sedimentary structures to coal mine bumps; to study and describe the trace fossils and inorganic sedimentary structures found in the rocks; and to ascertain the origin and mode of migration of petroleum and natural gas in the mines at Sunnyside.

Location

The Sunnyside district is in the western Book Cliffs, 27 miles east of Price, Utah (fig. 1). The district was named for the first town in the area. Sunnyside is the largest incorporated town in the district, with a population of approximately 1200. The district is accessible by State Highways 123 and 124, which connect to the west and south, respectively, with U. S. Highway 6 and 50. The Denver and Rio Grande Western Railroad hauls coal from Kaiser Steel

Figure 1. Index map of the Sunnyside district. Axis of San Rafael Swell from Stam, (1956). Topographic and Structural form lines after Howard (1966a), Osterwald and Dunrud (1964) and Stam (1956).


111°
45'
30'
110°15'
N
0
10 mi
45'
30'
15'
39°
D. & R. G. W. RR.
ROAN PLATEAU
BOOK CLIFF
1°
Price
area of study
Sunnyside
6-50
123
Corbon Co. Ry.
9°
124
Price River
WASATCH PLATEAU
10
Huntington
Topographic Form Line
San Rafael Swell
San Rafael River
Structural Form Line
Salt Lake City
Vernal
Price
UTAH
41°
40°
39°
38°
Moab
114°
112°
110°

Corporation's Sunnyside No. 1, 2, and 3 mines, and the Carbon County Railway hauls coal from the U. S. Steel Corporation's Columbia and Geneva mines. The region is situated off the northeast end of the San Rafael Swell and at the base of the Roan Plateau, a maturely dissected high plateau in the Colorado Plateaus physiographic province (Fenneman, 1931, p. 304), and is wholly within the Sunnyside 15-minute quadrangle of the U. S. Geological Survey.

Methods of Investigation

The principal base map (pl. 1) was constructed by using an enlargement of Osterwald's map (1962) for the area north of an east-west line through No. 2 Canyon. The southern part of the map area was constructed by enlarging a part of the Sunnyside 15-minute quadrangle topographic map and checking the "fit" of the enlargement with stereo-paired aerial photographs. Changes to topography and cultural features since map printing were corrected according to aerial photographs and personal observation. Osterwald's map (1962) shows lithology and structural geology, but does not group lithologies by formation and member. The geologic map accompanying this paper utilized Osterwald's lithologic contacts in the northern part of the area and geologic contacts mapped by the writer in the southern part.

Eleven stratigraphic sections (appendix 1) were measured with an Abney level and plotted as a panel diagram (pl. 2) to show details of facies changes within the rocks. The outcrops between sections were walked out to trace any changes and to observe relationships between trace fossils and sedimentary facies. Inaccessible points such as the very common sheer, high cliffs were studied at length with binoculars. Dip and strike of beds and attitudes of sedimentary structures within beds were measured with a Brunton compass. Trace fossils and lithologic samples were collected and studied in the laboratory and in the office. Selected lithologic samples were analyzed in an X-ray diffractometer. Petrographic thin sections of selected lithologic samples were prepared and were analyzed with a petrographic microscope. Library research completed the study methods; except where otherwise noted, terminology is defined in the Glossary of Geology and Related Sciences (1947).

Previous Work

The Book Cliffs coal field has been the subject of much scientific investigation. The coal deposits are thick and well exposed, with low dips. In the Sunnyside district the coal is high quality bituminous coking coal, which is particularly valuable to industry. The Sunnyside district is also the locus of spectacular mine bumps which have been studied intensively because they are hazardous to life and property.

Early publications by Taff (1906), Richardson (1907, 1909), and Lupton (1916) described the economic geology of the area as parts of large regional reconnaissance studies. Clark (1928) investigated the adjoining 15-minute Castlegate, Wellington and Sunnyside quadrangles, that include the western Book Cliffs and part of the Wasatch Plateau. In his classic work, Clark described in detail the formations within the Mesaverde Group from the standpoint of the lithologic associations with coal beds. Spieker (1931) and Fisher (1936) described the economic geology of the area. Holmes, Page and Averitt (1948) investigated bituminous sandstones of Tertiary age near Sunnyside.

Generalized and small-scale mapping and descriptions of regional stratigraphic relationships have been included in publications by Dutton (1880), Spieker and Reeside (1925, 1926), Gilluly and Reeside (1928), Spieker (1946, 1949a, 1949b), Cobban and Reeside (1952), by Abbott and Liscomb; Hail, Kinney and Zapp; Johnson; and Katich (all 1956). Weimer (1960a, 1961) gave definitive regional stratigraphic relationships and correlations, and set the framework for Cretaceous stratigraphy in the area of Colorado, Utah, and Wyoming.

Fisher, Erdmann and Reeside (1960) summarized results of separate investigations of each of the authors in a comprehensive paper on the Book Cliffs of Utah and Colorado. Sears, Hunt and Hendricks, (1941), working in the San Juan

Basin, outlined criteria for the recognition of transgressive and regressive marine deposits in a classic paper.

Young (1955, 1957) undertook detailed work concerning the facies interrelationships in the Upper Cretaceous rocks of the Book Cliffs, based largely on the work of Pike (1947) south of Sunnyside. Young named and defined members of the Blackhawk Formation, but his work was on a regional scale, and his conclusions are subject to some controversy.

The most detailed work in the Sunnyside district has been done by Osterwald and others (1962, <u>et</u>. <u>seq</u>.) who mapped part of the area at a scale of 1:6,000, and by Brodsky (1960) who studied the general stratigraphic relationships of the Mesaverde Group; these works are based primarily on lithologic variation, however, with emphasis on the relationship of lithologies to the coal seams of the Blackhawk Formation.

Howard (1966a, 1966b, 1966c), working in the Wasatch Plateau and western Book Cliffs, studied trace fossils and sedimentary structures in Blackhawk strata that are stratigraphically lower than Blackhawk rocks at Sunnyside. Howard's work strongly influenced the preparation of parts of this paper.

Acknowledgements

The writer enjoyed the counsel and encouragement of Dr. Frank W. Osterwald throughout the preparation of this report; his patience and understanding are greatly appreciated. Dr. James D. Howard of the University of Georgia Marine Institute instructed the writer in many aspects of trace fossils and sedimentary structures, furnished illustrations, and read critically some of the manuscript. Discussions and field conferences with Dr. Howard were particularly valuable in understanding and interpreting the phenomena discussed herein. Mr. John Peperakis and Mr. Harry Elkin, of Kaiser Steel Corporation, allowed access to the study area and provided maps and other information regarding the coal seams. Drs. R. J. Weimer, John Hayes, and R. H. DeVoto are thanked for their help during the preparation of the paper. Dr. George Johnson of the Colorado School of Mines read the paper and gave constructive criticism regarding construction and style.

Association and discussions with my colleagues in the U.S. Geological Survey, Mr. C. R. Dunrud and Mr. B. K. Barnes, were both enjoyable and helpful. Mr. E. E. McGregor analyzed selected lithologic samples with an X-ray diffractometer.

My wife Lori patiently and ably assisted in the investigation.

GENERAL STRATIGRAPHY

The Blackhawk Formation is the lower unit of the Mesaverde Group (Cretaceous) near Sunnyside, Utah (fig. 2). The formation was named by Spieker and Reeside (1925, p. 443) for an exposure near the Blackhawk mine in the Wasatch Plateau. As originally defined, it is a unit of "buff sandstone, shale and coal of the kinds common to the Mesaverde group throughout the southwest." In the type area, the Blackhawk conformably overlies the Star Point Sandstone and is overlain unconformably by the Castlegate Formation. Clark (1928, p. 18) extended the use of the name "Blackhawk" to the Book Cliffs (fig. 3). At Sunnyside the Blackhawk conformably overlies the Mancos shale and is unconformably overlain by the Castlegate Formation.

Fisher (1936, p. 10) redefined the Blackhawk Formation in the Book Cliffs and included in it, in ascending order, the Lower sandstone member, Middle shale member, Middle sandstone member, and Upper member. In 1955 Young (p. 183) redefined the formation, placing its base at the base of the Spring Canyon Sandstone near the Wasatch Plateau and its top

Figure 2. Intertonguing and lithologic relationships of Cretaceous rocks from the Wasatch Plateau to the Eastern Book Cliffs in east-central Utah (modified from Spieker, 1949a, and Young, 1966).

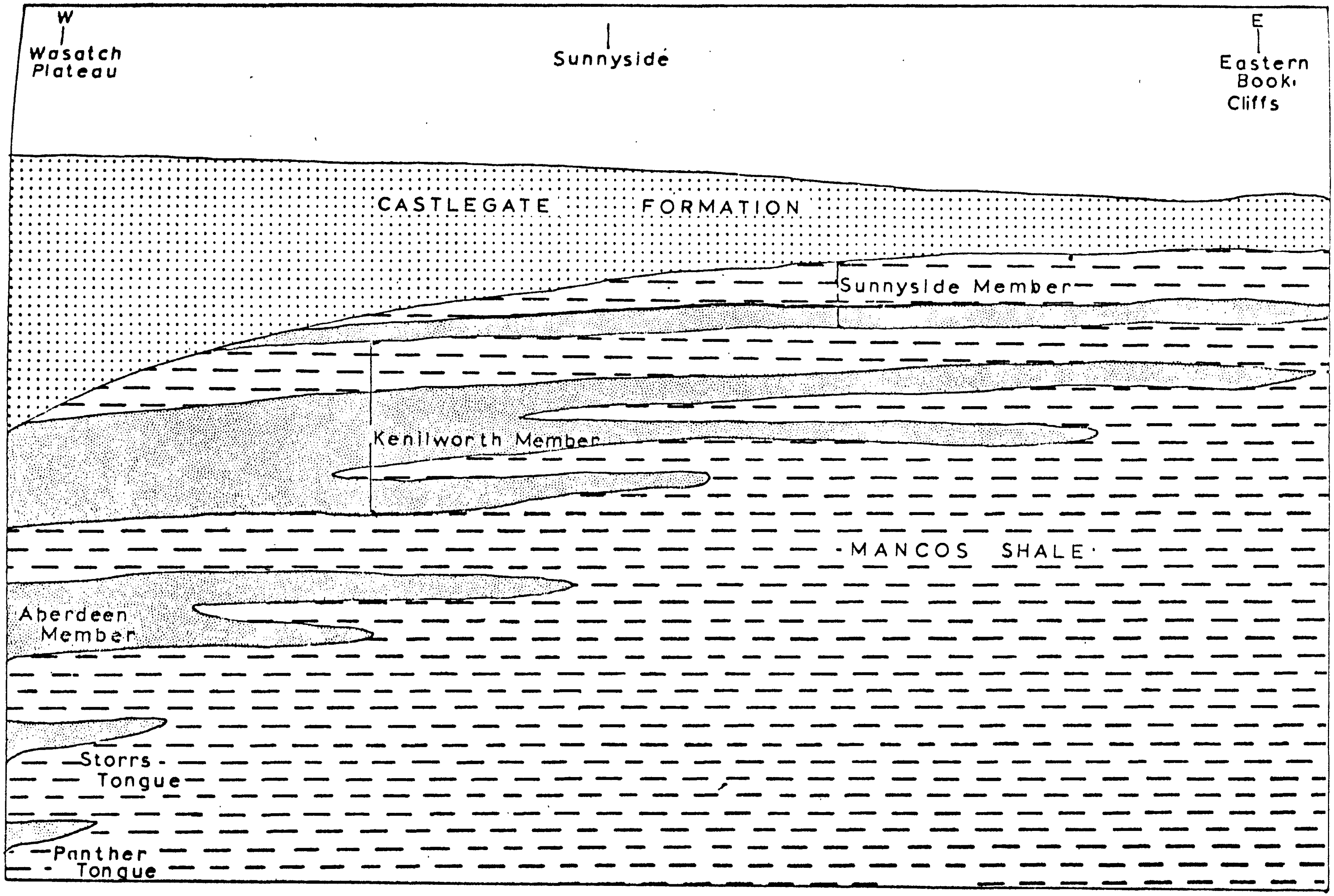

W
Wasatch Plateau
Sunnyside
E
Eastern Book Cliffs
CASTLEGATE FORMATION
Sunnyside Member
Kenilworth Member
MANCOS SHALE
Aberdeen Member
Storrs Tongue
Panther Tongue

Figure 3. Nomenclature applied to the Blackhawk Formation by various writers.

	Clark 1928	Fisher 1936	Young 1955	Fisher, Erdmann and Reeside 1960	Maberry 1968
MESAVERDE GROUP	Castlegate Sandstone mbr. Price River fm.	Castlegate Sandstone mbr. Price River fm.	Castlegate Sandstone Mbr. Price River Fm.	Price River Formation Castlegate Fm.	Price River Formation Castlegate Fm.
	Blackhawk formation: Coal-bearing member Aberdeen member	Blackhawk formation: Upper mbr. Middle Sandstone mbr. Middle Shale member Lower Sandstone mbr.	Blackhawk Formation: Desert Mbr. Grassy Mbr. Sunnyside Member Kenilworth Member Aberdeen Member Spring Canyon Member	Blackhawk Formation: Upper Mbr. Middle Sandstone Mbr. Middle Shale Member Lower Sandstone Mbr.	Blackhawk Formation: Sunnyside Member: Sunnyside Shale; Sunnyside Sandstone Kenilworth Member: Kenilworth Shale; Kenilworth Sandstone
	Star Point formation: Spring Canyon Tongue Storrs Tongue Panther Tongue		Star Point Fm.: Storrs Tongue Panther Tongue		Not present at Sunnyside
	Mancos Shale	Mancos Shale	Mancos Shale	Mancos Shale	Mancos Shale

Figure 3. Nomenclature applied to the Blackhawk Formation.

at the disconformable lower boundary of the "Castlegate Member of the Price River Formation." Fisher, Erdmann and Reeside (1960, p. 11) raised the Castlegate to formational rank.

Young (1955, p. 185) named six members of the Blackhawk and, using Spieker's illustration (1939), re-emphasized that the sandstone units of the Blackhawk feather out eastward into the Mancos Shale (fig. 2). Only two sandstone members of the Blackhawk are present at Sunnyside, the Kenilworth and Sunnyside Members. Young's Spring Canyon and Aberdeen Members tongue out northwest of Sunnyside, and the Grassy and Desert Members begin south of the area of interest.

Cobban and Reeside (1952) assigned the Blackhawk to the middle of the Campanian Stage (lower Pierre of the Western Interior) of the Late Cretaceous.

Objections have been raised to the use of the term "Mesaverde Group" in Utah and Wyoming, because there is some disparity in age between the Sunnyside section and the type Mesaverde at Mesa Verde National Park in Colorado. Others have pointed out, however, that the term "Group" has no time significance and that "Mesaverde Group" is the correct designation for the rocks under discussion (Abbott and Liscomb, 1956, p. 120; Brodsky, 1960, p. 17). The term is therefore retained for use in this report.

The writer has objections to Young's definition of the Kenilworth Member and the Sunnyside Member. Young (1955,

p. 181) places the lower boundary of the Kenilworth at the base of a "massive, cliff-forming, white-capped sandstone." He places the contact between the Kenilworth and Sunnyside at the top of a "barrier beach sandstone." He states that the Grassy Member first appears at Sunnyside. Rocks of Young's "marine Grassy Member" at Sunnyside are not considered by the author to be a mappable unit, but are included in the Sunnyside Member. His Sunnyside and Kenilworth boundaries are based both on lithology and inference of origin. Furthermore, the boundaries are unclear and field relationships show that the described boundaries are contained within mappable units. The boundaries of both members, therefore, are redefined in the section on detailed stratigraphy. The details of the trace fossil associations are important in the redefinition of these mappable members.

STRUCTURAL GEOLOGY

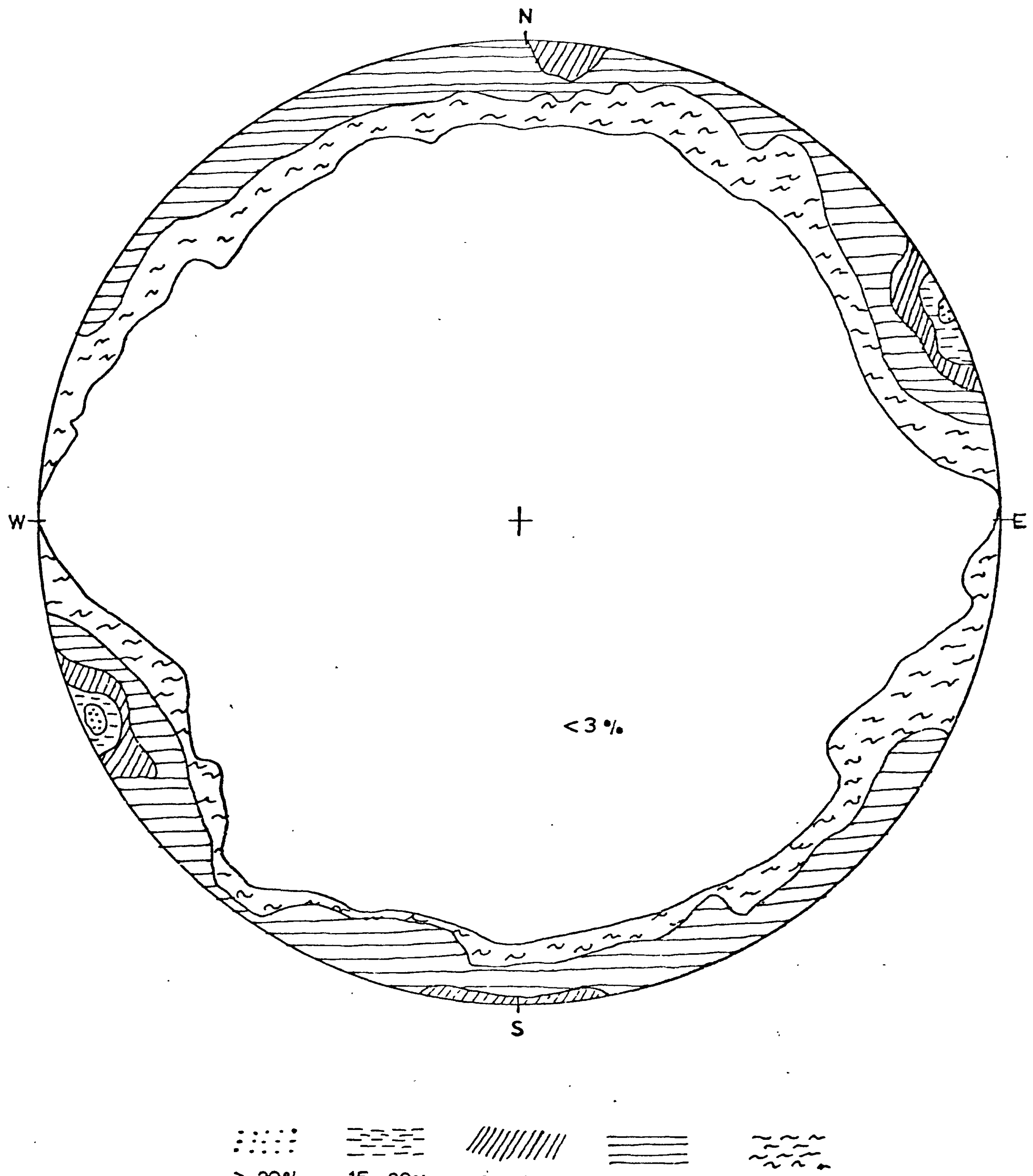
A major structural feature of east-central Utah is the San Rafael Swell, a northeast-trending, asymmetrical anticline that plunges northeastward under the Book Cliffs (fig. 1). The Swell is thought to be of Tertiary age (Osmond, 1964, p. 57) and therefore probably was not a control on the deposition of Blackhawk sediments at Sunnyside. The strata of the Blackhawk Formation crop out on the south- and west-facing scarp of the Book Cliffs. The cliff front is a faceted surface that resulted from erosion of the Roan Plateau. South of Sunnyside, strata strike northward; as the structural strike approaches the northwestern end of the San Rafael Swell the beds gradually change strike toward the west as they are gently folded over the crest of the Swell. North of Sunnyside beds strike westward and dip northward. Beds dip about 15 degrees north and east at the cliff front, and decrease down dip to about 7 degrees. The steeper dip at the cliff front is due to the proximity of the front to the crest of the Swell, where the structural inclination is greatest. Traced down dip, the strata pass into the Uinta Basin.

The regional joint pattern is characterized by two major sets of joints nearly at right angles to each other, striking N 75-85 W and N 12-20 W (fig. 4). Osterwald and Eggleton mapped 501 joints in the northern part of the area (1958) and the writer mapped 230 joints in the southern part. As might be expected, joints are best expressed and best preserved in sandstone units.

Known faults in the Sunnyside area are aligned subparallel to the regional joint pattern, and most faults strike N 12-20 W (pl. 1). All faults in the area are normal faults; fault planes dip 75 to 90 degrees. No known faults affect more than 150 feet of stratigraphic separation at the surface. A buried northwest-trending fault south of the area was discovered by seismic methods (Tibbetts, Osterwald and Dunrud, 1964); it may have as much as 2000 feet of stratigraphic separation. The principal fault system at Sunnyside is the Sunnyside fault zone (Osterwald and Dunrud, 1966) that trends northwest and is downthrown to the southwest. It is a series of long, northwest-trending faults with many short, curving spurs (pl. 1). The Sunnyside zone causes difficulties in mining because the faults offset the coal bed and necessitate changes in mining procedure.

Coal extraction underground commonly produces subsidence cracks at the surface. These structures are usually formed on a spur or nose above mine workings, and trend subparallel to joints. Joint orientation may be a control on formation

Figure 4. Poles of 730 joints measured in the Blackhawk Formation at Sunnyside, Utah, contoured on lower hemisphere of Schmidt equal-area net (modified from Osterwald and Eggleton, 1958).


N
W
E
S
<3 %
> 20%
15 - 20%
10 -15%
5-10%
3 - 5%

of subsidence cracks because many en-echelon subsidence cracks closely parallel nearby joint trends. Removal of the coal is removal of the support for overlying rocks. The rocks immediately above the coal fail, and the failure eventually continues upward to the surface. Mine air issues from some of the cracks, and some cracks are visible at the surface as much as 1,200 feet above the mine workings. Subsidence cracks vary in size from a split one-quarter inch wide and a few feet long to crevasses 4 feet wide and 50 feet long (pl. 3).

Plate 3. Subsidence cracks.

Figure 1. Small-scale en-echelon cracks trending northwest at surface about 800 ft. above Sunnyside coal, in tributary to Whitmore Canyon. (Photo by F. W. Osterwald.)

Figure 2. Large-scale crack trending northwest, about 900 ft. above Sunnyside coal in west wall of Whitmore Canyon. Mine air issues from crack. Hammer handle is 12 in. long. (Photo by F. W. Osterwald.)

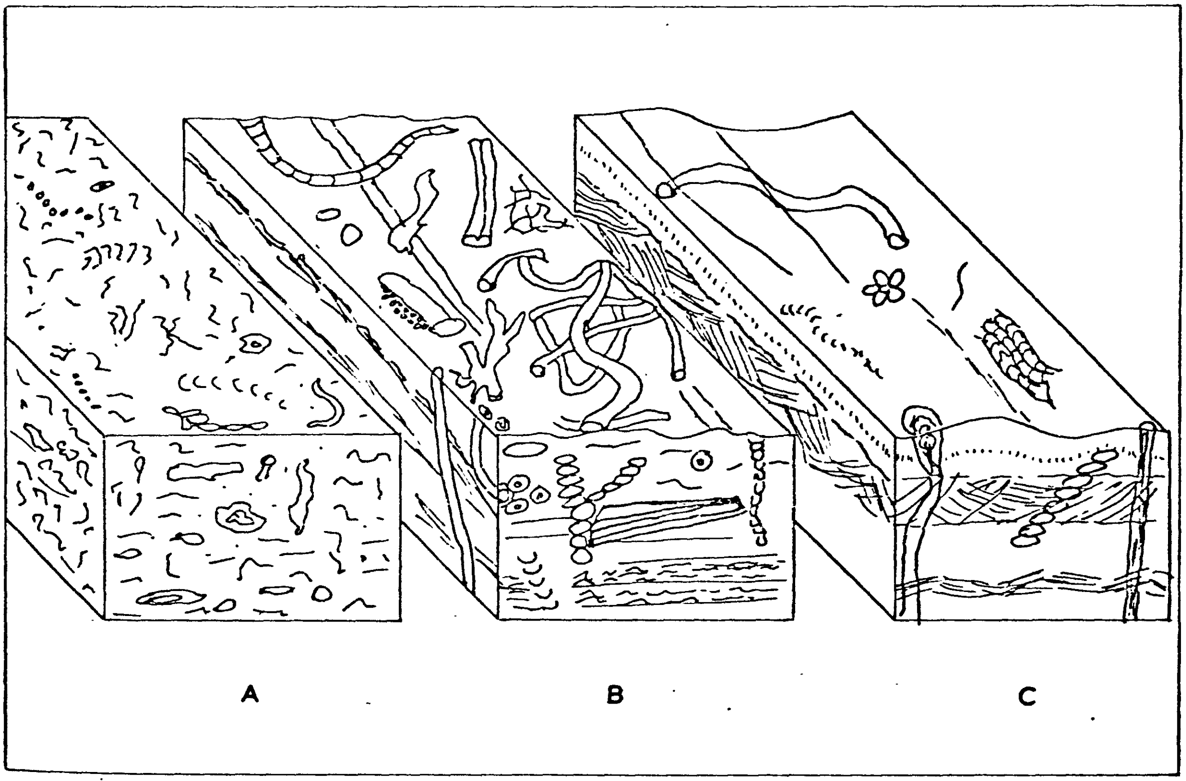
TRACE FOSSILS: BIOGENIC SEDIMENTARY STRUCTURES

Trace fossils are biogenic sedimentary structures--tracks, trails, burrows or borings made by animals and preserved in rock strata. In short, trace fossils are evidence of where animals have been. The lack of body fossils, particularly in sandstones, has been partly responsible for a lack of detailed stratigraphic work from the standpoint of paleoecology in much of the western United States. These trace fossils, or *lebensspuren* of European workers, are valuable paleoecologic indicators. Where body fossils are present, traces may be used to reinforce interpretations. Where body fossils are scarce or absent, trace fossils may be used effectively to interpret the paleoenvironment. Body fossils may be transported from the living site, or they may be destroyed by diagenesis. Trace fossils, on the other hand, are found almost unquestionably *in situ*, although J. D. Howard (oral communication, 1967) has indicated that *Ophiomorpha* burrow casts may be reworked.

Most of the investigation of trace fossils has been carried out by Europeans, particularly by the German geologists Häntzschel and Seilacher. A significant advance came for American geologists in 1962 with the chapter "Trace Fossils and Problematica" in the Treatise on Invertebrate Paleontology, Part W (Häntzschel). Much of the material included in the term "trace fossils" has heretofore been assigned to categories such as algae, fucoids, *incertae cedis*, problematica, inorganic, worms, or feces. The accurate description and classification of trace fossils, will, hopefully, help bring to American geologists a valuable tool to be used in reconstructing the geologic history of an area.

Recent investigators (Häntzschel, 1962; Seilacher, 1964, 1967) have shown that trace fossils are grouped in sedimentary facies according to the environments preferred by their creators (fig. 5). Some are definite indicators of shallow marine conditions for example; some indicate terrestrial deposition. The orientation of traces of the same type of organisms indicates the relative rate of sedimentation. Seilacher (1967, p. 421) emphasizes that vertical burrows in shallow water deposits and the gradual tendency toward horizontal burrows with increase in water depth correspond to a trend from suspension to sediment feeding. The type of feeding is a response to the amount of suspended nutrients at different levels: in shallow zones, food for organisms is in suspension; at depth, in quiet water, nutrients settle out

Figure 5. Environmental grouping of trace fossils. (A) Very calm water, shallow and deeper neritic and lagoon environments with much silt, clay and very fine sand, carbonaceous debris. Sediments thoroughly reworked and mottled by organisms, primary structures and bedding destroyed. Poorly preserved trace fossils. (B) Medium energy environment of the shallow neritic zone. Very fine- to fine-grained sand, moderately well sorted, low cross-stratification. Extremely well populated by trace fossils, mostly well preserved. (C) High energy environment of the littoral zone. Well sorted, fine- to medium-grained sediments. Much cross-stratification. Few trace fossils, mostly poorly preserved (modified from Howard, 1966a).


A
B
C

of suspension and become part of the sediment. Hence, in quiet waters the trend is toward horizontal, intricately patterned burrows. By studying trace fossil forms and associations on the outcrop, in mine workings, and in the laboratory, the history and environment of deposition of strata can be deduced. From these deductions the positions of various strata in the depositional framework can be postulated with an increasing degree of accuracy.

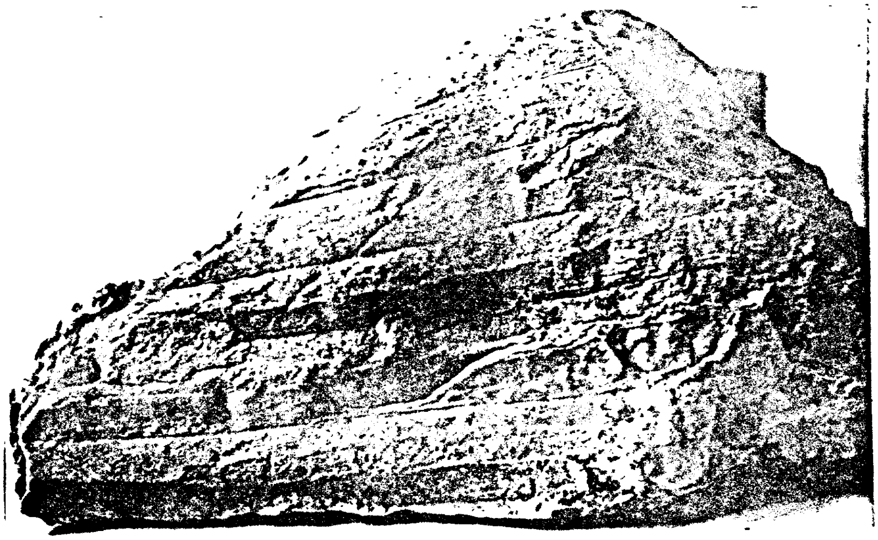
The Upper Cretaceous strata of Wyoming, Colorado and Utah have been the subject of intensive trace fossil studies in recent years because of the paucity of their contained body fossils and extreme wealth of trace fossils. Representative investigations are those of Toots (1961), who used trace fossils to delineate beach zones and strand lines; and Masters (1965), who studied the Mesaverde Group of northwestern Colorado and used trace fossils as environmental indicators. Howard (1966a, 1966b, 1966c) carried out an exhaustive study of trace fossils in units slightly older than those discussed herein. Howard's work in the Wasatch Plateau to the west of Sunnyside dovetails with the studies which are described in this paper.

The creators of all trace fossils described herein had an affinity for warm waters. Reeside (1957, p. 505) has postulated a nearly tropical climate for the area under consideration for most of the Cretaceous period; an interpretation based primarily on body fossils. Parker (1968) collected fossil flora from the Blackhawk Formation near Salina, Utah, and concluded from the study that the regional climate was subtropical during Late Cretaceous time. The conclusions of Reeside and Parker agree with the writer's interpretation, which is based on the thick coals in the geologic sections and on *Ginkgo*-type plant fossils found in terrestrial deposits within the Blackhawk Formation (fig. 6).

Uses of Trace Fossils

Most sedimentary syngenetic economic minerals are controlled by physical and chemical conditions extant at the time and place of deposition. Oil and natural gas in stratigraphic traps associated with near shore marine sediments are well known. Use may be made of trace fossils as environmental indicators to predict areas that are favorable to entrapment of such deposits and loci for exploration consequently may be delineated. Localization of sedimentary mineral deposits of manganese, phosphate, barite, iron and evaporites is controlled by factors such as depth of water, temperature, salinity, circulation barriers, or organisms that will facilitate precipitation. In the western United States, most coal deposits are associated with marine or transitional-marine sedimentary rocks. When trace fossils can be recognized in drill cores, depositional conditions may be ascertained at some distance from the outcrop. Body fossils need not be present to interpret sedimentary

Figure 6. *Ginkgo*-type plant fossil found in upper Sunnyside Member. Inferred to be part of a leaf, based on morphology of the fossil.



environments. Recent discussions among geologists seem to indicate an awakening of interest in trace fossils and the onset of research into their definition and uses (Howard, 1968). Some mining conditions of various commodities might also be predicted through knowledge of associated trace fossils.

Descriptive Nomenclature

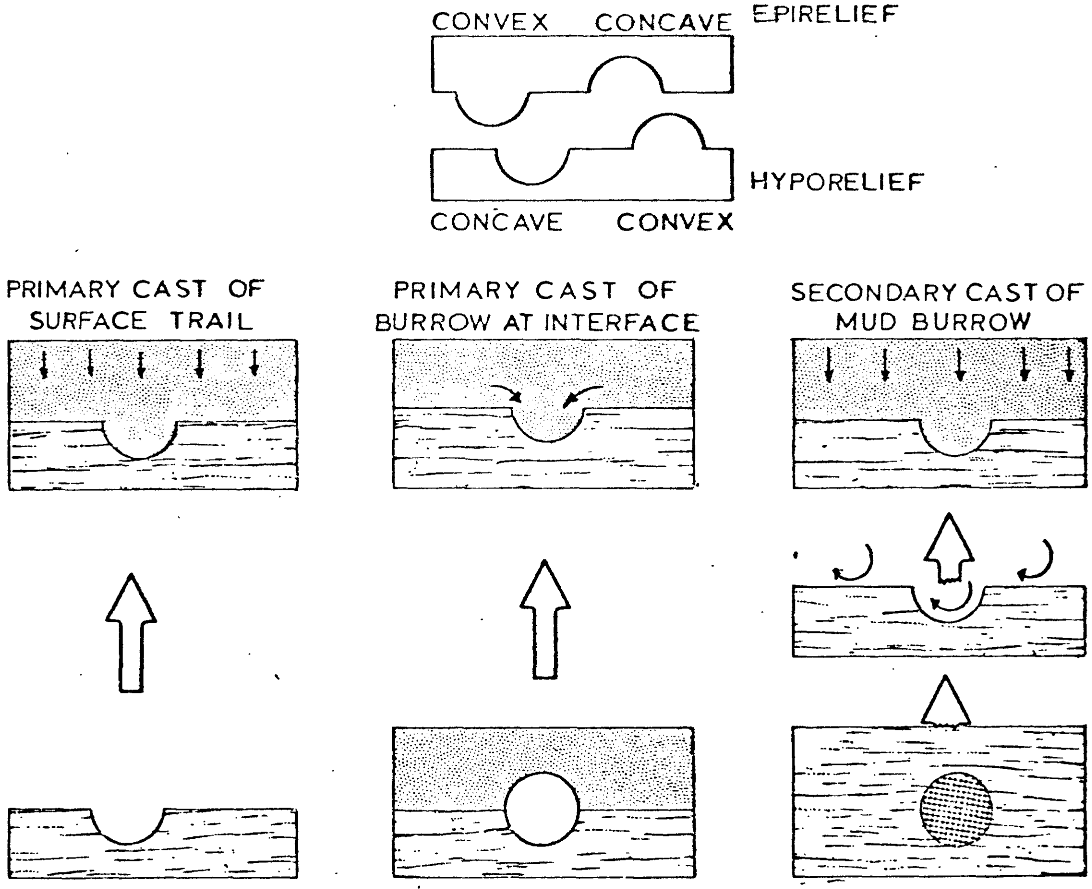
Because it is not definitely known which genus and species of organisms made individual trace fossils, traces cannot be grouped into normal systematic taxonomic units. As described herein, trace fossil nomenclature is based on the function, or ethology, of the fossil and follows the methods developed by Seilacher (1964). Traces are described partially on the basis of their relationship to the substrate on which they were formed.

Lithologic Relationship

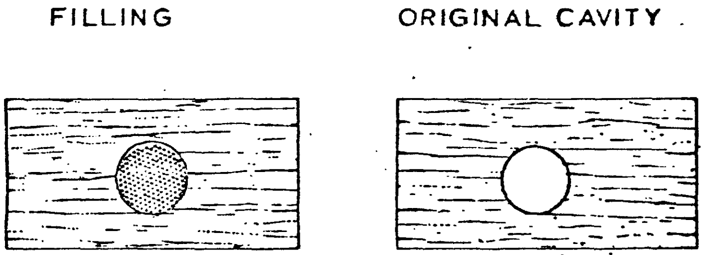
Trace fossil preservation is classed as epirelief, in which traces are present on the lower surfaces of beds, (fig. 7); or hyporelief, in which traces are present on the upper bedding surfaces. Full relief describes those traces that are completely contained within the strata and are preserved as the original cavity or cavity filling. Original cavity, full relief trace fossils are very rare in the Book Cliffs, as field work in preparation for this paper shows, and in the Wasatch Plateau (J. D. Howard, 1967, oral

Figure 7. Types of preservation of trace fossils (modified from Seilacher, 1964).

SEMIRELIEF



FULL RELIEF



communication). Epirelief and hyporelief are subdivided into convex and concave. A convex feature is one that projects above the upper bedding surface or below the bottom bedding surface.

Subdivision of Blackhawk Trace Fossils

Every outcrop of Blackhawk rocks in the area of interest exhibits some evidence of organism activity in the sediment at the time of deposition. The environment in which organisms responsible for trace fossils were most abundant and most varied is represented by interbedded siltstones and very fine- to fine-grained sandstone. Some mudstones are also intensively burrowed, but preservation of trace fossils is poor in mudstone. The siltstones and fine-grained sandstones are rich in finely divided organic material, and are very thinly and evenly bedded.(fig. 5 A). The organisms that inhabited this environment were dominantly detritus feeders, organisms that prowled the surface of deposition and/or burrowed below the surface in search of food. Detritus feeders, also called filter feeders or sediment feeders, are organisms that derive nourishment from nutrients that are part of the sediment. Such nutrients may be living microorganisms or detrital organic material. The actions of these detritus feeders in their search for food thoroughly altered the primary sedimentary structures and destroyed all but a few traces and suggestions of the morphology of the organisms themselves.

Evidence of primary lamination is scattered, because the organisms churned the sediments before lithification. The pattern of organic mottling suggests that the original sediments were thinly laminated with little or no dip.

The environment in which organisms responsible for trace fossils lived in moderate abundance is represented by thin-bedded, very fine- to fine-grained sandstones which occur above the interbedded siltstone and sandstone unit described above. The rocks of this unit are cross stratified in long, low-angle wedge-shaped sets. Both complete and truncated large ripples are common in this interval. The depositional environment supported a mixture of detritus feeders and suspension feeding organisms, which are organisms that filter the suspended load of the water in order to obtain nourishment. In beds where detritus feeders were dominant, the strata are mixed and mottled. They are not quite as intensively disturbed as in the siltstone and sandstone zone below, however; mottling commonly occurs in patches or pockets within a bed. Laterally the sediments may be relatively undisturbed in the same bed. Such strata are described as "clean-to-mottled" in the field. Where suspension feeders were the dominant organisms, sediments are moderately well sorted and slightly carbonaceous (fig. 5 B). The current velocity was high enough to winnow out the finely divided sediment, including carbonaceous matter, but not so great as to permit constant reworking and mobilization of the substrate. Trace fossils of detritus feeders in rocks of this environment indicate an attempt by the organisms to escape to a more favorable habitat (Seilacher, 1967, p. 421).

The smallest population of trace fossils is found in rocks that are fine-to medium grained, moderately well sorted sandstones (fig. 5 C). Sediments were often affected by currents that built ripplemarks and cross lamination, and shifted and reworked the sediments. The power of the transporting medium was sufficient to winnow out fine sediments and prevent deposition of organic detritus. Organisms in this environment were almost exclusively suspension feeders that built burrows which were strong enough or deep enough to exist in a mobile substrate. The organisms built their shelters upward to keep pace with sedimentation. Progressively fewer traces are found in rocks indicative of environments of increasingly stronger current velocity.

Ethological Classes. Seilacher (1964) has established the following nomenclature for trace fossils, based on the function of the structure:

1. Repichnia: Trails or burrows left by vagile benthos forms during directed locomotion.
2. Pascichnia: Winding trails or burrows of vagile mud eaters which reflect a "grazing" search for food by covering a given surface more or less efficiently and by avoiding double coverage.

3. Fodinichnia: Burrows made by hemisessile deposit feeders. These reflect the search for food and at the same time fit the requirements for shelter.

4. Domichnia: As the root suggests, permanent shelters dug by vagile or hemisessile animals procuring food from outside the sediment as predators, scavengers, or suspension feeders.

5. Cubichnia: Shallow resting tracks left by vagile animals hiding temporarily in the sediment or lurking or resting on the sediment surface, and obtaining their food as scavengers or suspension feeders.

Bathymetry of Trace Fossils. Seilacher (1964, 1967) grouped trace fossils according to the bathymetric conditions preferred by organisms that made the traces (table 1). The "universal ichnofacies", or trace fossil groupings are:

1. Nereites-facies, defined by Seilacher (1964, p. 311) to be "bathyal with turbidite sedimentation." Dominant trace fossils--repichnia and pascichnia.

2. Zoophycos-facies, in the zone sublittoral to bathyal, below wave base and without turbidite sedimentation. Dominant trace fossil--fodinichnia of detritus feeders.

3. Cruziana-facies, in the littoral to sublittoral zone, above wave base. Dominant trace fossils--

UNIVERSAL ICHNOFACIES

	Nereites-Facies	*Zoophycos*-Facies	*Cruziana*-Facies
Dominant groups:	Paschichnia Repichnia	Fodinichnia	Cubichnia Domichnia of suspension feeders (shallow, turbulent zone) Fodinichnia of detritus feeders (deeper zone)
Diagnostic inorganic sedimentary structures:	Load casts, convolute lamination, other turbidite structures	Bedding and lamination poor	Oscillation ripples, foreset bedding in shallow zone, well laminated in deep water
Dominant lithology	Mudstones, muddy and silty sandstones with high carbonaceous content.	Mottled siltstones and mudstones	Well sorted sandstones
Probable depth:	Bathyal	Sublittoral to bathyal, below wave base	Littoral to sublittoral, above wave base.

Table 1. Universal ichnofacies (modified from Seilacher, 1964, p. 310, 311).

domichnia and cubichnia; fodinichnia of detritus feeders found in deep water.

Environmental significance of trace fossils in the following chapter is based largely on the work of Seilacher; interpretations of the author that differ from Seilacher are duly noted.

Systematic Description of Blackhawk Trace Fossils

A structure commonly observed in trace fossils is spreite, defined by Häntzschel (1962, p. W178) as "a German noun literally translated as 'spread' and meaning something spread between two supports, as the web of a duck's foot." Formal generic and specific names are underlined both in the following descriptions and elsewhere in the text. Unless otherwise noted, names of individual trace fossils are from Häntzschel (1962). In the interest of brevity, a semitelegraphic style has been adopted for the following descriptions.

Pascichnia

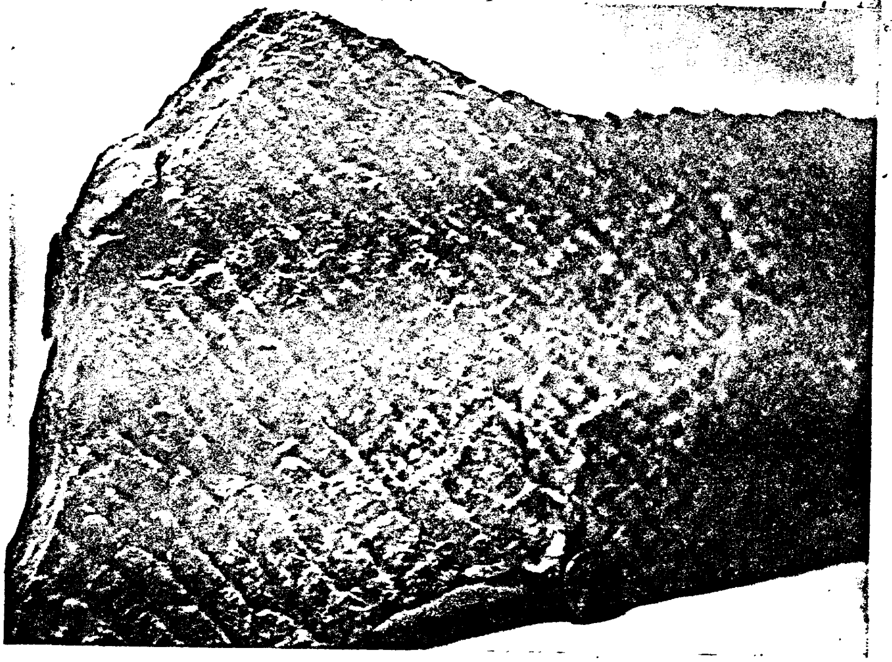
Chevron trails (pl. 4, figs. 1 and 2).

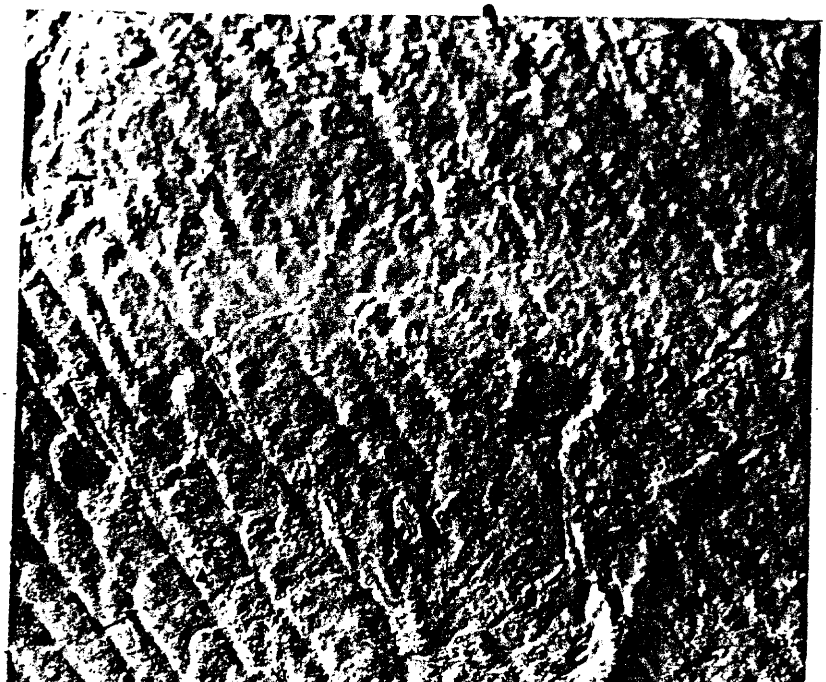
Trace fossil occurring as convex epireliefs on bedding surfaces of very fine-grained sandstones. Width of track varies from 10 to 15 mm and averages 12 mm. Commonly multitudinous, subparallel to parallel trails. Often aligned parallel to shoreline, as shown by measurement of associated ripplemarks, sole markings, and alignment of detritus on bedding surfaces. Apparently pascichnia formed by organisms

Plate 4

Figure 1. Chevron trails on bedding surface of Kenilworth Sandstone. Coin diameter is 1.90 cm.

Figure 2. Close view of figure 1. Movement from upper left to lower right. Distance between arrows in lower left corner is 1.15 cm.





grazing at the sediment-water interface. Shallow neritic marine indicator (Howard, 1966a).

Fodinichnia

Teichichnus A (pl. 5, figs. 1, 2 and 3).

Burrow consisting of a series of spreite which form a vertical blade. When viewed from the side, resembles a narrow-angle "lazy" V. Interlayered with the spreite are carbonaceous, silty laminae which have not been burrowed. The nonburrowed material is fine grained and not resistant, and hence forms a constriction in the blade. The constrictions give Teichichnus A the gross appearance of a series of superposed round tubes, all emanating from a primary, or main tube. Height of the blade varies from 2 to 4 cm; width is usually about 5 mm, and a length of more than 75 cm has been observed on outcrops. The blade itself is always normal to bedding, but spreite of the blade vary from horizontal to vertical, and commonly form a sinuous pattern. Found in dense sandy siltstone deposited in marine neritic environments (Seilacher, 1964, p. 310). A feeding burrow of a detritus feeder, possibly a polychaete worm.

Teichichnus B (pl. 6, figs. 1 and 2).

Possibly formed by the same organisms as type A, but is a much larger structure, always in the form of a vertical blade cutting across bedding, with spreite forming superposed tubes. The individual tubes are oval in cross-section,

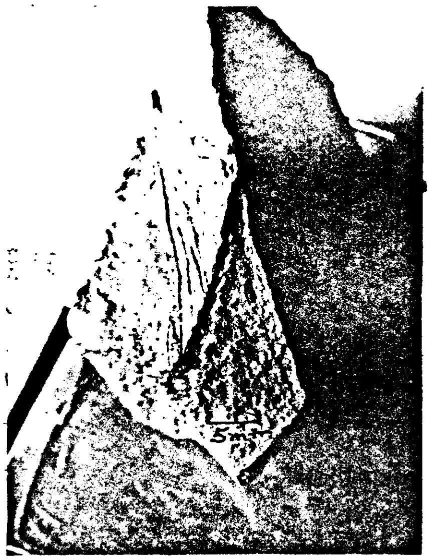
Plate 5

Figure 1. Teichichnus A in Kenilworth Sandstone (arrow). Pencil scale (circled).

Figure 2. Teichichnus A, showing spreite in end-on view.

Figure 3. Teichichnus A, 3/4 view. Arrow indicates up.


1



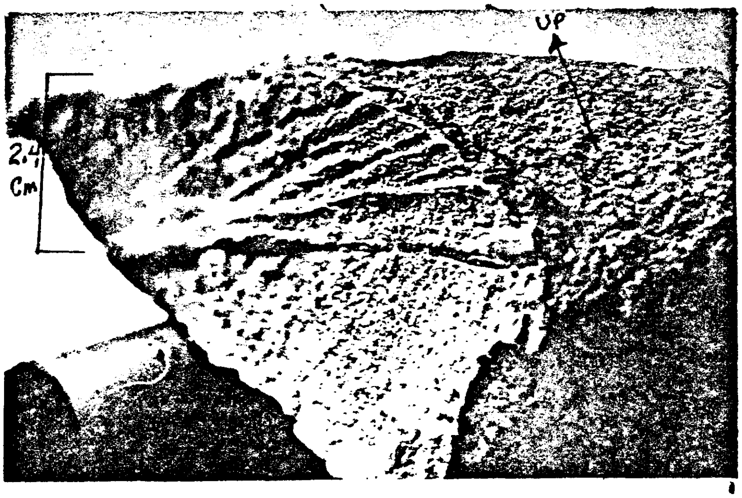
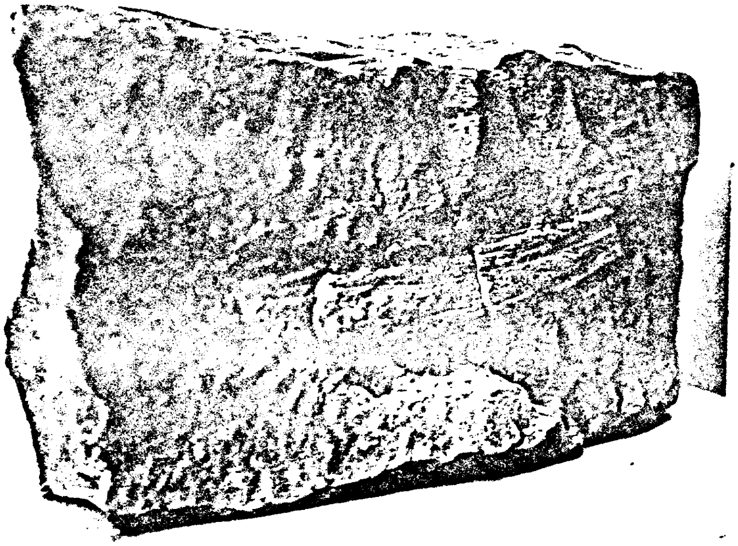

UP
2.4 Cm

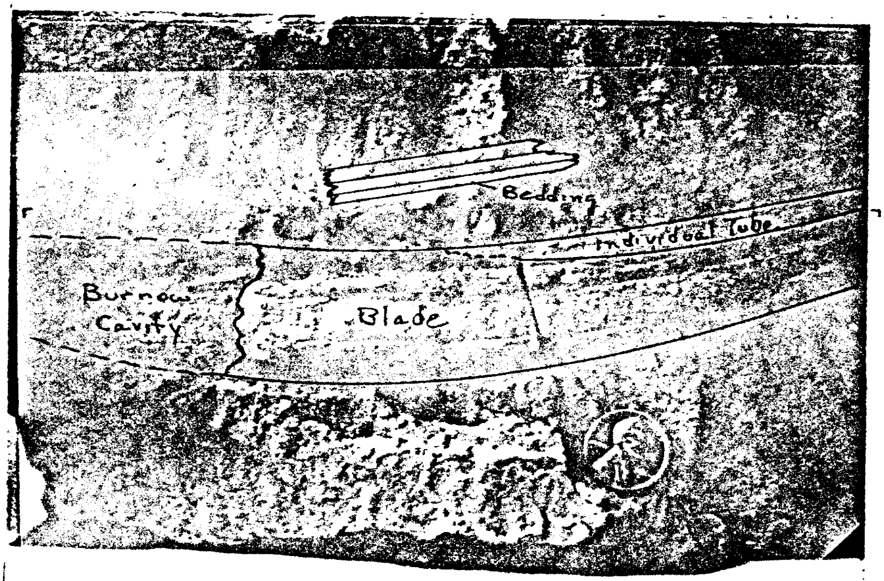
Plate 6

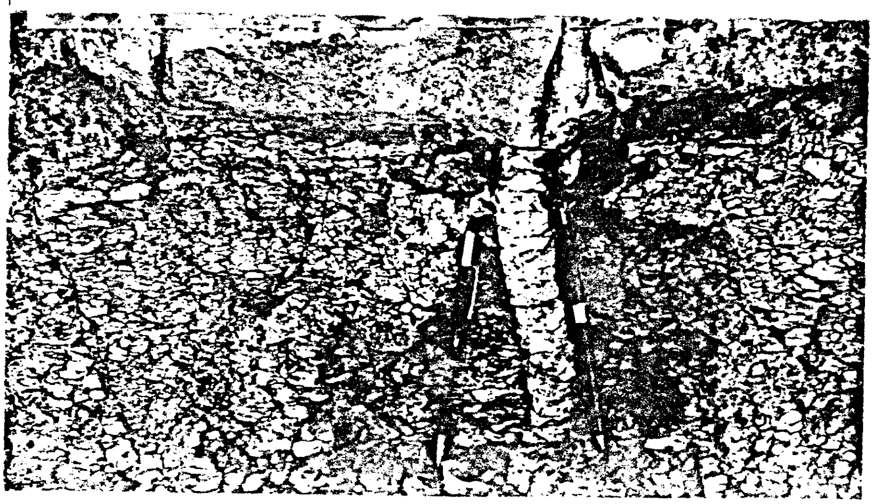
Figure 1. _Teichichnus B_, from lower Kenilworth Sandstone. Coin diameter is 1.90 cm.

Figure 2. _Teichichnus B_, close view of figure 1, illustrating bladed structure. Coin diameter is 1.90 cm.

Figure 3. _Arthrophycus_ in nodular carbonaceous siltstone of Sunnyside Member. Pencil and pen scales on either side of trace fossil.




Bedding
Individual Tube
Burrow Cavity
Blade



however, and are commonly as much as 1 cm high, 5 mm wide, and in all observed specimens the tubes are subparallel throughout their length. Most blades are about 5 cm high, 1 to 5 cm wide, and vary in length due to the random grazing habit of their creators. A fodinichnia-type burrow found in very fine- to fine-grained sandstone; believed to represent deposition in shallower water than type A (J. D. Howard, 1967, oral communication), because of increased size of organism and better sorting of sediments where Teichichnus B is found.

Arthrophycus (pl. 6, fig. 3).

A conduit-like segmented trace commonly normal to bedding. Preservation varies from full relief to convex epirelief, commonly filled. Some branching forms have a slight bulge at the point of branching, but these are uncommon. Round to flattened oval in cross section, 5 to 15 mm in diameter, length is indeterminate where trace passes into sandstone or away from the outcrop. Often confused with Ophiomorpha because of its rough exterior and branching nature. Most common in siltstone and very fine- to fine-grained sandstone. A fodinichnia burrow, indicative of a relatively wide depth range (Seilacher, 1964, p. 311).

Smooth tubes (pl. 7, fig. 1).

Full relief or convex epireleif burrows, preserved as smooth, curving, unornamented tubes oriented at random

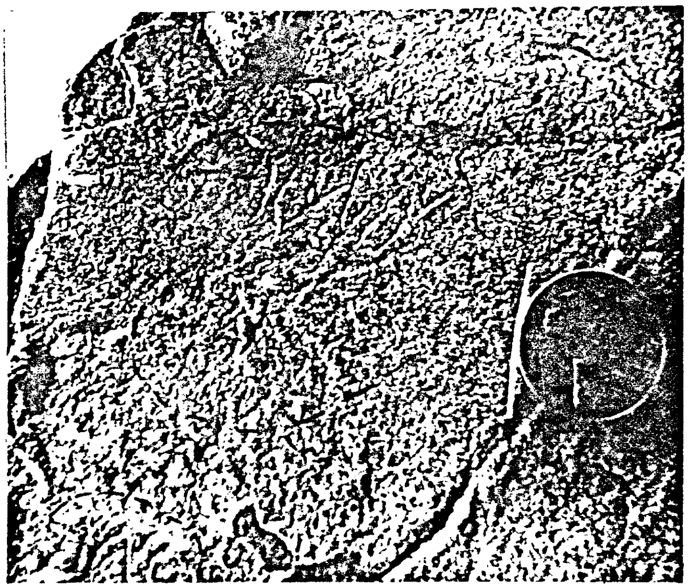


Plate 7

Figure 1. Smooth tubes (arrows) from siltstone above Sunnyside coal. Diameter of coin is 1.90 cm.

Figure 2. *Chondrites* (circled) from middle Sunnyside Sandstone. Diameter of coin is 1.90 cm.

throughout the rock. May be Arthrophycus. Cross section is round to oval, with a diameter 8 to 15 mm; indeterminate length. Found in finely mottled siltstones and "clean to mottled" fine-grained sandstones. Neritic marine indicator (Howard, 1967, oral communication).

Chondrites (pl 7, fig. 2).

Concave epirelief trace characterized by plant-like appearance with numerous short branching segments. Horizontal branching trails reflecting short excursions from a central vertical burrow. Diameter of the branches is 1 to 3 mm. Found in very fine-grained sandstone, very shallow neritic to littoral marine sandstone (Seilacher, 1964, p. 311).

Cylindrichnus concentricus Toots (pl. 8, figs. 1, 2 and 3).

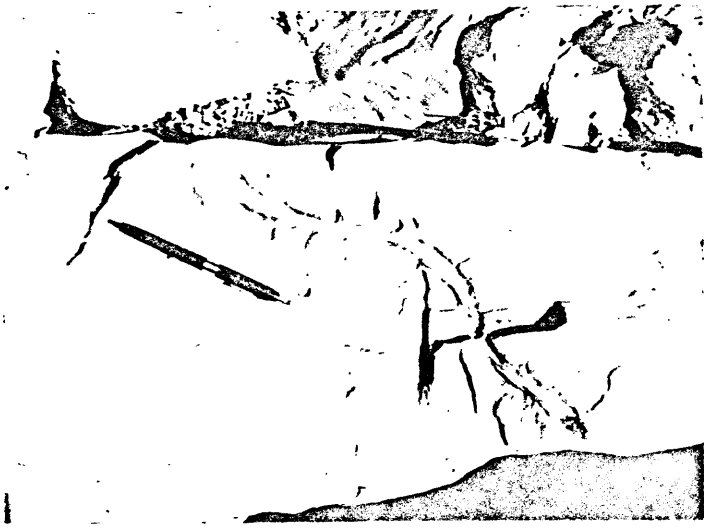
Cited by Howard (1966a, p. 73) as described by Toots (1961). A full-relief burrow found in all orientations from horizontal to vertical. Horizontal burrows are found in very fine-grained carbonaceous sediments. They reflect a random, contented grazing search for food in an hospitable environment. In this environment they roil and mottle sediments intensively. Steeply angled burrows are escapeways from hostile environments. Cylindrichnus built steep burrows as the current velocity increased and food was winnowed from the sediment, or as the rate of sedimentation increased and there was less food for the animal, as the finely divided

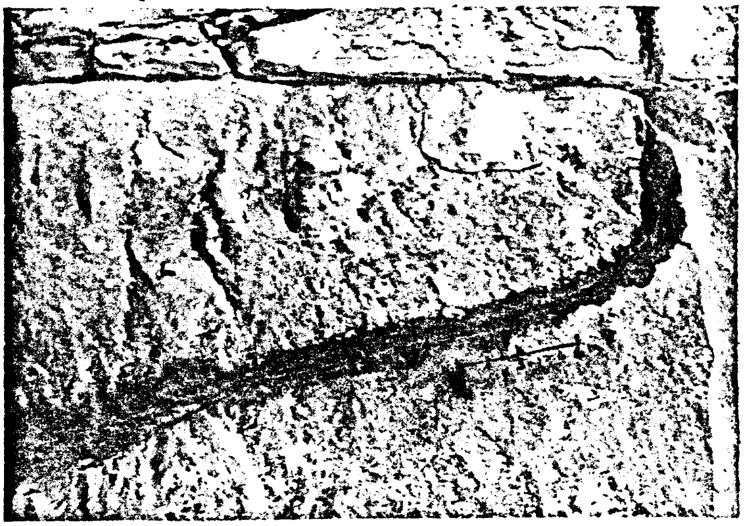
Plate 8

Figure 1. *Cylindrichnus concentricus* in fine-grained sandstone of Kenilworth Member. Pen scale.

Figure 2. *C. concentricus*, left of pencil, Sunnyside Sandstone. Pencil and pen scales.

Figure 3. *C. concentricus* escape burrow in well sorted sandstone of Kenilworth Member. Six inch scale drawn on rock face.





nutrients were winnowed out. High-angle and vertical burrows are common in clean, well sorted sandstones, where they are associated with Ophiomorpha. High-angle Cylindrichnus burrows culminate upward in what Howard (1966a, p. 70) calls helicoid funnels (pl. 9, figs. 1 and 2); full relief, vertically oriented, funnel-shaped structures varying in diameter at the top from 4 to 25 cm. These funnels reflect a change in the animal's burrowing habits, a fresh influx of carbonaceous material into the environment, and a lowering of current velocity (J. D. Howard, 1967, oral communication).

Cylindrichnus reptilis Bandel (pl. 10, fig. 1).

Named by Bandel (1967, p. 6). A vertical full-relief tube of 1 to 3 cm in diameter, usually 8 to 14 cm high, cylinder-shaped burrows found in coarsely mottled silty sandstones. Comparable in form to Cylindricum Linck. Common in thinbedded sandstones in both members of the Blackhawk Formation. Believed by the author to be an indicator of littoral to sublittoral marine zones.

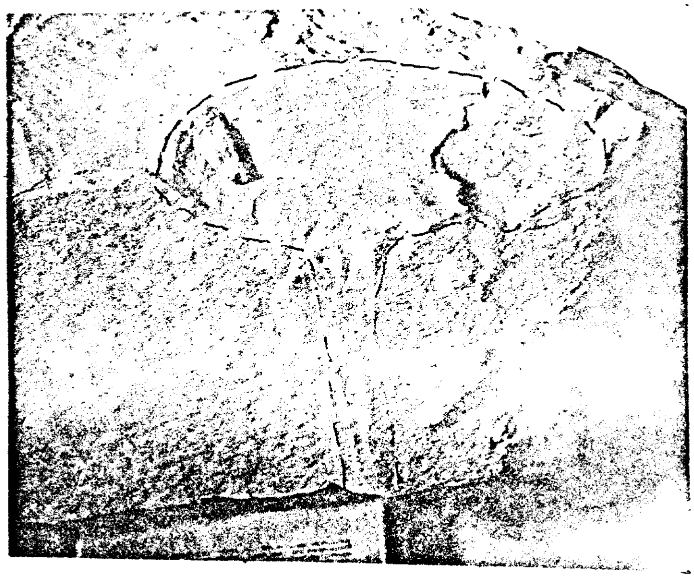
Labyrinth castings (pl. 10, figs. 2 and 3).

Locally found as pockets of tightly interwound trails or castings preserved as convex epireliefs on the bottom surfaces of fine- to medium-grained sandstone beds. Similar morphologically to Phycodes (Häntzschel, 1962, p. W208). The small interstices between castings are filled with carbonaceous dust. Commonly associated with pieces of woody debris.

Plate 9

Figure 1. Helicoid funnel of <u>Cylindrichnus concentricus</u>, at top of fine-grained sandstone bed. Depression of funnel is 20 cm across. Specimen broken across trace fossil.

Figure 2. Helicoid funnels (arrows), in lower Kenilworth Sandstone. Brunton compass scale.



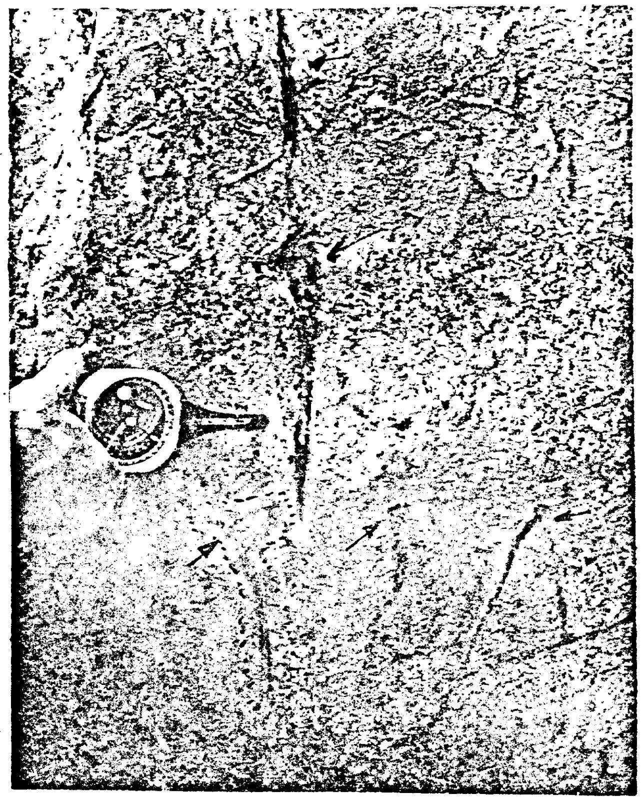
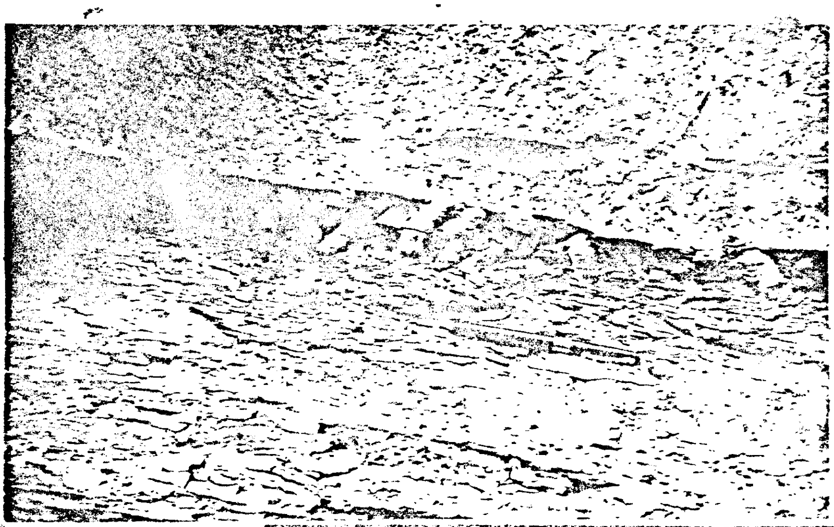


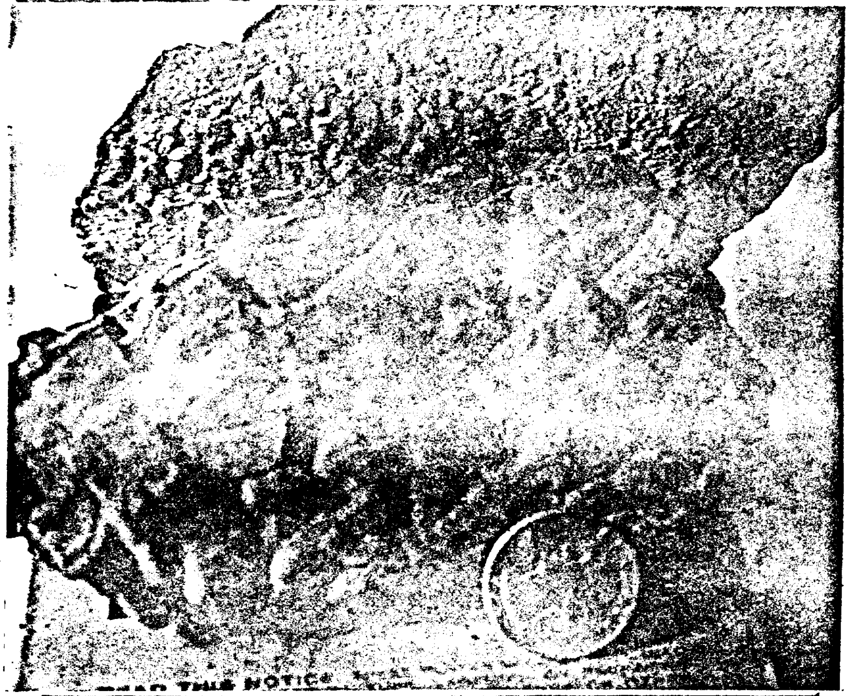
Plate 10

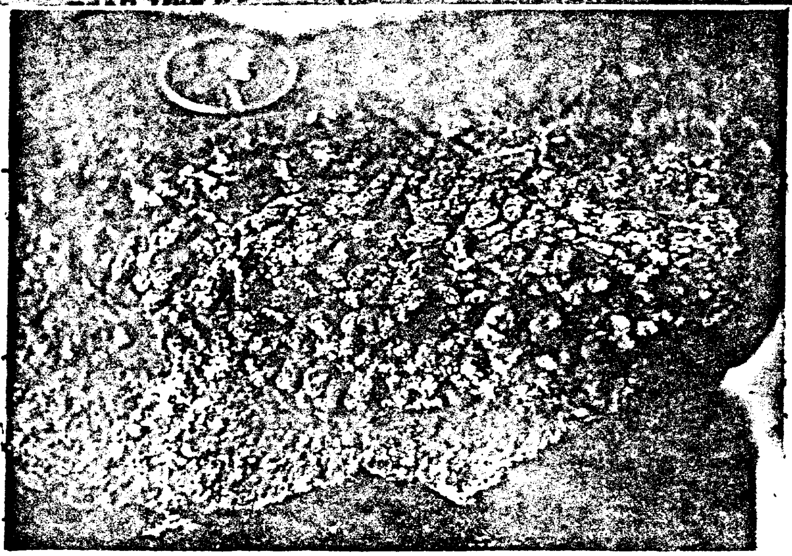
Figure 1. Cylindrichnus reptilis, at interface between carbonaceous sandstone and overlying medium-grained well sorted sandstone, in Sunnyside Sandstone. Pen scale.

Figure 2. Labyrinth castings, from upper Sunnyside Member. Note different sizes of fossils. Coin diameter is 2.38 cm.

Figure 3. Labyrinth castings, from base of Castlegate Sandstone. Coin diameter is 1.90 cm.







Indicative of tidal zone to floodplain environment, probably made by polychaete worms (J. D. Howard, 1967, oral communication).

Gyrochorte (pl. 11, fig. 1).

Simple, bilobate trail preserved as convex hyporelief in well sorted, fine-grained sandstones. Characterized by mediun furrow. Superficially resembles Aulichnites. One to 7 mm wide, of indeterminate length, 1 to 3 mm high. Generally smooth surfaces; crossing burrows pass over or under each other, never destroying another burrow. Random, meandering locomotion. Not branching. Described by Seilacher (1964, p. 311) as nondiagnostic of depth, but because of the traces with which Gyrochorte is associated (fig. 23), the author believes that Gyrochorte indicates sublittoral to littoral environment. Trace probably made by gastropods (Häntzschel, 1962, p. W198).

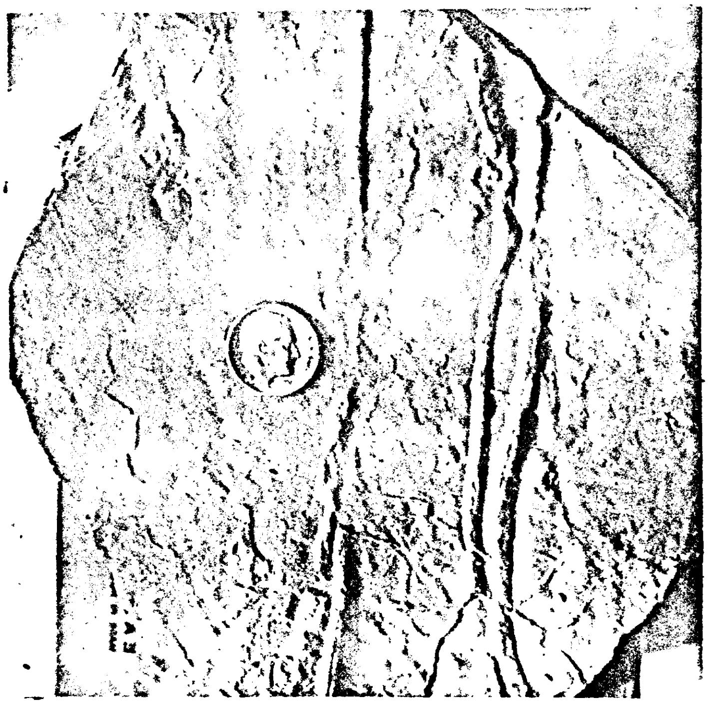
Aulichnites (pl. 11, fig. 2).

Simple, bilobate crawling trail preserved as convex epirelief forms in very fine- to fine-grained, well sorted sandstones. Median furrow in all trails. Meandering directions, reflecting a grazing search for food. Trails are 1 to 5 mm wide, 1 to 3 mm high, with smooth surfaces. Burrows not re-used, not branching. Probably a gastropod trail, may be same genus as Gyrochorte, but different habits. Indicates littoral deposits. (Description from Bandel, 1967, p. 4.)

Plate 11

Figure 1. Gyrochorte, in Sunnyside Sandstone. Coin diameter is 1.78 cm.

Figure 2. Aulichnites, from Kenilworth Sandstone. Coin diameter is 1.78 cm.



Domichnia

Ophiomorpha (pl. 12, figs. 1, 2 and 3
pl. 13, figs. 1, 2 and 3).

Known for many years as Halymenites major Lesquereaux, a European algal form which it superficially resembles, Ophiomorpha is one of the most widely distributed trace fossils in Mesozoic to Recent sediments in the United States. A full relief burrow, frequently vertical, preserved as either cores or casts with characteristic bumpy surfaces. Casts of burrows found in deposits of shallow water environments have a thick outer wall, similar to burrows of the modern shrimp Callianassa major Say, which is considered the modern counterpart of Ophiomorpha (Weimer and Hoyt, 1964; Hoyt and Weimer, 1965). Burrows of Ophiomorpha vary widely in size with variation in sedimentation. Well sorted fine- to medium-grained sediments contain the largest burrows; burrows are smaller as the content of carbonaceous debris in the sediments increases. Ophiomorpha preferred environments with little suspended sediment for its role as a suspension feeder because when there was an excess of suspended sediment, the phytoplankton upon which the animal fed would not be present. It is found in many different types of sedimentary rocks at Sunnyside, however. Several different species of Callianassa are found in estuaries, open lagoons, or tidal inlets, but burrows of other species than C. major Say would not be confused with Ophiomorpha. Burrows of other species of

Plate 12

Figure 1. _Ophiomorpha_, from Sunnyside Sandstone. View parallel to bedding surfaces. Coin diameter is 1.90 cm.

Figure 2. _Ophiomorpha_, from Sunnyside Sandstone. View normal to bedding surfaces. Hammer handle is 4.07 cm measured diameter.

Figure 3. _Ophiomorpha_, from Sunnyside Sandstone. View normal to bedding surfaces. Hammer head is 18.65 cm long.

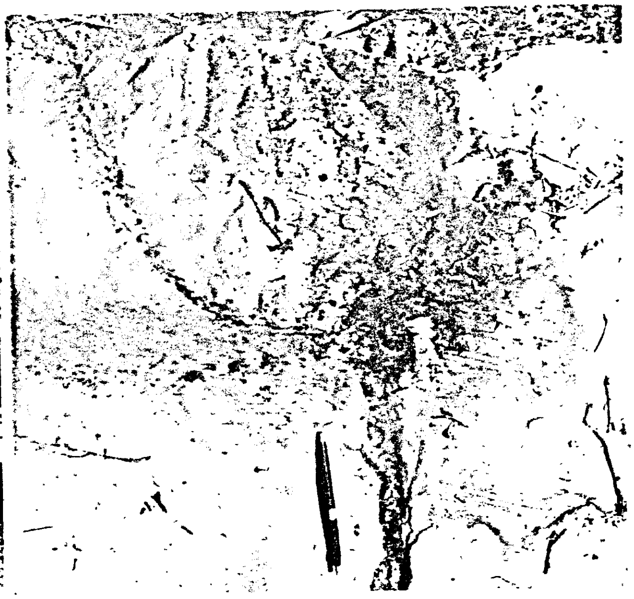
Plate 13

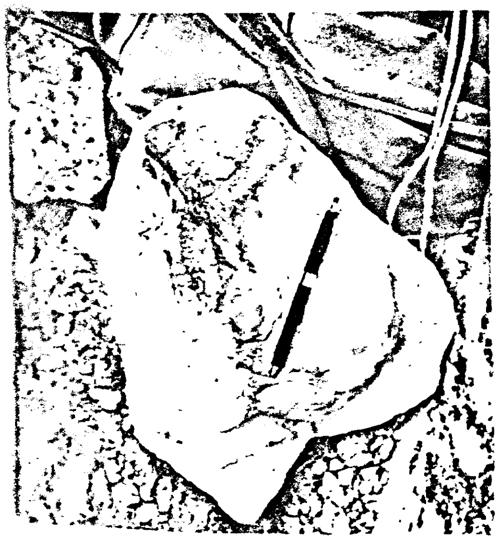
Figure 1. Ophiomorpha, upper Kenilworth Sandstone. Hammer scale.

Figure 2. Ophiomorpha, from upper Sunnyside Sandstone, illustrating branching nature of burrows. Pen scale.

Figure 3. Ophiomorpha, from upper Sunnyside Sandstone, illustrating branching nature of burrows. View parallel to bedding surfaces. Pen scale.

Figure 4. Arenicolites (circled), expressed as pairs of indentations on top of bed, Kenilworth Sandstone. View normal to bedding surface. Coin diameter is 1.90 cm.





Callianassa may resemble *Arthrophycus*, smooth tubes, or large horizontal burrows (R. J. Weimer, 1968, written communication). Seilacher (1964, p. 313) points out the bathymetric inferences drawn from trace fossil orientations.

Arenicolites (pl. 13, fig. 4).

A full relief, vertically oriented, U-shaped burrow with a diameter of 5 to 7 mm. Most burrows are oval in cross section, probably because of compression during lithification. The length of the burrow is controlled by thickness of the enclosing bed. *Arenicolites* is preserved on bedding surfaces as pairs of depressions, usually 10 to 50 mm apart. A domichnia or fodinichnia type burrow of a polychaete worm, found in well sorted, fine- to medium-grained sandstones; burrow indicates littoral environments (Seilacher, 1964, p. 311).

Thalassinoides (pl. 14, figs. 1 and 2).

A convex epirelief burrow, very common in sandstones throughout the area. Burrows are a series of Y-shaped, branching tubes, intimately interwoven. Tubes are circular to oval, with a diameter of 5 to 15 mm. Burrows are developed at a sand-to-sand, sand-to-muddy siltstone interface. Considered by Häntzschel (1962, p. W218) to be burrows of a decapod crustacean. Indicates shallow neritic conditions close to the littoral zone (J. D. Howard, 1967, oral communication).

Plate 14

Figure 1. Thalassinoides, underside of bedding, lower Kenilworth Sandstone. Coin diameter is 1.90 cm.

Figure 2. Thalassinoides, in Sunnyside Sandstone. Overhead view, pen scale.

Plural curving tubes (pl. 15, figs. 1 and 2).

Description by Howard, (1966a, p. 76) for groups of subparallel, curving, vertically oriented full relief tubes that have definite wall structure. Tubes are very light grey to white and are very noticeable on outcrops. Tube diameter is constant at about 7 mm, and the tube wall is 1 to 2 mm thick. Tubes are open at top and bottom. Grain size of the wall is the same as that of the enclosing rock, but organic matter and clay are absent. Probably the permanent burrow of a filter feeder (Howard, 1966a, p. 77), in fine-grained sands of the littoral zone (Seilacher, 1964, p. 311).

Large horizontal burrows (pl. 15, figs. 3 and 4).

Large, branching burrows preserved in full relief and as convex epirelief in silty, carbonaceous, sandy mudstones. Described by many writers as "fucoids", the trace is similar to Planolites montanus. In the Sunnyside district these traces are found only above coal beds or above medium-grained sandstones. Often aligned subparallel to strike of ripple mark crests where associated with them, but no indication of mechanical reworking of burrows. Burrow is oval in cross section, with a maximum diameter of 10 to 60 mm. Burrows filled with very fine- to fine-grained sand with clay matrix and some carbonaceous material. Distinctive on the outcrops. Believed by the author to be constructed by detritus feeders in terrestrial subaqueous deposits; interpretation based on

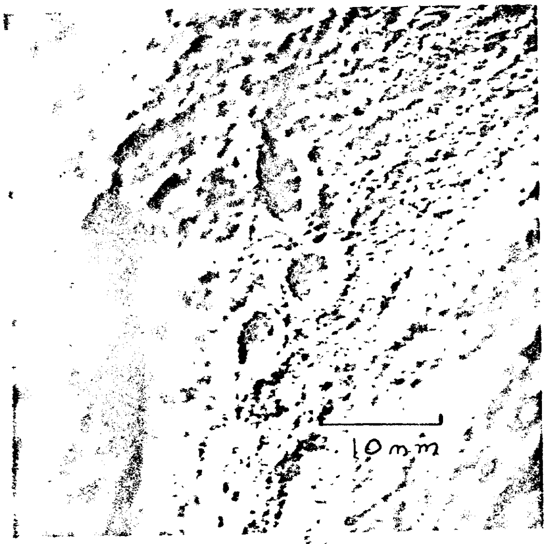
Plate 15

Figure 1. Plural curving tubes, natural size, middle Kenilworth Sandstone.

Figure 2. Plural curving tubes, Sunnyside Sandstone. Pen scale.

Figure 3. Large horizontal burrows, top of Kenilworth Sandstone. Pick scale.

Figure 4. Large horizontal burrows, from siltstone roof rock, Sunnyside coal. Coin diameter is 1.90 cm.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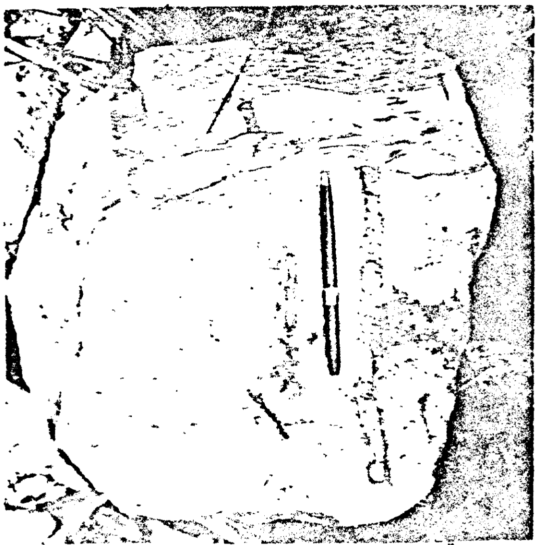
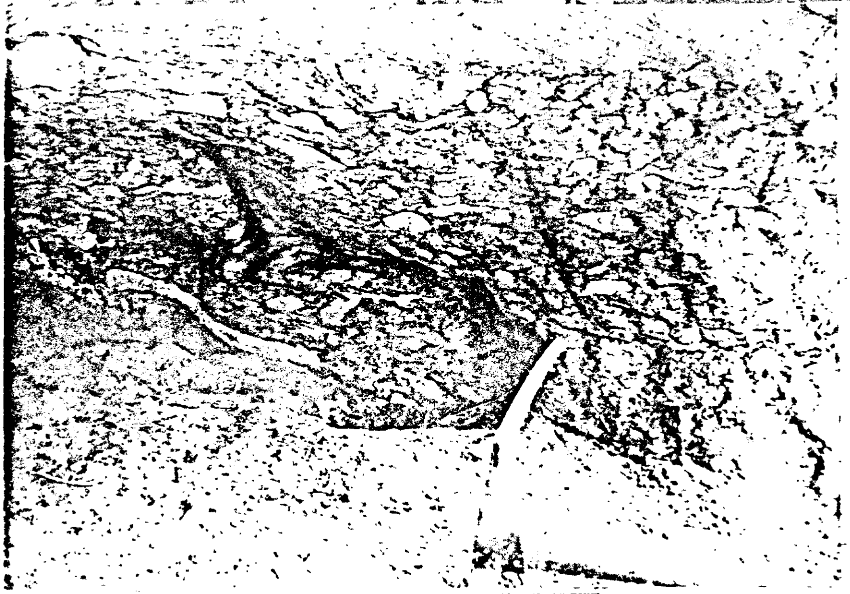




both stratigraphic position and lighologic association of the trace fossil.

Cubichnia

Ruhespuren (pl. 16, figs. 1 and 2).

Resting traces preserved as concave hyporeliefs in fine- and medium- to fine-grained sandstones. Traces may form a circular pattern, an apparent trail, or may occur singly. Suggested by Howard (1966a, p. 78) to be made by "jellyfish or an animal with similar bottom configuration." Traces are oval, and have constant diameter of 10 to 15 mm. In cross section they exhibit a peripheral trough 2 to 5 mm deep with transverse walls. The center is a raised boss slightly lower than the surrounding surfaces, 5 to 10 mm wide, and is saucer-shaped. The trace is uncommon, but its occurrence on outcrops is probably limited by the scarcity of horizontal bedding surface exposures. Indicative of littoral to sublittoral environment (Seilacher, 1964, p. 311).

Fecal Material

Pellets (pl. 17, figs. 1 and 2).

Pellet-like structures preserved as convex epirelief or convex hyporelief at sand-to-sand interfaces. Ovoid, with a major axis of 5 to 10 mm and minor axis about 5 mm. Locally abundant, these features exhibit no interior structure. Similar morphologically to Sagittichnus Seilacher, 1953 (Hantzschel, 1962, p. W215). The trace fossil is believed by

Plate 16

Figures 1 and 2. Ruhespuren (arrows), pattern and trail on t
of bedding, lower Kenilworth Sandstone. Coin diameter is
1.90 cm.

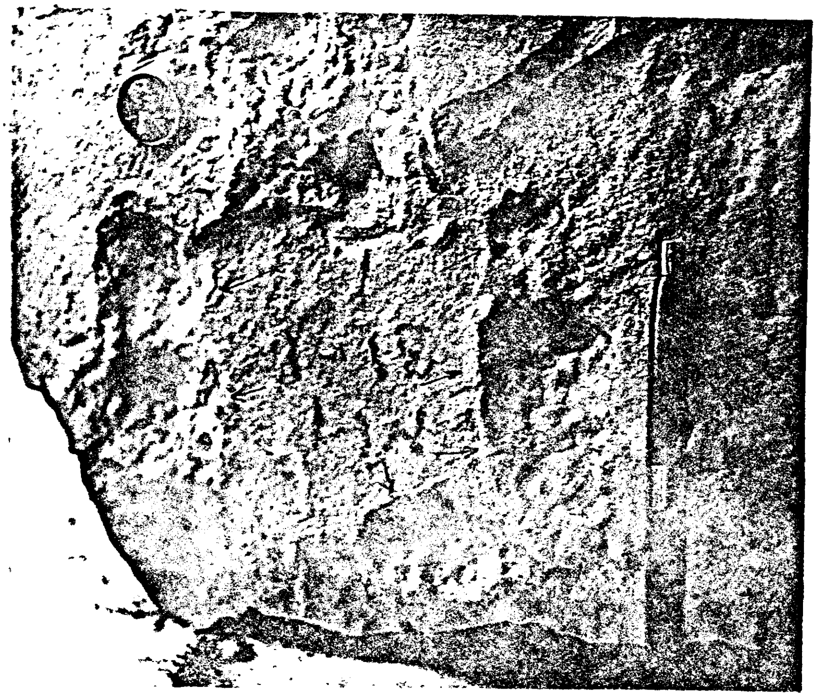
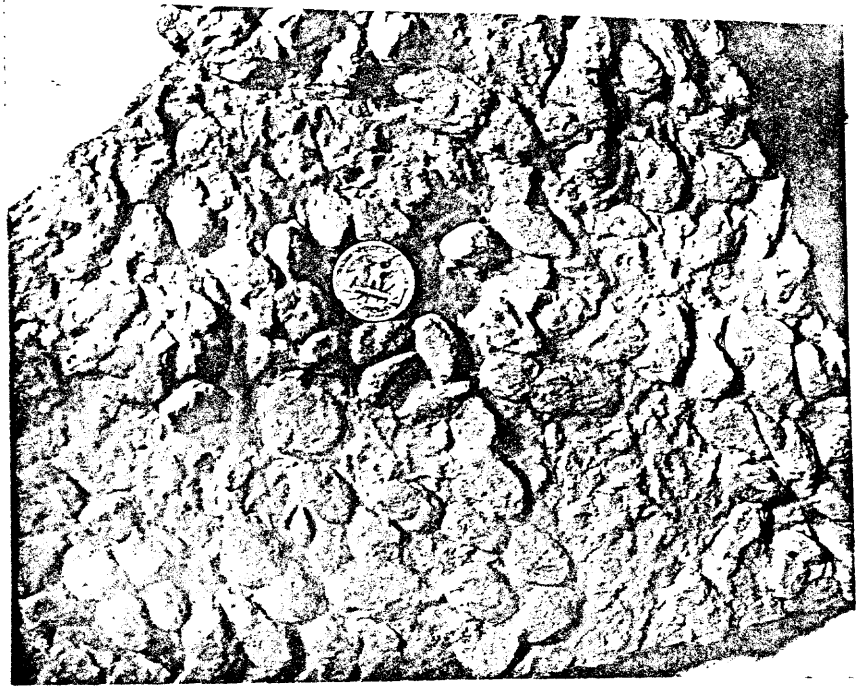
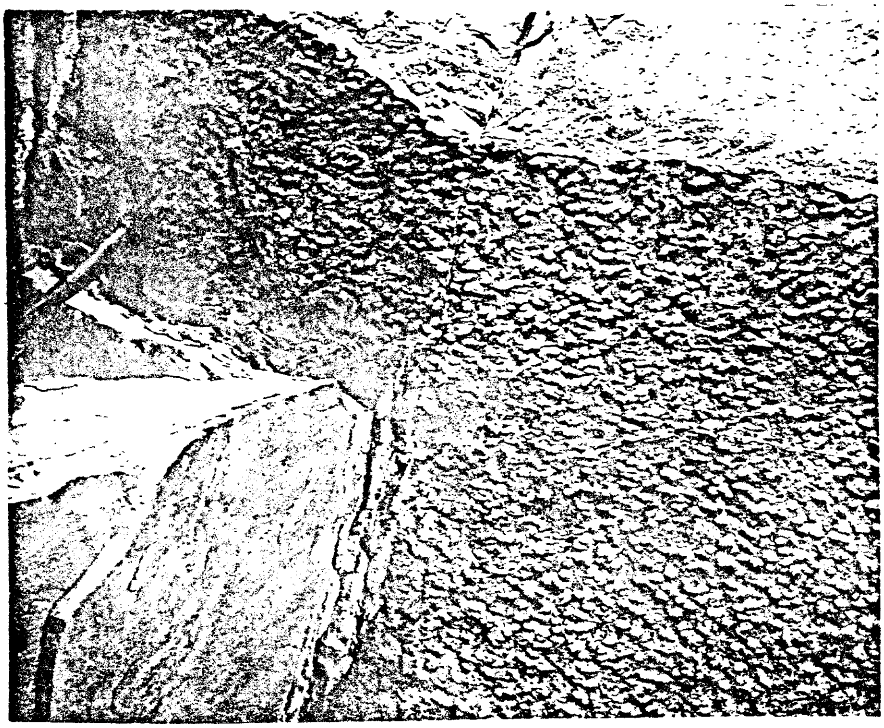


Plate 17

Figure 1. Fecal pellets, on top of bed, middle Sunnyside Sandstone. Coin diameter is 2.38 cm.

Figure 2. Fecal pellets, on base of Castlegate Sandstone. Overhead view, pick scale.





the author to represent feces of fish or of large amblypod crustaceans in a shallow neritic to littoral environment, because of the stratigraphic position and lithologic association of these trace fossils.

INORGANIC SEDIMENTARY STRUCTURES

Sedimentary structures of the Blackhawk Formation may be grouped into two categories: biogenic structures, built by organisms; and inorganic structures, which are primary features developed mechanically. Biogenic sedimentary structures in the rocks under investigation were described in the section on trace fossils. This section is therefore concerned with inorganic structures.

Klein (1967) and Potter and Pettijohn (1963) made exhaustive studies of the role of sedimentary structures in analysis of sedimentation patterns and depositional environments. Klein's work described Holocene deposits, while Potter and Pettijohn concentrated on paleoenvironments. Both works contain comprehensive reference sections. Interpretations of environmental significance of sedimentary structures made in this paper are based upon these two publications and on papers by McKee (1957, 1964).

Bedding Structures

Sandstones of the Blackhawk Formation commonly are cross-stratified. The nature of the cross-stratification varies with the current velocity in which it was produced. Thickness and type of stratification depends mostly upon the velocity of the transporting medium. In strata deposited in quiet water, laminar bedding is dominant, and depositional cross-stratification is uncommon; deposits in environments of higher kinetic energy are thin- to thickbedded (2 in. to 5 ft), and most are crossbedded in wedge-shaped sets (fig. 8) 6 inches to 2 feet thick. Such sets are tangential at their bases, and have planar tops (fig. 9). Sole markings in beds of this type are parallel to the direction of crossbedding. This indicates that the beds were built up in the direction of sediment transport. Primary dip of crossbedding varies with the energy of the environment, but dip angles greater than 20 degrees are rare. Most crossbedding in Blackhawk sandstones at Sunnyside dips to the southeast at 2 to 15 degrees; measurements of direction of transport indicate a nearly constant direction of S 80 E. Of 80 measurements of features indicative of transport direction selected at random from field notes, 74 are within 2 degrees of S 80 E, and none deviated more than 20 degrees. The directional features measured include crossbedding, flute casts and other sole markings, asymmetrical ripplemarks, and orientation of plant debris on bedding surfaces. The nearly unidirectional

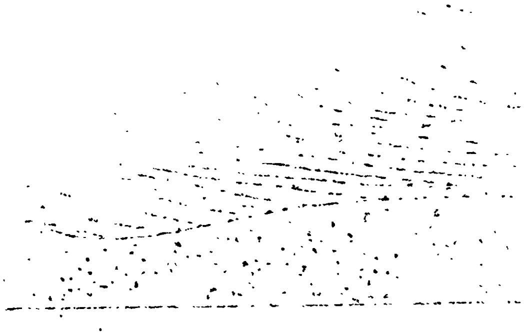
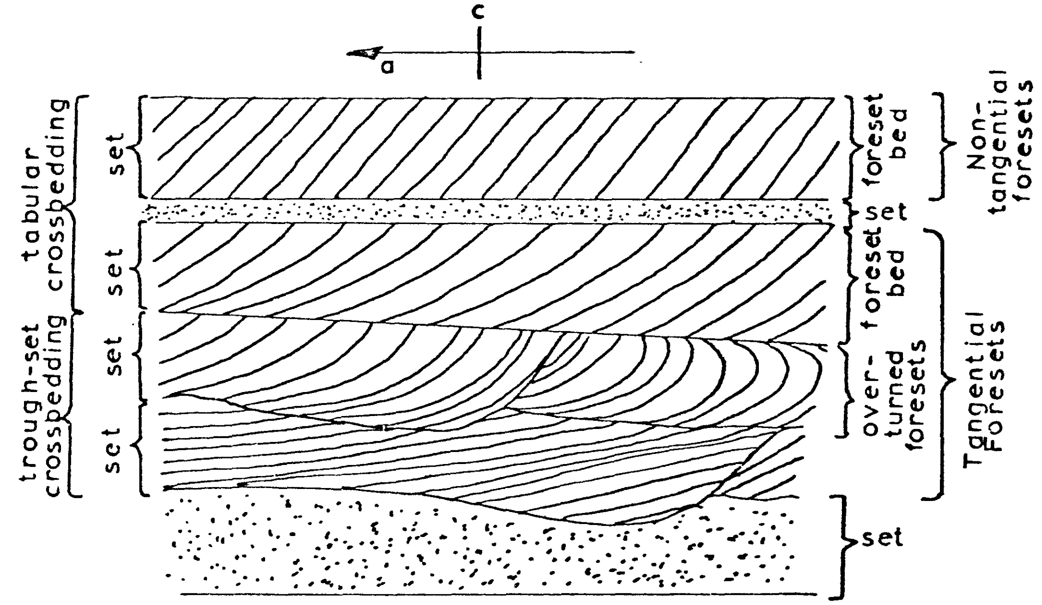
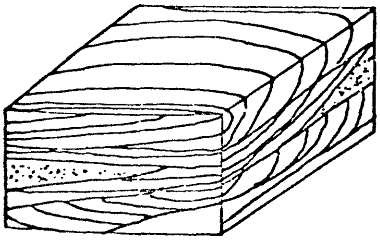
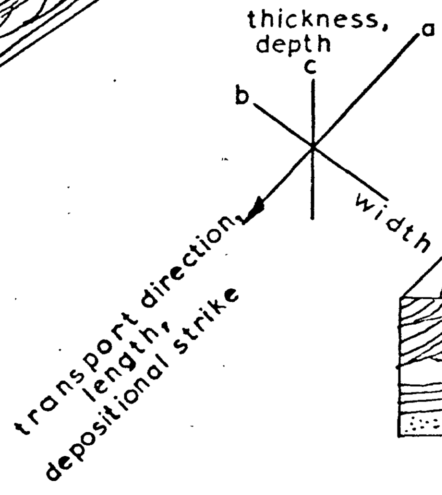


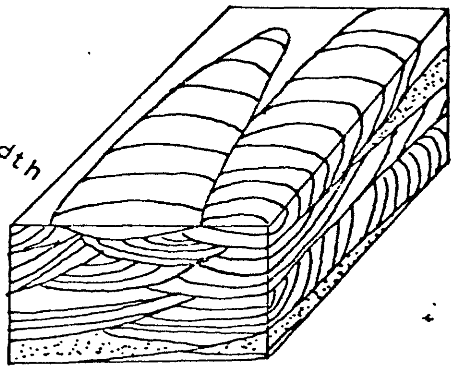
Figure 8. Terminology of Crossbedding (modified from Potter and Pettijohn, 1963, p. 69). No scale.





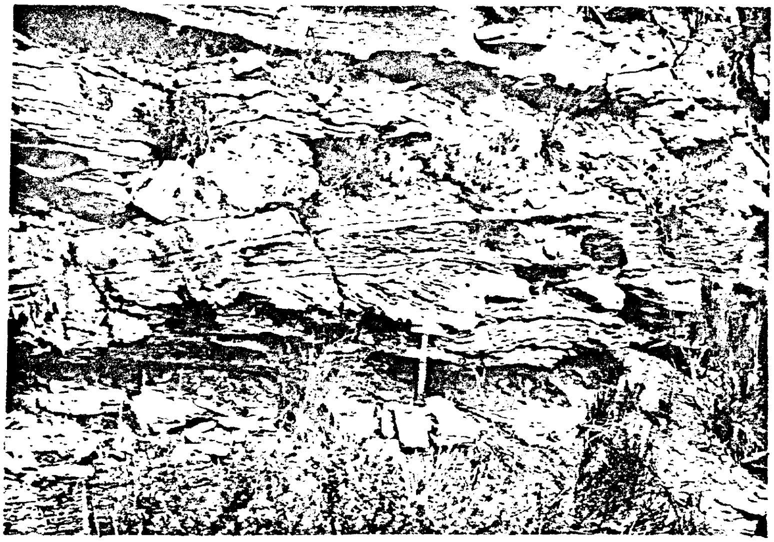
Tabular
Crossbedding





Trough
Crossbedding

Figure 9. Tangential crossbedding in lower Kenilworth Member.



sediment transport is a major factor in the interpretation of depositional environment, to be treated in a later section.

Many sandstone beds exhibit ripple cross-lamination (fig. 10), a bedding feature formed by low velocity current drag penecontemporaneous with deposition (Potter and Pettijohn, p. 155). Laminae are built up by ripplemarks migrating in one direction. Where this feature was found near Sunnyside, measurements of the direction of laminae buildup indicate ripple migration to the east-southeast.

Crossbedding that indicates sediment transport in opposite directions in successively overlying sets (fig. 11) formed in local areas of deposition. This type of crossbedding is preserved in some outcrops of the Blackhawk Formation. Particularly good outcrops in the upper Sunnyside Sandstone in Water Canyon (fig. 11) of such beds display a vertical sequence of foresets 6 inches to 1 foot thick that dip in opposite directions at low angles. Potter and Pettijohn (p. 96) point out that most crossbedding points down the paleoslope.

The upper surface of the main cliff of both the Sunnyside Sandstone and the Kenilworth Sandstone is planar at nearly every exposure (fig. 12). The planar surface may be an indication of subaerial erosion prior to deposition of the overlying sediments (Howard, 1966b, p. 32). Rootmarks occur in the upper foot of the uppermost sandstone bed in each

Figure 10. Ripple cross-lamination, middle Sunnyside Sandstone.

Figure 11. Crossbedding in opposite directions in successively overlying sets, upper Sunnyside Sandstone. Oblique view to depositional strike.

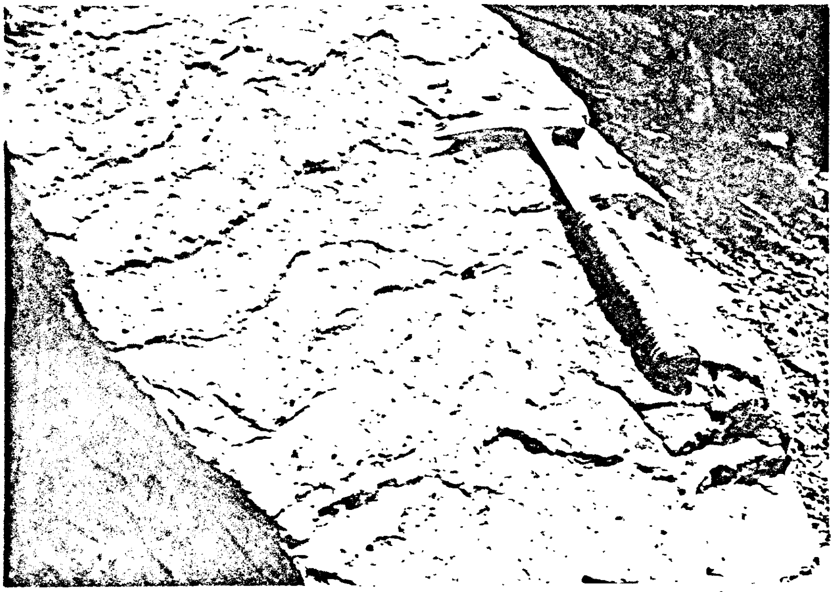


Figure 12. Top of Sunnyside Sandstone, ill... ustrating plan nature of bedding surfaces.

member (fig. 26), indicating that plants once grew at these horizons.

Current Structures

Ripplemarks are the most common types of current-built structures in the rocks at Sunnyside. Many are symmetrical (fig. 13) with relatively straight, subparallel crests that are transverse to the oscillatory water movement that formed them (Potter and Pettijohn, p. 29). Current ripples (fig. 14), which are formed by directional movement or transport (Potter and Pettijohn, p. 29), are abundant in thinbedded, fine-grained sandstones in the Sunnyside area. Oscillation and current ripplemarks vary widely in measured amplitude and wave length. Megaripples (Potter and Pettijohn, p. 89) with maximum amplitudes of 1.5 inches and wave lengths of 7.5 feet occur in the middle Kenilworth Sandstone in Slaughter Canyon (fig. 15). Megaripples are best preserved at this locality, although they are common elsewhere in the Sunnyside area. Gilbert (1899, p. 138) postulated that ". . . ripplemarks are only half as broad as the waves rolling above them are high." If this postulation is true, waves that formed the megaripples described above were about 15 feet high. Heezen and Hollister (1964) have photographed current ripples on the sea floor at depths as great as 8,000 meters, thereby proving that fossil ripplemarks have no bathymetric significance. Current ripples in the Blackhawk Formation are

Figure 13. Oscillation ripplemarks, upper Sunnyside Sandstone.

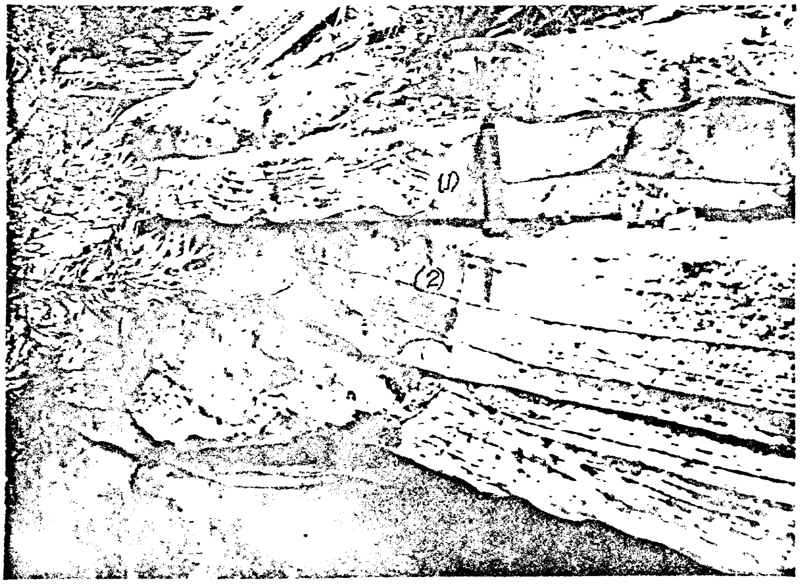
Figure 14. Current ripplemarks, upper Sunnyside Sandstone. Overhead view.

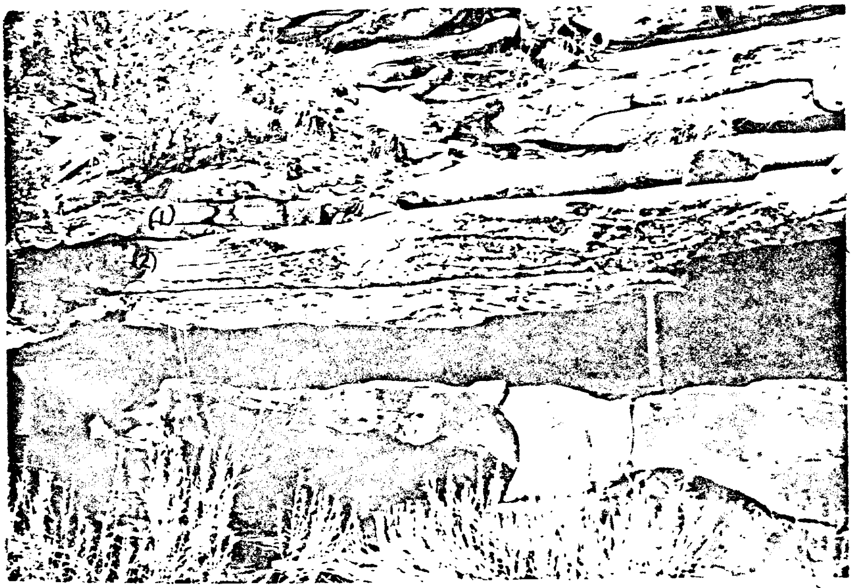

N50E

Figure 15. Megaripples in middle Kenilworth Sandstone.

(A) Sharp peaked ripplemarks (1) overlying and truncating low amplitude, long wave length ripples (2).

(B) Megaripples with wave length of 6 to 8 ft and amplitude of 1.5 in. Hammer scale.


(1)
(2)


(1)
(2)

transverse to the direction of crossbedding; according to Potter and Pettijohn (p. 94), these ripples aid in delineating the depositional strike. Interference ripplemarks (Potter and Pettijohn, p. 93) formed by currents operating at large angles to each other, and characterized by polygonal cusps, are found in some beds (fig. 16).

Channel Structures

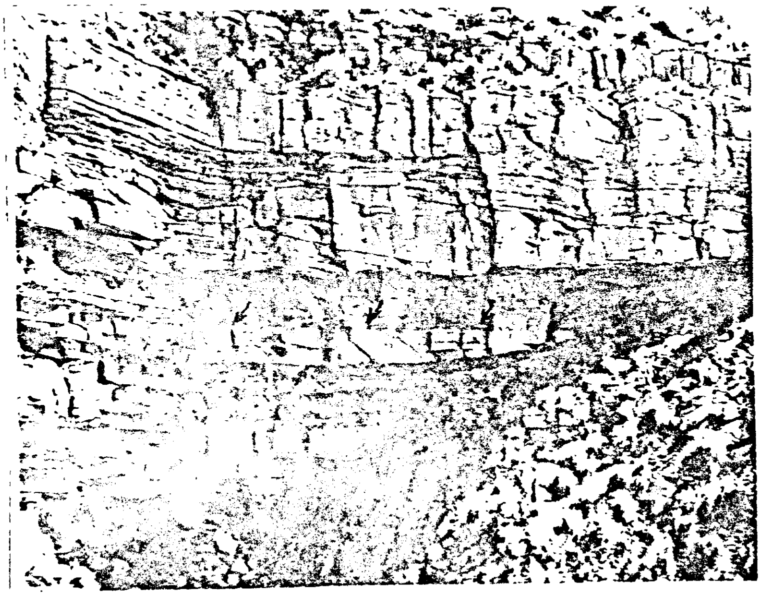
Channel deposits occur in nearly all types of beds. They vary in width, depth, direction of transport, and orientation within beds; channel deposits can seldom be traced for any appreciable distance laterally, however, because they commonly crop out high on vertical cliffs and are inaccessible, and because they are covered by colluvium on north-facing slopes.

Channel deposits are found in two lithologic relationships: scours into mudstone that are filled with sandstone, and scours into sandstone that are filled with sandstone. Because these lithologic relationships may have some bearing on interpretation of depositional environment, their data will be presented separately.

Channel deposits of sand in mudstone (fig. 17). are commonly the smaller of the two types. Most are bilaterally symmetrical about a thalweg at the center of the channel. Channel deposits of this type observed at Sunnyside are less than 50 feet wide and less than 20 feet deep. They are lenticular sandstone bodies, convex downward with nearly planar

Figure 16. Interference ripplemarks on bottom of bed, middle Kenilworth Sandstone, illustrating ploygonal cusps.

Figure 17. Sandstone-in-mudstone channel (arrows) in upper Sunnyside Shale. Channel at thalweg is 12 ft thick.



tops, and are enclosed in and covered by the same type of sediment into which the channels were cut. The structures are foreset crossbedded in trough sets (Potter and Pettijohn, p. 70) that have their long axis parallel to the direction of dip of the foresets. The sets thicken in the direction of the foreset dip, and truncate other sets throughout the depth and breadth of the deposit. Most trough sets display moderately graded bedding. No trace fossils were observed in units of this type.

Channels of sandstone in sandstone are larger than channels of sandstone in mudstone. The smallest observed channel of the sandstone-sandstone type (fig. 18) is at the mouth of Slaughter Canyon in Whitmore Canyon (pl. 1). Although one side of this channel is removed by erosion, the projected width is 60 feet; it is 10 feet thick. The largest channel structure of this type is located in the south wall of Whitmore Canyon, and was measured by pacing and with steel tape; it is 150 feet wide and 45 feet thick at the thickest point. These channels are asymmetrical in cross-section, with the thalweg well to one side. Sediments in these channel fills are crossbedded in wedge-shaped sets that thicken laterally, normal to the long direction of the channel (fig. 19). Foreset bedding within sets dips in the direction of thickening of the sets. Sandstones that fill scours in sandstone are coarser-grained and contain less carbonaceous debris than the

Figure 18. Small sandstone-in-sandstone chanel in upper Kenilworth Sandstone. View northwest.

Figure 19. Sandstone-in-sandstone channel in upper Sunnyside Shale. View northeast.

beds into which the channels were cut. The scoured beds commonly are thinly and evenly bedded, very carbonaceous, and commonly are interbedded with siltstone. No trace fossils were found in channel fill sandstones, but traces are often abundant in scoured beds. Most channel deposits of the type described here crop out high on the cliffs, hence they are easier to trace laterally than the smaller channels.

Load Structures

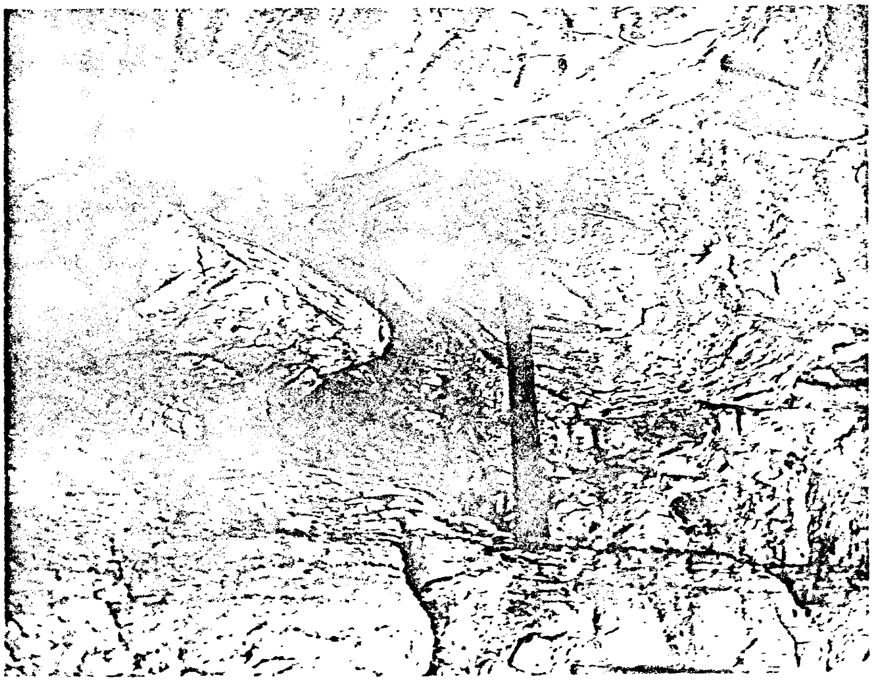
Ball-and-pillow structures and load casts are the most common types of load structures in the rocks of the Sunnyside district. Both features are caused by foundering of a sediment into a less-dense sediment while both bodies are still hydroplastic (Potter and Pettijohn, 1963, p. 145, 148).

Ball-and-pillow structures at Sunnyside are characterized by individual segments of a stratum which have settled into the underlying sediment. Ball-and-pillows are most commonly segments of fine-grained sandstone which have foundered into mudstone, with stringers of mudstone squeezed up around the segments.

Load casts are formed by settling caused by differential loading of irregular sediment surfaces. Initial depressions on hydroplastic mud beds are filled with sediment, resulting in unequal loading (Middleton, 1965, p. 249). Load casts do not break away from the parent bed, as do ball-and-pillow structures; they form pendants into the less-dense sediment.

Load casts are most common where sands are deposited on argillaceous sediments (fig. 20).

Figure 20. Load cast of very fine-grained, dense sandstone into underlying carbonaceous mudstone, middle Kenilworth Shale. Pick scale.



STRATIGRAPHY

OF THE BLACKHAWK FORMATION

The Blackhawk Formation at Sunnyside comprises, in ascending order, the Kenilworth and Sunnyside Members of Young (1955). Each member is defined (fig. 3) to consist of a "basal whitecapped sandstone and the overlying lagoonal and offshore bar deposits" (Young, 1955, p. 181). Field observations by the author show that the sandstone unit of each member is a physically prominent and mappable unit (pl. 1) and that the lithologic dissimilarity between the sandstones and coal-bearing argillaceous sediments indicates that a different set of conditions governed the deposition of each. The "basal white-capped sandstone" of Young also occurs at the top of individual sandstone sequences in each member. For these reasons, the author proposes to divide both the Kenilworth Member and the Sunnyside Member. [redacted] In each member, the divisions are a sandstone [redacted] and an overlying coal-bearing unit [redacted] (fig. 21). The divisions [redacted] are [redacted] the Kenilworth Sandstone, Kenilworth Shale, Sunnyside Sandstone, and Sunnyside Shale.

Figure 21. Blackhawk Formation at Sunnyside, Utah.

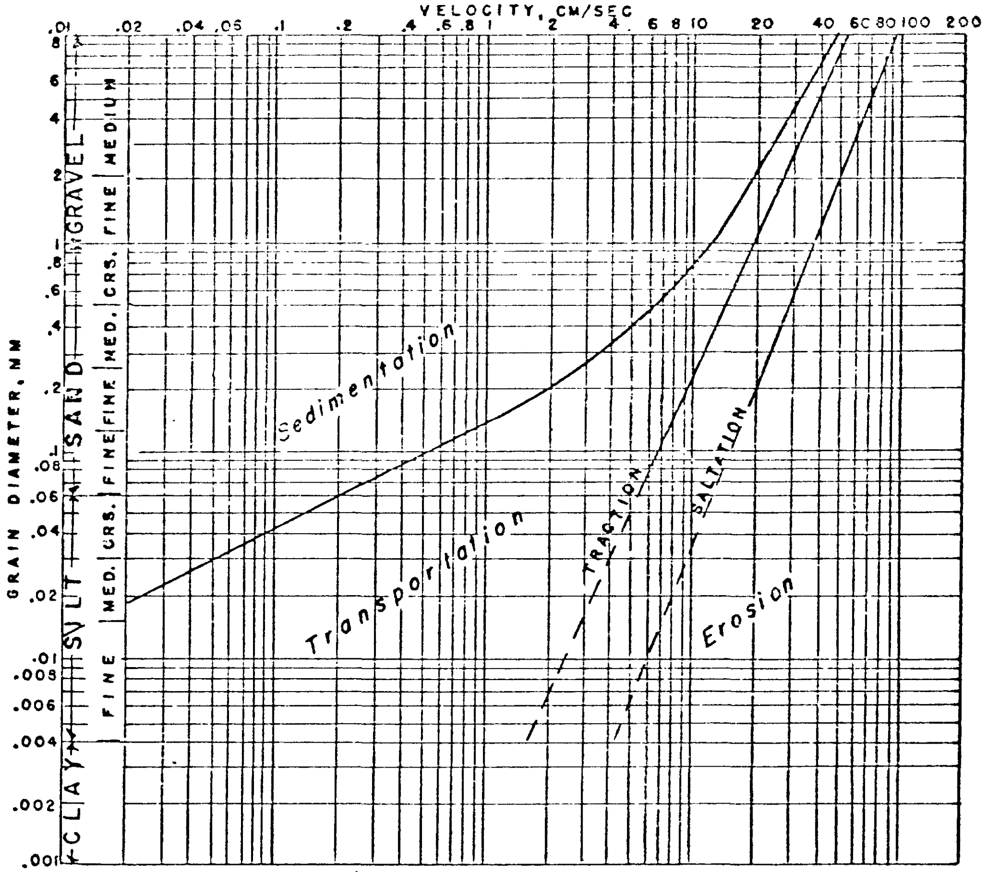
Key: C Castlegate Formation
S Sunnyside Member
K Kenilworth Member
M Mancos Shale


C
S
K
M

In this report the term "sandstone" refers to indurated sediments comprising particles from .062 to 2.0 mm diameter. "Siltstone" refers to nonfissile indurated sediments composed of silt-sized particles from .062 to .004 mm diameter. "Claystone" in this report refers to nonfissile, indurated beds of clay-sized particles less than .004 mm diameter. "Mudstone" indicates poorly indurated, indistinctly bedded sediments of grain size less than .004 mm diameter, nonfissile, laminar or massive. The term "Shale" is a group term indicating a collection of beds of dominantly argillaceous sediments; "shale" refers to fissile mudstone, claystone, or siltstone. Grain size notations are in accord with the Wentworth scale for clastic sediments used by the U. S. Geological Survey. Figure 22 shows current velocities necessary to transport and deposit particles of these sizes.

Each member exhibits a depositional sequence that varies slightly laterally at Sunnyside. The sequence begins at the base of the sandstone submember with alternating layers of very thin-bedded, carbonaceous sandstone and sandy, carbonaceous siltstone. The sandstones are evenly bedded, well sorted texturally, and contain numerous trace fossils; most siltstones were thoroughly reworked by organisms. Although the two lithologies are interbedded, there are sharp boundaries between layers. Ophiomorpha is the dominant trace fossil in the lowest sandstones; the siltstone interbeds contain abundant Cylindrichnus, fecal pellets, and labyrinth castings if

Figure 22. Current velocities required for erosion, transportation, and deposition of sediments. Curves are based upon experiments with particles of specific gravity 2.60 to 2.65 (modified from Heezen and Hollister, 1964, p. 171).


VELOCITY, CM/SEC
.01 .02 .04 .06 .1 .2 .4 .6 .8 1 2 4 6 8 10 20 40 60 80 100 200
GRAIN DIAMETER, MM
8 6 4 2 1 .8 .6 .4 .2 .1 .08 .06 .04 .02 .01 .008 .006 .004 .002 .001
CLAY
SILT
SAND
GRAVEL
FINE
MED.
CRS.
FINE
FINE
MED.
CRS.
FINE
MEDIUM
Sedimentation
Transportation
TRACTION
SALTATION
Erosion

if carbonaceous material is present. Labyrinth castings are most abundant at the interface of siltstone and overlying sandstone, a horizon that represents a surface of deposition. Disturbance of the sediment was so intense in these beds (fig. 5A) that few identifiable trace fossils are preserved in the rocks.

The next overlying portion of the sequence is mostly thinbedded, very fine-grained sandstone with minor, discontinuous lenses and pods of carbonaceous, fossiliferous siltstone. The fine-grained sandstone commonly contains megaripples, current ripples and oscillation ripples; most beds are crossbedded in tangential foreset sets. This sandstone contains abundant trace fossils of the kind interpreted by Seilacher and others to be indicative of shallow water (p. 45 to 55 of this paper). Thinbedded sandstones are characterized by an abundance of trace fossils. _Thalassinoides_, _Ophiomorpha_, _Cylindrichnus_, _Teichichnus_, _Gyrochorte_, _Aulichnites_ and _Arenicolites_ are some fossils that are preserved in the rocks of this type. One factor that governs the association of trace fossils is the amount of silt, mud and organic debris in the environment. Where much fine sediment and organic detritus was present during deposition, _Ophiomorpha_ is small, most _Cylindrichnus_ are horizontally oriented, and excellent helicoid funnels are associated with _Cylindrichnus_. _Teichichnus_ is common in the more carbonaceous rocks.

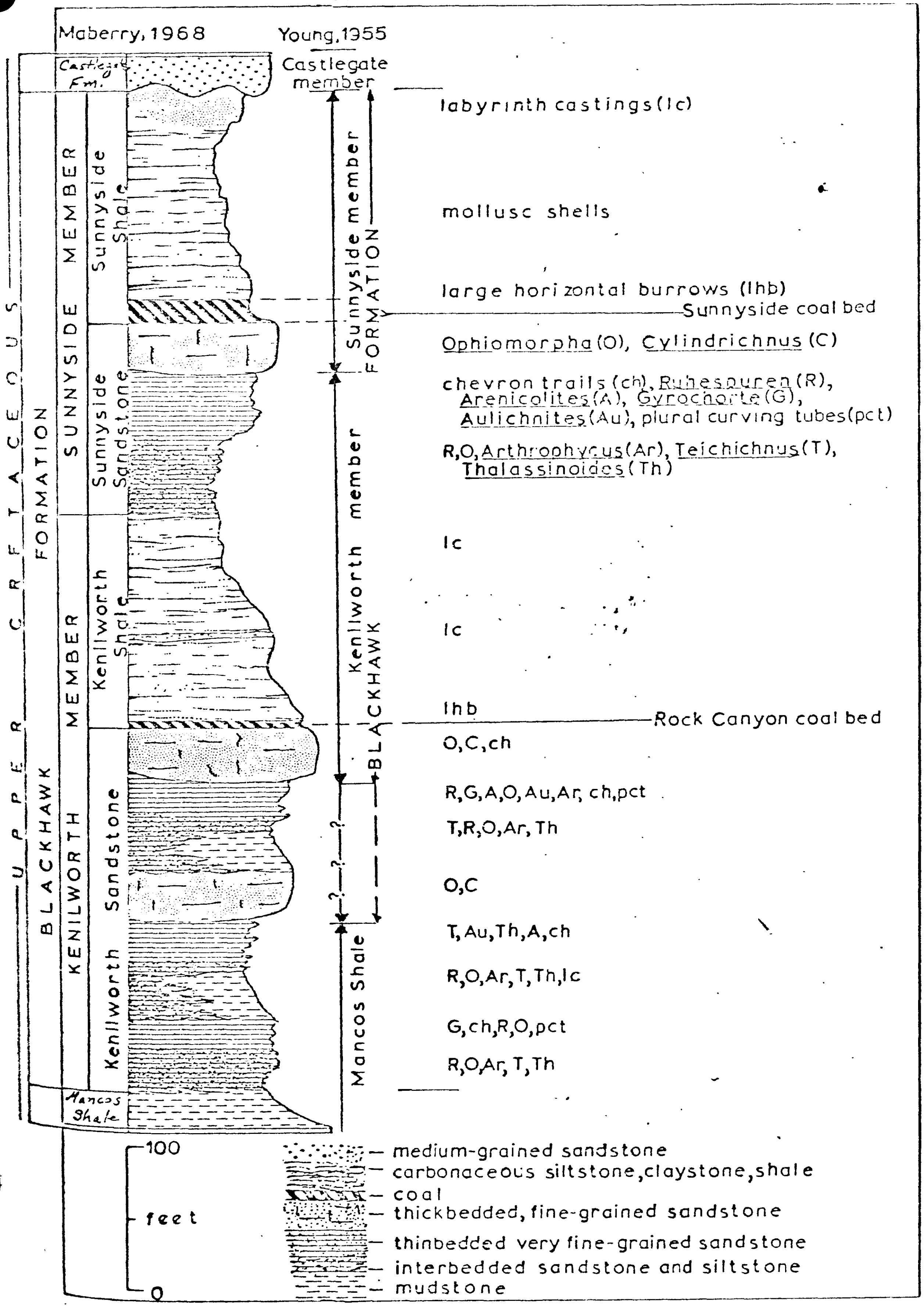
The third portion of the depositional sequence is a moderately well sorted, thickbedded sandstone that commonly makes a massive cliff. It contains variable amounts of carbonaceous debris, and commonly contains an abundant trace fossil fauna. The thickbedded sandstone is coarser grained than the underlying units.

The uppermost unit in the sequence is a very light-grey sandstone, normally well sorted, fine- to medium-grained, and nonfossiliferous; most stratification is in tangential foreset crossbeds. This unit is the "bleached zone," or "whitecap" of Young (1955, p. 85); it is commonly the uppermost unit of a sandstone submember, but is also found in many outcrops some distance below the top of the submember. Thickbedded, well sorted sandstones in the submember are characterized by large Ophiomorpha burrows (3 to 5 cm diameter), and by common Arenicolites burrows. Cylindrichnus burrows are vertical, and tracks and trails on bedding surfaces are abundant.

Any parts of the sequence may be missing from the section at a given point, depending upon conditions at the time of deposition (fig. 23).

Rocks in the coal-bearing units include a basal, irregular and discontinuous, very carbonaceous sandy siltstone; an overlying coal bed; a siltstone or fine-grained sandstone bed; and dark mudstones with thin, discontinuous, cross-strafitied beds of claystone, siltstone, or very fine-grained sandstone. Channel-fill sandstones occur in the

Figure 23. Columnar stratigraphic section of the Blackhawk Formation in the Sunnyside district, showing generalized trace fossil lithologic association.



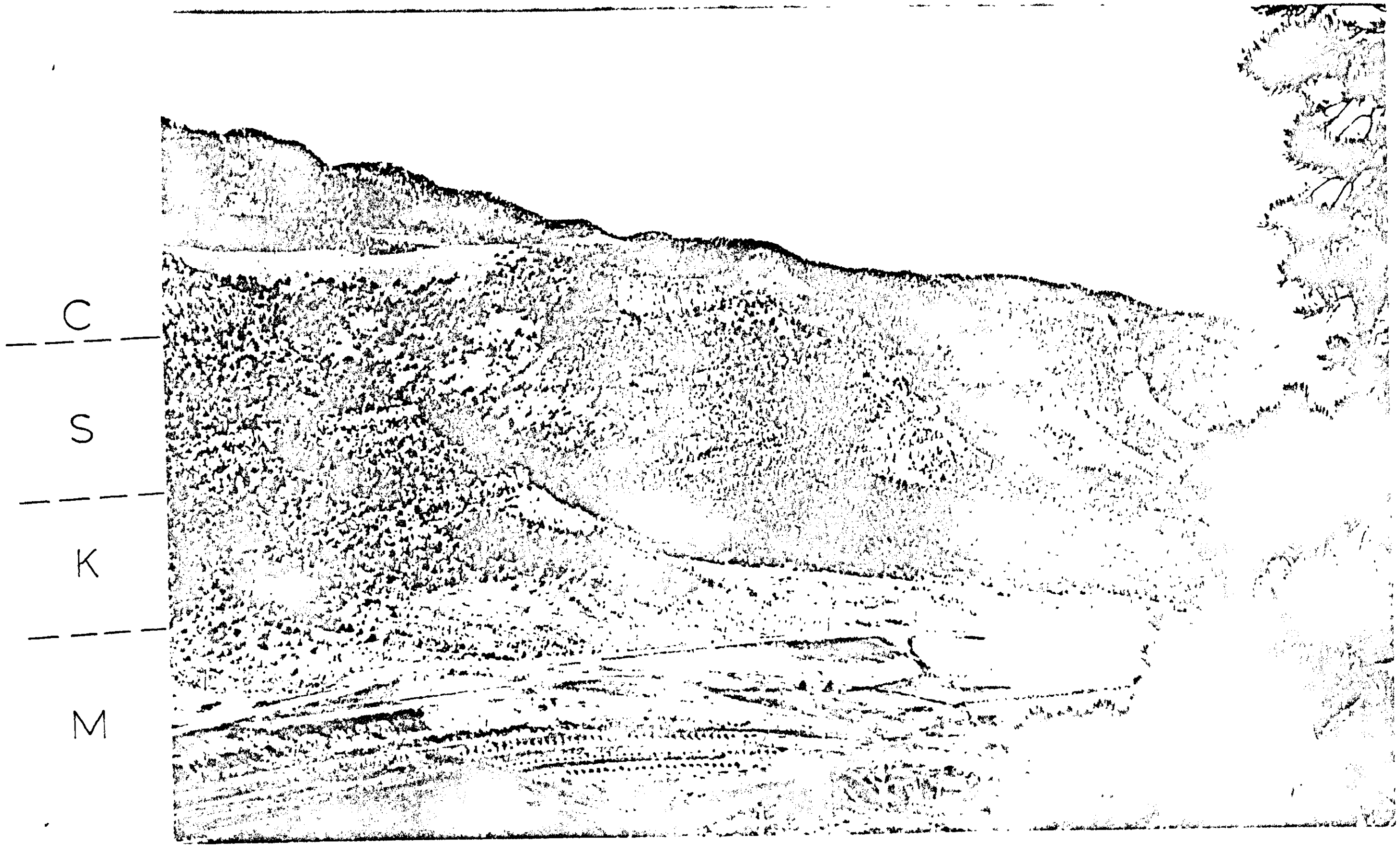
Maberry, 1968
Young, 1955
Castlegate Fm.
Castlegate member
UPPER CRETACEOUS
BLACKHAWK FORMATION
SUNNYSIDE MEMBER
KENILWORTH MEMBER
Sunnyside Shale
Sunnyside Sandstone
Kenilworth Shale
Kenilworth Sandstone
Mancos Shale
Sunnyside member
Kenilworth member
BLACKHAWK FORMATION
Mancos Shale
labyrinth castings (lc)
mollusc shells
large horizontal burrows (lhb)
Sunnyside coal bed
Ophiomorpha (O), Cylindrichnus (C)
chevron trails (ch), Ruhespuren (R), Arenicolites (A), Gyrochorte (G), Aulichnites (Au), plural curving tubes (pct)
R, O, Arthrophycus (Ar), Teichichnus (T), Thalassinoides (Th)
lc
lc
lhb
Rock Canyon coal bed
O, C, ch
R, G, A, O, Au, Ar, ch, pct
T, R, O, Ar, Th
O, C
T, Au, Th, A, ch
R, O, Ar, T, Th, lc
G, ch, R, O, pct
R, O, Ar, T, Th
100
feet
0
medium-grained sandstone
carbonaceous siltstone, claystone, shale
coal
thickbedded, fine-grained sandstone
thinbedded very fine-grained sandstone
interbedded sandstone and siltstone
mudstone

The base of the sandstone is at the base of the lowest of three sandstone tongues in the Kenilworth Member at Sunnyside. The three tongues are mostly sandstone, and are separated by thin units of rock lithologically similar to the Mancos Shale. The lower and middle tongues are vertical successions of interbedded siltstone and sandstone, interbedded sandstone and siltstone, and thinbedded sandstone. The upper tongue comprises a lithologic succession like the lower tongues, but is capped by a thickbedded, well sorted, medium-grained sandstone bed. The thickbedded layer contains local bodies of very light-grey to white sandstone at various stratigraphic levels. This is the "basal, massive, white-capped sandstone" of Young (1955, p. 181). The sandstone submember forms an abrupt cliff, up to 200 feet high, that rises steeply above slopes of Mancos Shale. It is distinctive in the field (fig. 24), and is a mappable unit (pl. 1).

The Kenilworth Shale is composed of a 150 to 200 foot thick sequence of coal-bearing, dark grey, clayey shales, mudstones, and sandy siltstones. It forms a slope above the cliff of the Kenilworth Sandstone. The interval is made up of a discontinuous, very carbonaceous, sandy siltstone at the base, overlain by the irregular, thin Rock Canyon coal bed, which persists throughout the area. The coal is in turn overlain by very fine-grained, argillaceous rocks that contain abundant coalified carbonaceous debris.

Figure 24. Blackhawk Formation at Sunnyside, Utah.

Key:
- C Castlegate Formation
- S Sunnyside Member
- K Kenilworth Member
- M Mancos Shale


C
S
K
M

Thin, discontinuous, lenticular beds of limonitic siltstone are common throughout the interval. Large horizontal burrows and labyrinth castings are very common trace fossils in the argillaceous rocks; the lenticular siltstone beds commonly contain Ophiomorpha, Cylindrichnus, and Arenicolites.

The coal of the Kenilworth Shale (Rock Canyon coal bed) in the Sunnyside district varies in thickness from a few inches at numerous places to six feet in No. 1 Fan Canyon. It is detrital coal, composed of small pieces of plant material derived from ferns, angiosperms and conifers (Tidwell, 1968, p. 88). No large plant pieces such as trees or stumps are known in the coal. It is not commercially exploited in the Sunnyside district at present.

The upper boundary of the Kenilworth Shale is placed at the base of the lower continuous sandstone of the cliff-forming Sunnyside Member that overlies the coal-bearing interval of the Kenilworth. This horizon is the inter-member boundary between the Kenilworth and Sunnyside Members, and is one of apparent unconformity.

Sunnyside Member

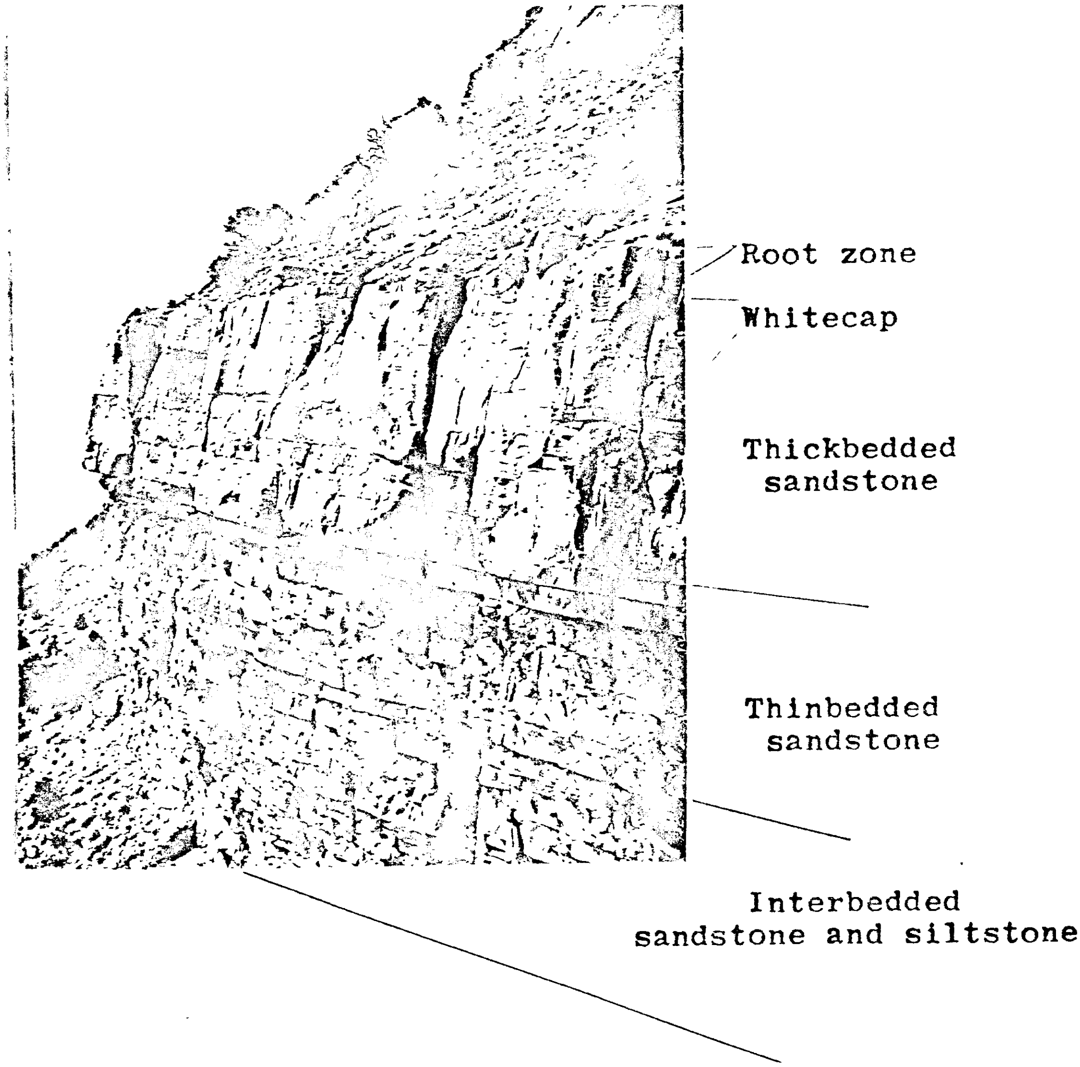
The Sunnyside Member was named and was defined by Young (1955, p. 185) to comprise

> ...a massive, basal sandstone tongue and the overlying coal-bearing rocks which are replaced eastward by offshore bar sandstones.

Young's definition derives from bedding characteristics, lithology, and inference of origin. Detailed field investigations by the author show that Young's "massive, basal sandstone" is the top unit in an orderly stratigraphic succession from interbedded sandstone and siltstone at the base to thickbedded, medium-grained sandstone at the top. The distinctive sandstone unit is overlain by a sequence of fine-grained, coal-bearing, argillaceous rocks that form a separate, distinctive unit. The names Sunnyside Sandstone (lower) and Sunnyside Shale (upper) are proposed for these two lithologically dissimilar units.

The base of the Sunnyside Sandstone is placed at the base of the continuous, cliff-forming unit above the Kenilworth Shale. The basal facies of the sandstone at Sunnyside is interbedded siltstone and thinbedded, very fine-grained sandstone (fig. 25). The siltstone is extremely carbonaceous, and is so intensively reworked by organisms that traces of original bedding are rare. Trace fossil preservation in siltstones is uncommon, because the thoroughness with which the substrate was reworked either destroyed or altered the biogenic sedimentary structures. The sandstones are less carbonaceous than the siltstones, and are not as "mottled" by organisms as the siltstones. Trace fossils are abundant in the sandstones; Ophiomorpha, Cylindrichnus, Teichichnus, Thalassinoides and Arthrophycus are the most common types found in the thinbedded sandstones.

Figure 25. The Sunnyside Sandstone interval at the mouth of Slaughter Canyon. View southward. Thickbedded sandstone is 45 feet thick.


Root zone
Whitecap
Thickbedded sandstone
Thinbedded sandstone
Interbedded sandstone and siltstone

The interbedded basal sequence of the sandstone is overlain by thinbedded, cross-stratified sandstone that contains variable amounts of carbonaceous debris. Foreset crossbedding is the most common type of cross-stratification. The sandstone beds contain an abundant trace fossil fauna; the individuals of the fauna of each bed vary with the amount of carbonaceous detritus in the sediment. The less carbonaceous beds contain Aulichnites, Gyrochorte, Ophiomorpha, vertical Cylindrichnus, plural curving tubes and chevron trails. Beds with a moderate to high carbonaceous debris content contain Teichichnus, Thalassinoides, Arenicolites, horizontal Cylindrichnus and helicoid funnels.

The next overlying unit in the sandstone is a thickbedded, cross-stratified, fine- to medium-grained sandstone. Trough set crossbedding is the most common type of cross-stratification. Small channels occur in the unit at different stratigraphic positions. Lenses of coalified carbonaceous debris occur at numerous localities, and these lenses commonly contain labyrinth castings associated with the carbonaceous material. The facies is well sorted texturally; grain size varies in discrete beds, and size increases upward within the unit. Trace fossils in this facies are similar to those in the less carbonaceous beds of the underlying thinbedded sandstones.

The upper unit of the Sunnyside Sandstone is a thickbedded, well sorted medium-grained sandstone. The upper sandstone contains patches of very light-grey to white sandstone at various stratigraphic positions; this is the "basal, massive, white-capped sandstone" of Young (1955, p. 181). A yellow mineral that megascopically resembles jarosite ($KFe_3(SO_4)_2(OH)_6$) commonly occurs in the upper 3 to 6 feet of the sandstone. The upper foot of the unit contains abundant rootmarks (fig. 26). The upper surface of the sandstone body is nearly planar. Trace fossils are rare in this facies; bedding forms are tangential foreset and trough set crossbedded sets.

The upper boundary of the Sunnyside Sandstone is placed at the top of the uppermost sandstone bed in the continuous vertical cliffs.

The Sunnyside Shale submember contains a basal thin, discontinuous, sandy siltstone, overlain by a thick coal bed and 250 to 300 feet of dark, laminated shales, massive mudstones with lenticular bodies of sandstone and siltstone.

The coal is the Sunnyside coal bed of Taff (1906, p. 295), a hard, bright, brittle coking coal of high-volatile B bituminous rank. The coal has an irregular break, due in part to the matting and interlayering of the plant parts which make up the coal. The Sunnyside coal is rich in waxes and spores. Fossil megaspores form resin blebs in the coal, and are very common throughout the vertical and horizontal extent of the seam. The common spores and waxes, together with coal composed mostly of plant debris instead of woody

Figure 26. Rootmarks in upper one foot of upper Sunnyside Sandstone. Unit above upper planar surface is siltstone which underlies Sunnyside coal bed. Pen scale.

material, indicates formation of detrital coal in shallow water (Tschudy, 1961, p. 57). The Sunnyside coal bed is split by siltstone and mudstone a few inches to as much as 75 feet thick (fig. 27). Consequently, miners and some earlier workers believed the coal to be two different beds. Detailed surface mapping and correlation of underground sections show that the "upper seam" and "lower seam" are splits of the same bed and were formed in the same swamp (Brodsky, 1960, p. 36). The split is not everywhere present in the area; it thins to the north and east, and thickens to the south and west.

The sedimentary sequence overlying the coal is characterized by very carbonaceous shales, mudstones, and siltstones, and lenticular sandstones and siltstones. The only trace fossils observed in rocks of this sequence are large horizontal burrows and labyrinth castings. Large horizontal burrows are nearly ubiquitous in the rocks overlying the upper split of the coal. Labyrinth castings are associated with large pieces of carbonized material which are stratigraphically above or below the coal. The thin-shelled, small, poorly preserved molluscan fauna previously referred to in this paper (p. 81) was found 40 to 60 feet above the coal bed.

The upper boundary of the Sunnyside Member, which is also the upper boundary of the Blackhawk Formation, is placed at the lowest appearance of sediments of the Castlegate Formation (Forrester, 1918, p. 24). The Castlegate at Sunnyside (fig. 3) is a light yellow-grey sandstone on fresh exposure, medium-grained, friable, and contains large pieces of woody debris. The formation averages 2?0 feet in thickness in the area of interest, and forms an impressive vertical cliff. The interformational boundary is irregular because of the unconformable nature of the deposition of Castlegate on Blackhawk. The length of the period of erosion and deposition represented by the unconformity is unknown.

INTERPRETATION

There seems to be little question that deposition of the Blackhawk Formation at Sunnyside was in the shallow water of an epicontinental Late Cretaceous sea. Spatial relationships of the Blackhawk to strata of undoubted Late Cretaceous age preclude an argument over age of the Blackhawk (fig. 23). Trace fossils that occur elsewhere in beds of undoubted marine origin occur also in the Blackhawk, and fossils of organisms that are known to be marine are found in the underlying Mancos Shale (Fisher, Erdmann and Reeside, 1960, p. 26-31). Spore and pollen analysis by Sarmiento (1957, p. 1693) supports the shallow water concept. The question left to this paper, therefore, is how the sediments were transported into the site of deposition, and what the environment was during deposition of the Blackhawk Formation at Sunnyside.

The data presented in the foregoing sections are adaptable to two interpretations of depositional environment. One interpretation is that the sediments were deposited as part of a periodically prograding coastline succession of offshore bar, barrier beach, lagoon-swamp, and piedmont environments.

The other interpretation is that the sediments were part of a seaward-prograding deltaic sequence, much like parts of the Holocene Mississippi River delta. In the following discussion, lines of evidence are discussed for each interpretation as though it is the only acceptable interpretation. This style is adopted in the interest of brevity and to preclude monotonous repetition.

Prograding Beach Environment

The Blackhawk Formation was deposited as a series of eastward-prograding offshore bar, shallow marine, barrier, and beach-swamp-coastal plain environments (Spieker, 1949a, p. 62). The observed relationship of trace fossil assemblages with lithologic type indicates that depositional environments became shallower westward (fig. 28). The shoreline trended north-northeast (Fisher, Erdmann and Reeside, 1960, pl. 11, Zapp and Cobban, 1962, p. D52). None of the sandstone bodies studied by the author has the geometry of an offshore bar; the tops of all sandstones at Sunnyside are nearly planar. The depositional environments indicated by the sedimentary structures in the Blackhawk rocks at Sunnyside are deeper neritic, shallow neritic, littoral, beach, lagoon-swamp, and coastal plain (fig. 28).

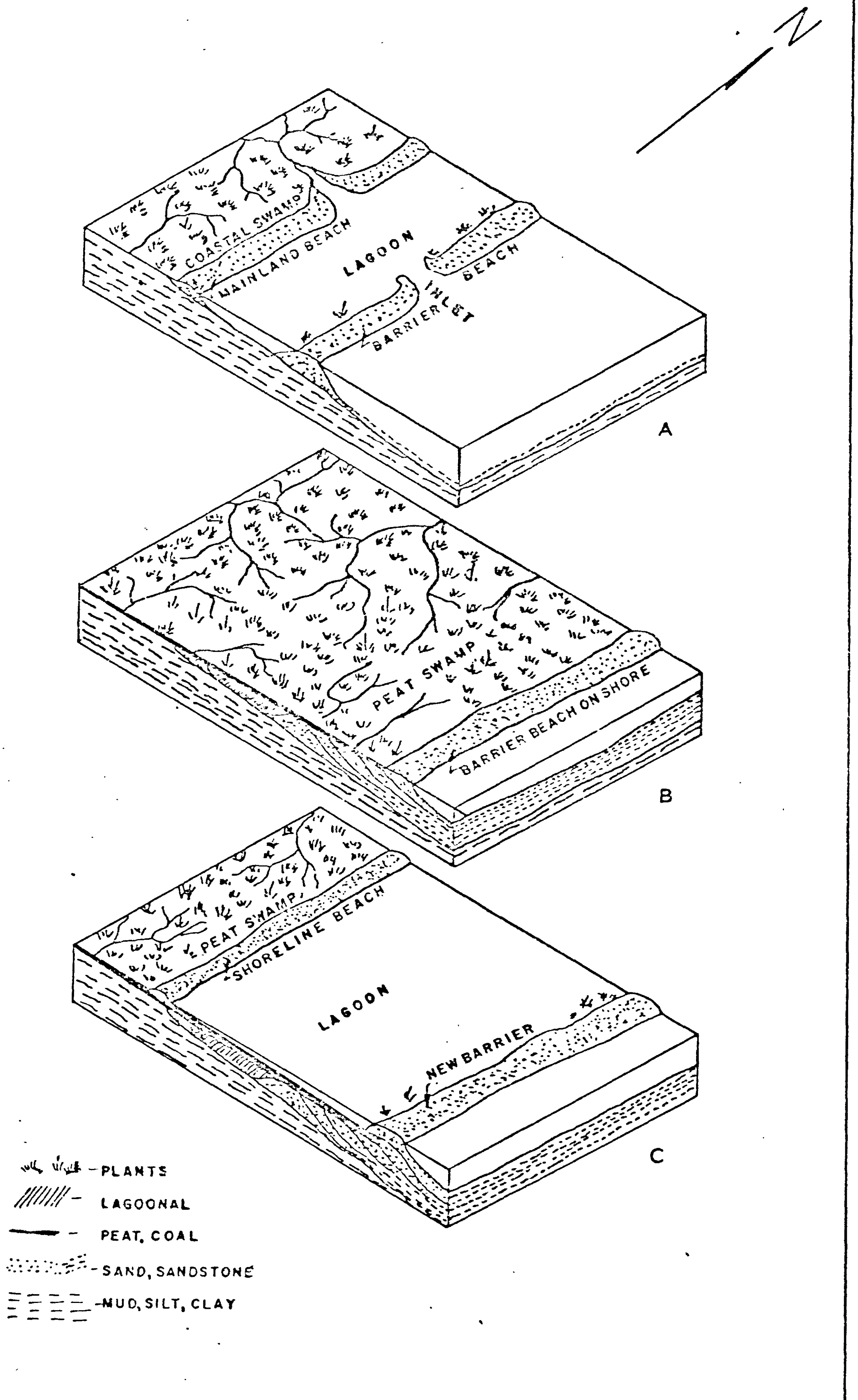
Deeper neritic deposits are characterized by dark-grey, carbonaceous mudstones, siltstones, and very fine-grained sandstones. The sediments are thinly and evenly laminated,

Figure 28. Model of prograding marine beach environment.

(A) Barrier beach builds offshore on gently sloping floor, forming lagoon and terminating growth of mainland beach. Swamp forms along coast.

(B) Barrier beach progrades seaward with addition of sand from upland. Lagoon fills and is covered by swamp, which buries former beach profiles.

(C) Subsidence hinging near shore inundates beach and part of swamp. New barrier beach builds in shallow water, lagoon fills, and old swamp again spreads eastward. (Modified from Young, 1966, p. 18.)


N
COASTAL SWAMP
MAINLAND BEACH
LAGOON
BEACH
INLET
BARRIER
A
PEAT SWAMP
BARRIER BEACH ON SHORE
B
PEAT SWAMP
SHORELINE BEACH
LAGOON
NEW BARRIER
C
-PLANTS
- LAGOONAL
- PEAT, COAL
- SAND, SANDSTONE
-MUD, SILT, CLAY

contain a large trace fossil fauna that indicates deposition in deep, quiet water (Seilacher, 1964, p. 311). Small, thin-walled *Ophiomorpha* burrows are abundant in the lowest sandstones; the siltstones commonly contain *Cylindrichnus*, *Teichichnus*, fecal pellets and, if much carbonaceous debris is present, labyrinth castings. The restricted association of labyrinth castings with large pieces of woody debris prevents this trace fossil from being of great value as a bathymetric indicator. Load casts and ball-and-pillow structures are found in the siltstones and sandstones where they overlie mudstone. Traced toward the paleoshoreline, sediments of this environment contain progressively increasing amounts of sand, and pass into interbedded very fine-grained sandstone and clayey siltstone.

Rocks of the shallow neritic environment comprise mostly sandstone, with lenses and stringers of grey siltstone. The sediments are thinly bedded, with prominent unidirectional, low-angle, tangential foreset crossbedding. A large trace fossil fauna is found in this group of sediments. *Ophiomorpha*, *Thalassinoides*, *Cylindrichnus*, *Teichichnus*, *Gyrochorte*, *Aulichnites* and *Arenicolites* all occur here, and are grouped according to the amount of mud and carbonaceous debris in the environment. Where much fine sediment and organic debris was present during deposition, *Ophiomorpha* is small, there is a large population of horizontally oriented *Cylindrichnus* and associated helicoid funnels. *Teichichnus* is also associated with the carbonaceous environment. When the site of deposition was swept by stronger currents in the transporting medium, interpreted here as shallowing due to deposition, Ophiomorpha burrows became larger and thicker walled to resist the current. Cylindrichnus burrows are vertically oriented, indicating an attempt by the animal to escape to a more favorable environment. Gyrochorte and Arenicola are more numerous in areas of well sorted sand, where water was clear.

The beach environment is preserved as thickbedded, well sorted sandstone. These rocks contain very little silt- and clay-size material. Particle size ranges from very fine- to fine-grained sand, and the rocks are mostly quartz sandstone with carbonate cement. Ophiomorpha burrows are at maximum size (2 to 4 cm diameter), and Arenicolites burrows are common. Tracks and trails on bedding planes are abundant. Low-angle, tangential foreset and trough crossbedding is common throughout. The sorting and foreset crossbedding are interpreted to be the result of reworking and deposition by tidal currents. Body fossils of organisms are unknown from sediments in this zone. Logs, leaves and other plant debris are common, but poorly preserved. Bedding is thicker at the top of the unit than at the bottom, and grain size increases upward. Current and oscillation ripplemarks are common in these sediments. Tops of the beach beds are planar, indicating subaerial gradation as the sand was swept into the sea and was reworked by the waves (Spieker, 1949a, p. 64). The sandstone beds form tongues eastward, with each higher tongue reaching farther eastward (fig. 29). These sandstone tongues built out into the sea as successive accumulations of sand (Spieker, 1949a, p. 62). The sands were furnished to the environment by streams (Hale and Van De Graaf, 1964, p. 136). The consistent eastward direction of transport normal to the shoreline indicates an absence of longshore currents during and after sedimentation. Sandstone-filled scours in sandstone beds are inlets carved into the beach (fig. 28) by tides that allowed a mixing of marine and nonmarine waters and fauna. The most probable reason for the lack of body fossils in the rocks is that the bottom environment was unfavorable for fossil preservation. The shells of organisms may have been dissolved if they were deposited under conditions in which their chemical components were unstable (Weimer, 1960a, p. 19). The mixing through channelways may account for the occurrence of marine forms such as Ophiomorpha and Arenicolites in sediments stratigraphically above the beach deposits. "Bleached" zones of beach-deposited sandstones were caused by leaching out of iron by waters from the overlying swamp (Spieker, 1949a, p. 64; Young, 1955, p. 178).

The coal-bearing sequence above the sandstone units was formed behind the beach in a lagoon-swamp-salt marsh environment. The coal swamp existed immediately behind the beach, and was characterized by low, small plants; large plant pieces in the coal are rare. Small pieces of plants and

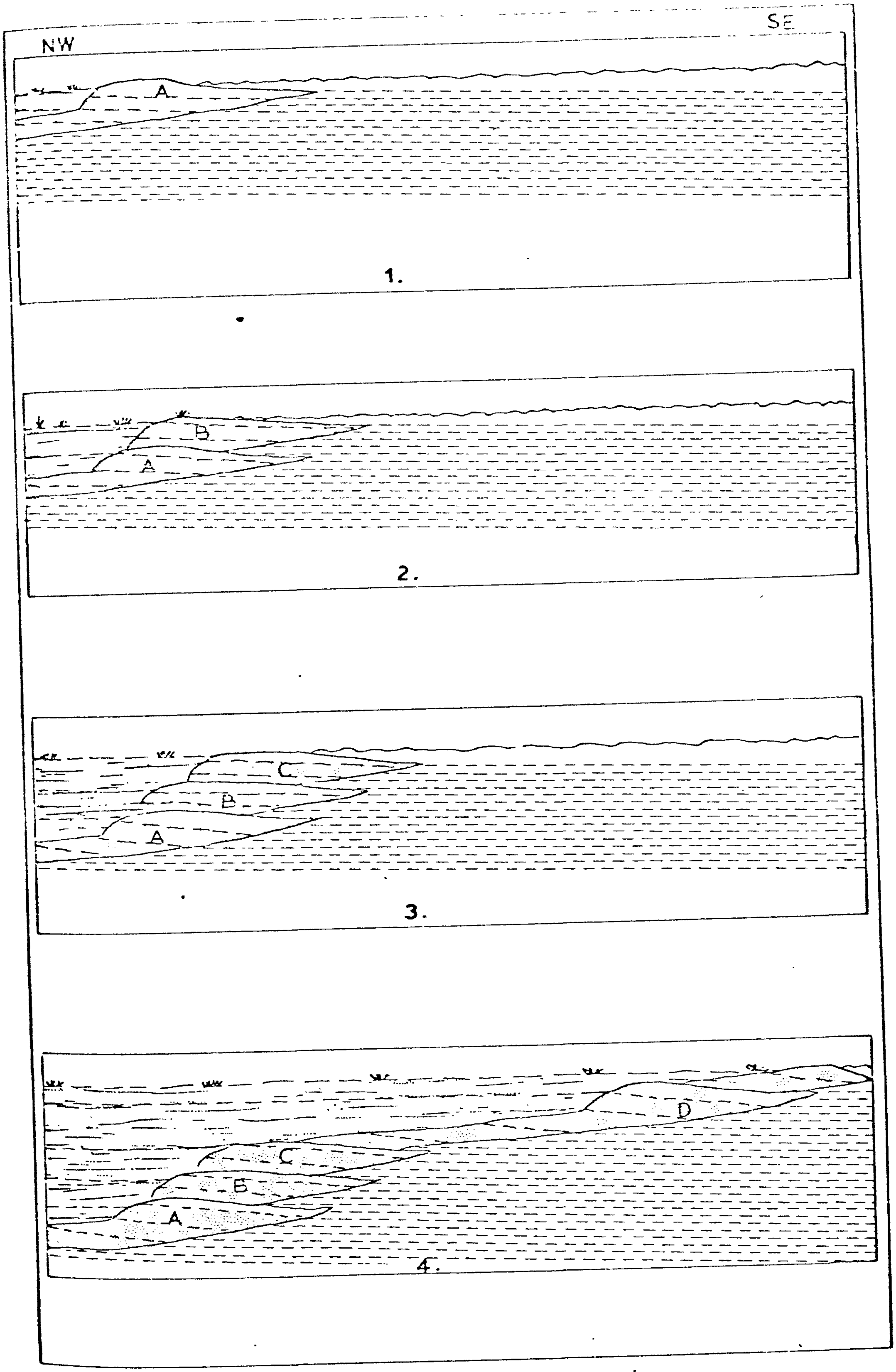
Figure 29. Diagrammatic cross-sections illustrating the successive deposition of marine, nonmarine and mixed environment sediments in the Sunnyside area. Following these events, a short period of further regression was followed by a marine transgression, and the seaward progradation began anew (modified from Hollenshead and Pritchard, 1960, p. 103).

Stage 1. Strandline stabilized (subsidence in equilibrium with sedimentation) at A, resulting in deposition of sand bench A.

Stage 2. Slight increase in sediment supply, in relation to subsidence, caused strandline to shift seaward to B, and stabilize once again, resulting in deposition of sand bench B.

Stage 3. Slight increase in sediment supply, in relation to subsidence, caused strandline to shift seaward to C, and stabilize once again, resulting in deposition of sand bench C.

Stage 4. Sizeable decrease in rate of subsidence, in relation to sedimentation, caused strandline to shift rapidly to D, leaving relatively thin sand section in its wake. Strandline once again stabilized at D, resulting in deposition of bench D.


NW
SE
A
1.
B
A
2.
C
B
A
3.
D
C
B
A
4.

leaves and blades of grass-like plants are commonly observed in the coal. The coal contains some minor pyrite and minor sulfate minerals which may be derived from pyrite. Sulfides and sulfates indicate a strongly reducing depositional environment. Rock splits in the coal were formed when streams carried sediment out onto the swamp surface, possibly after storms in the source area. A lagoon with local salt marsh conditions existed just landward of the coal swamp. This environment is characterized by laminated to massive mudstones with local thin lenses of carbonaceous siltstone. Pyrite in these mudstones and siltstones weathers to give joint fillings of gypsum (selenite). Rocks of the lagoon environment contain abundant large horizontal burrows. These trace fossils are most common at the interface between coal and the overlying sandy, carbonaceous siltstone. Subsidence of the basin progressed apace with sedimentation for the thick lagoonal sequence to have been deposited. Brodsky (1960, p. 58) postulates that a rise in the water table in the swamp would allow accumulation of a thick sediment wedge.

Channel sandstones in shale and mudstone which occur near the top of the Sunnyside member must represent stream courses that formed as a result of continued seaward progradation of the coastal plain. Although these sandstones are lenticular and discontinuous, they may be of marine beach or offshore bar origin as suggested by Young (1955, p. 186).

The Castlegate Formation; which unconformably overlies the Blackhawk Formation is of lowland floodplain origin, with no coal contained in it at Sunnyside (Spieker, 1949a, p. 72). The Castlegate may be an inland floodplain facies of a marine beach-lagoon sequence that extends farther eastward (Young, 1955, p. 188).

The described conditions were brought about by an overall regression of the sea, with accompanying seaward progradation of the coastal plain. The sequence was deposited during the earliest stages of a regional regression, designated R-3 by Weimer (1960a, p. 7). From the standpoint of lithologic variation, the Sunnyside Member is nearly identical to the Kenilworth Member; this phenomenon gave rise to Young's interpretation of cyclic deposition (1957). Young recognized a four part cyclothem of basal marine shale, overlain in turn by littoral marine sandstone, lagoonal deposits and coal at the top (1957, p. 1766).

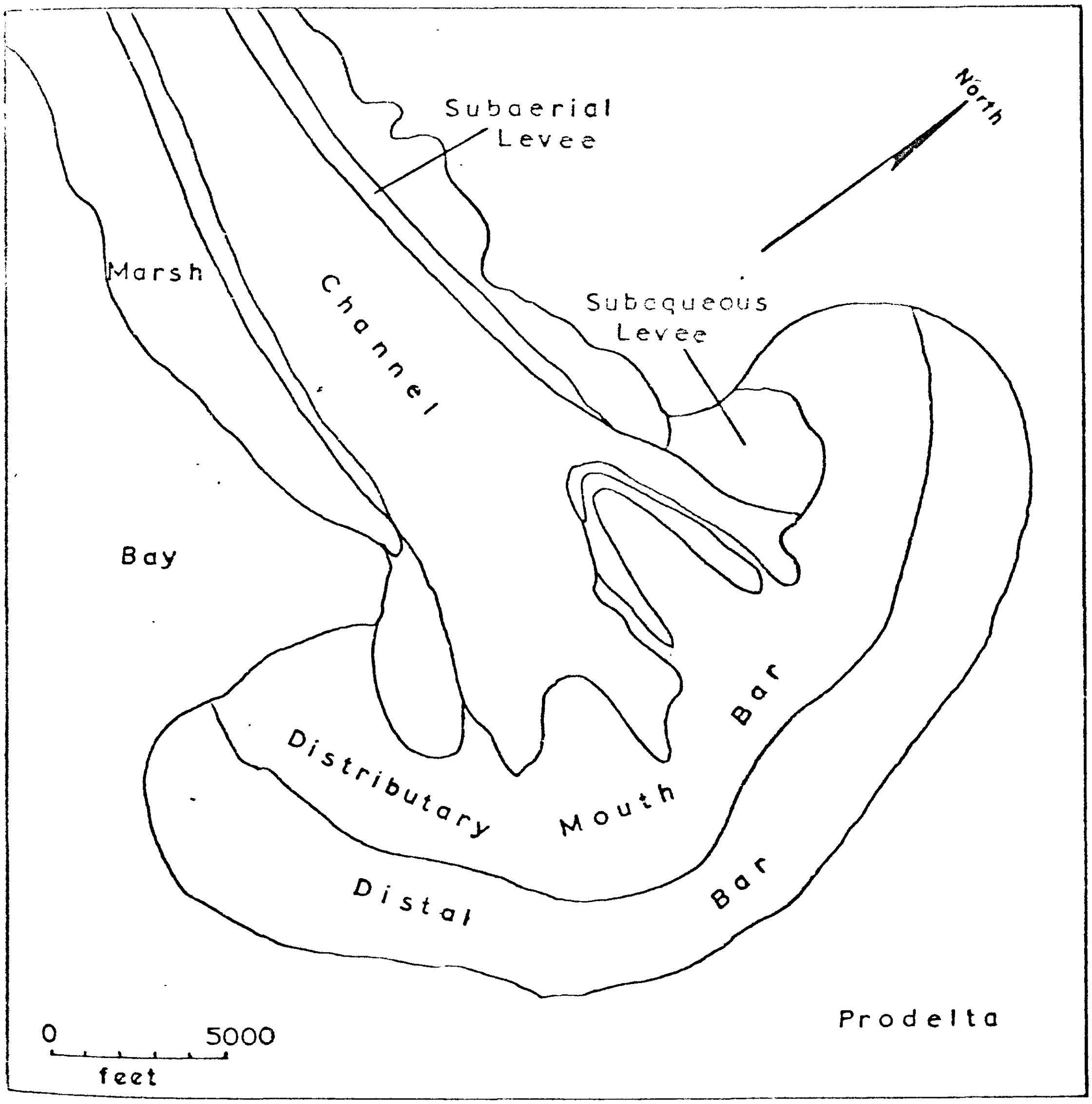
In summary, the Blackhawk Formation at Sunnyside was deposited on the shelf of a slowly subsiding marine basin as a seaward-prograding sequence of successively shallower water deposits, culminating upward in terrestrial deposits of the upper part of the Sunnyside Member. According to Spieker (1949a, p. 65), the interpretation outlined above is the only tenable interpretation.

Deltaic Plain Environment

An alternate interpretation is that the Blackhawk Formation at Sunnyside was deposited as a seaward-prograding deltaic sequence at the mouth of a stream or network of streams emptying into a shallow epicontinental sea (fig. 30). The nearly unidirectional sediment transport is one of the strongest lines of evidence for this interpretation. Nearly all indicators of transport direction indicate deposition to the east-southeast, a direction normal to the shoreline. The low-angled foreset crossbedding, tangential at the base and with nearly planar boundaries indicates strong-current deposition (McKee, 1965, p. 81). Grain size and sorting generally increase upward in sandstone sequences, indicating successively stronger currents in each depositional environment. Strong unidirectional currents, normal to the shoreline are typical of fluviatile-marine environments, and the alluvial sand bodies that form in these environments are elongate downdip in the direction of transport (Potter, 1967, p. 345). In contrast, currents impinging upon a beach coastline from offshore are seldom directed normal to the shoreline; these currents flow onto the shore at an angle, and ebb normal to the shore, resulting in an overall longshore drift.

Van Straaten (1960) and Potter (1967) summarized the characteristics of deltaic sediments. Among the characteristics of deltaic sand bodies that are similar to those

Figure 50. Model of deltaic plain environment, based upon Southwest Pass, Mississippi River delta (modified from Coleman and Gagliano, 1965, p. 144).


North
Subaerial
Levee
Marsh
Channel
Subaqueous
Levee
Bay
Distributary
Mouth
Bar
Distal
Bar
Prodelta
0
5000
feet

observed in the Blackhawk Formation at Sunnyside are these: detrital origin; abundant carbonaceous debris; petrographically moderately mature; detrital plus chemical cements; faunal content low to absent (probably because of high rate of deposition--Van Straaten, p. 426); poor to moderate sorting; abundant silt in the fine-end tail; tendency to poor rounding; asymmetrical ripplemarks and abundant well oriented cross-bedding, commonly unimodal; gradational lower boundary and sharp upper surface; lenticular bedding with erosional scour; tracks and trails common; larger channel-fill sandstones tend to be coarser grained than smaller bodies; channel-fill sandstones are usually courser grained than the sands into which they are scoured; elongate downdip; excellent correlation of internal directional structures and elongation; associated silty shales; coal beds common; multistory vertically and multilateral horizontally (comprising multiple beds); abundant roots, leaves and stems of plants. There is no absolute evidence of the location of the wedge-edge of the Sunnyside and Kenilworth sandstones, but Hale and Van De Graaf (1964, p. 125) indicate that the Blackhawk sandstones thin and pinch out northward into the Uinta Basin. It is reasonable to assume that the Sunnyside and Kenilworth Members do the same.

The coal and carbonaceous mudstone and shale are postulated to have formed in marshes and swamps. Coleman and

Gagliano (1965, p. 146) define marshes as

> ... low tracts of periodically inundated land supporting non-woody grasses, reeds, and rushes. The marsh surface approximates mean high tide level. There is...abundant plant life.

Swamps, according to the same authors (p. 146).

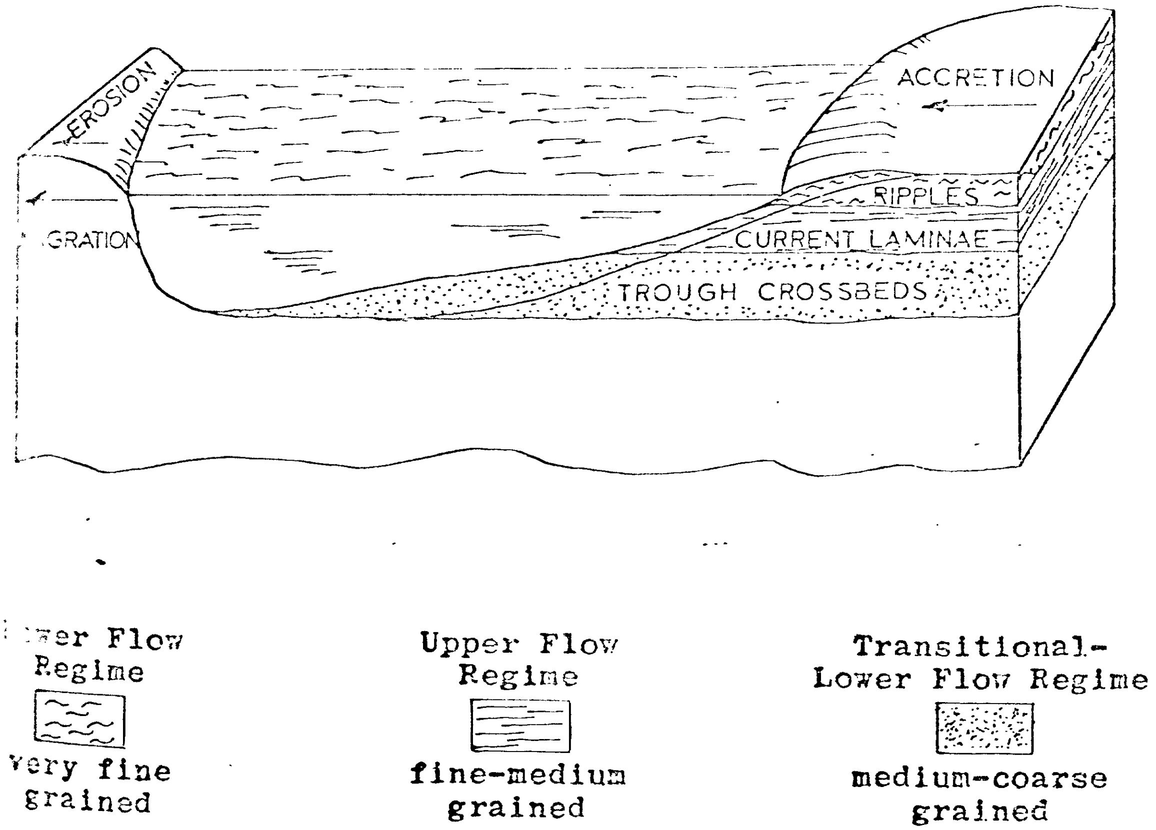
> ...constitute low, flat areas periodically covered with water and supporting a cover of woody vegetation with or without shrub undergrowth. ...best developed in fresh basins of the upper delta.

The sandy, carbonaceous, irregular siltstone immediately below the coal beds at Sunnyside is very similar in form and content to subaerial levees that form between channels and marshes in deltaic environments (Coleman and Gagliano, 1965, p. 145). Such detrital bodies contain: abundant carbonaceous debris; wavy-laminated bedding; intensive burrowing activity; abundant rootmarks; occasional ferric and calcareous nodules as the result of weathering. The subject siltstone contains all these features. Splits in the coal beds formed as the result of spillovers of fine silt and very fine sand from the main channel.

Channel-fill sandstones in the upper part of the coal-bearing sequences at Sunnyside are postulated to have formed as fluvial sedimentation occurred in meandering distributary channels (fig. 31). Trough-set crossbedding built up as depositional sequences in the direction of scour in the meanders.

In summary, the Blackhawk Formation was deposited in a deltaic sequence that prograded generally southeastward

Figure 31. Model of fluvial channel environment, illustr[illegible] vertical distribution of sedimentary structures and g[illegible] sizes (modified from Visher, 1965, p. 132).


EROSION
ACCRETION
GRATION
RIPPLES
CURRENT LAMINAE
TROUGH CROSSBEDS
Lower Flow Regime
very fine grained
Upper Flow Regime
fine-medium grained
Transitional-Lower Flow Regime
medium-coarse grained

throughout Blackhawk time in east-central Utah. The sequence began with deposition of the Panther Tongue of the Star Point Formation in what is now the Wasatch Plateau (Howard, 1966b, p. 23-30). The deltaic framework persisted, and prograded seaward in response to sediment supply from the west. The environment at Sunnyside at any specific point in time comprised the prodelta, delta plain complex, and coastal plain. Subaerial erosion of the area took place before deposition of the Castlegate Formation ended the fluviomarine succession.

Stratigraphic data on a more regional basis are needed to accurately reconstruct the processes on and along the entire deltaic plain. The interpretation presented here is the simplest possible to explain the observed stratigraphic data in the Sunnyside area.

The author supports the deltaic plain environment interpretation for the origin of Blackhawk rocks at Sunnyside. Observed stratigraphic data correlate better with examples from known deltaic plain environments than with examples from prograding beach environments.

ENGINEERING AND ECONOMIC GEOLOGY

Coal mine bumps are sudden, catastrophic releases of stress in the rib, roof or floor of a coal mine. Bumps cause much property damage (fig. 32) and work loss, as well as loss of life. Sunnyside mines long have been loci for violent bumps (Clark, 1928, p. 32; Osterwald and Eggleton, 1958, p. 14). Coal mine bumps are partly the result of vertical pressure on the coal from the overburden. The total stress on a point in space in a coal bed is a reflection of the surface topography and the thickness of the overburden; for a point under a high ridge, one of the principal compressive stresses is directed vertically, and the lesser components of compressive stress outline the adjacent topography. Tensile stress is directed horizontally away from the point toward an area of less compression, in an attempt toward stress equilibrium. In mines, the area of least compression is the void created by the removal of coal when driving an entry. Much stress, therefore, concentrates around the entry, and most stress is at large angles to the axis of the entry.

Figure 32. Aftermath of a coal mine bump in the Sunnyside No. 1 mine, December, 1957. Rib failed catastrophically from right to left. Entry closed for more than 250 ft. Roof bolts are 1 in. diameter steel. (Photo by J. C. Witt.)

Some areas in the Sunnyside mines are characterized by [illegible] that continually "squeezes" into the entries and spalls, thereby continually releasing stress (fig. 33). Other [illegible] are marked by floor anticlines, roof synclines, and [illegible]ed ribs, all conditions resulting from stress buildup in coal (Osterwald, 1961, p. C349). The roof rock above "[illegible]ing" areas commonly is a fine-grained siltstone or [illegible]stone. The roof rock in other areas of coal deformation is a coarser-grained siltstone or fine-grained sandstone. [illegible]rwald (1962, p. 65) has shown that, other factors being [illegible]al, the difference in coefficient of friction with the [illegible]l between the fine-grained and the coarse-grained roof [illegible]cks determines the relative ease with which the coal can [illegible]ve laterally.

Where the coal is able to move laterally with relative ease, the coal near the roof may spall off into the entry and effect the continual release of stress in the coal (fig. 34). Bumps that occur under these roof conditions are believed to be of lower magnitude than bumps that occur in areas of coarse-grained roof rocks. The coarse rocks, with their higher coefficient of friction with the coal, contribute to a high buildup of stress in the coal, and, thereby to favorable conditions for large bumps.

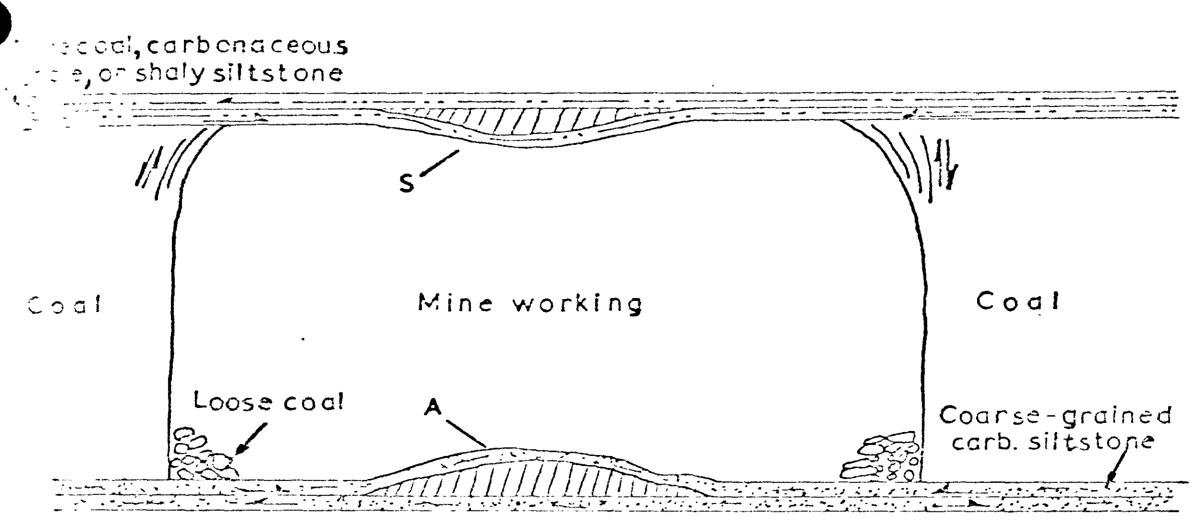
Inorganic and biogenic sedimentary structures are three dimensional. Both types of features may have reliefs of up to 18 inches in Blackhawk rocks, as do some load casts and

Figure 33. Deformed roof bolts in the roof of Sunnyside No. mine. Deformation resulted from "squeezing" of upper coal and siltstone split into entry from lateral pre[illegible] in pillar. (Photo by J. C. Witt.)

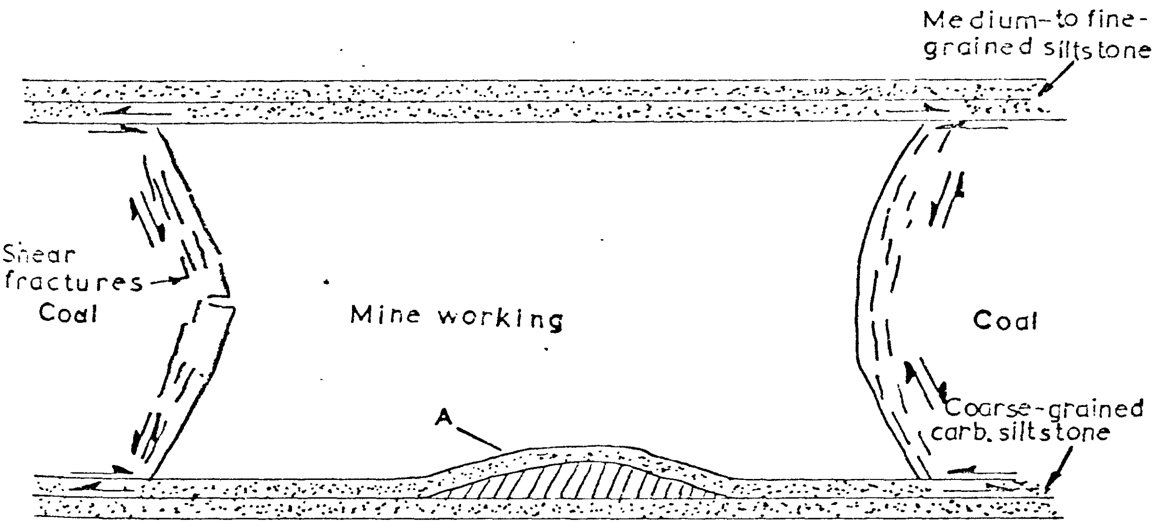
Figure 34. Diagrammatic sections showing deformation around mine workings in Sunnyside No. 1 mine. Diagonally line areas are hollow. (Modified from Osterwald, 1961, p. C352.)

(A) Roof syncline (s) and floor anticline (a) develope where coal slips along argillaceous roof but adheres to coarse-grained rocks in the floor.

(B) Bulged and buckled ribs where coal adheres to roof and floor.


coal, carbonaceous
or shaly siltstone
S
Coal
Mine working
Coal
Loose coal
A
Coarse-grained
carb. siltstone

A.


Medium-to fine-
grained siltstone
Shear
fractures
Coal
Mine working
Coal
A
Coarse-grained
carb. siltstone

B

...-and-pillow structures, or they may be only films on the ...ding surface, such as the trace fossil *Chondrites*. Most ...ctures, however, are of sufficient relief to influence ... friction between two rock bodies when structures occur ... their interface. A spatial and directional orientation of ...uctures exists in the rocks at Sunnyside, because such an ...ientation must exist in any rock that was deposited by a di...ectional agency. The continuity of orientation varies with the type of structure: the trace fossil *Thalassinoides* exhibits no preferred orientation, whereas current ripple-...ks and large horizontal burrows (fig. 35) both have highly preferred orientations. Rocks containing large horizontal burrows, which are tubes of sandstone in a carbonaceous silt-stone or mudstone matrix, have lower shear strength than rocks that are structurally more homogeneous. Youash (1965, p. 96-98) performed triaxial and unconfined uniaxial compres-sion tests on roof rocks from the Sunnyside No. 1 mine; he found that the shear and cohesive strength of roof rock with burrows and other contained lithologic and structural dis-continuities is less than rocks of similar lithology but without contained structural inhomogeneities. Youash further found (p. iii) that failure of the rocks varies with the angular difference between the direction of principal stress and bedding surfaces in the rocks.

The relief and orientation of the sedimentary structures in the rocks of the roof and floor of a coal mine probably

Figure 35. Large horizontal burrows in roof rock, oriented at a small angle to the long axis of entry; Columbia Mine, Utah. This mine is approximately two miles south of Sunnyside, and is developed in the Sunnyside coal bed. Photo taken after a bump-related roof failure at intersection of workings. Timbers, lower right, are 6 in. diameter. (Photo by F. W. Osterwald.)

have a bearing upon the amount of stress that builds up in the coal seam. Where the preferred long direction of the sedimentary structures is parallel to, or at a small angle to the direction of the long axis of the mine entry, these structures hinder movement of coal past rock at the inter-lithologic interface, and cause the friction between the bodies to be greater. In areas where the dominant long direction of structures is normal to, or at a large angle to the long axis of the entry, these structures form no barrier to movement, and may actually aid movement by trapping and forming conduits for such interformational and intraformational fluids as might be present in the rocks.

Experiments with British coals (Evans and Pomeroy, 1966, p. 179) show that wetting the interface between coal and a steel plate decreases the coefficient of friction by a factor of 0.7. Soaking of the coal reduced its compressive strength by 5 percent for a low volatile coal and by 20 to 25 percent for high volatile coal (op. cit., p. 182). The modulus of elasticity of coal decreases with wetting by 7 to 10 percent. Evans and Pomeroy (p. 183) conclude that the overall effect of water is to reduce the friction of coal; a water layer, possibly adsorbed on the mating surfaces of a plane of weakness, reduces the stress at the interface and so lowers the friction.

Because the Sunnyside mines are dry, no such fluids were observed in this study.

Osterwald and Brodsky (1960, p. B146) concluded that if entries intersect fault zones at a small angle, slippage will occur in the rib before much stress can accumulate. If the long axis of the entry intersects a fault or fracture at a large angle, slippage will be less likely to occur, causing a large stress concentration.

In 1964 an oil seep was encountered during development work in the Sunnyside No. 3 mine. Earlier, 4 feet of saturated sandstone core was recovered from the coal interval in Pasture Canyon. Enough oil flowed from a channel-fill sandstone in the roof of the mine workings to cause a flurry of excitement among mine personnel. The oil at Sunnyside is believed by the author to be a strictly local phenomenon. The oil probably was formed diagenetically from either organisms that inhabited the marsh or swamp areas, or from the extremely carbonaceous sediments that surround the coal seam. The oil probably formed in discrete particles, then migrated into conduits formed by channels in the roof of the coal. When mining exposed the channels and disturbed the pressure equilibrium, the oil flowed into the opening. The oil seep has long since dried up. Exploration for oil in the Blackhawk Formation at Sunnyside should concentrate on the stratigraphic traps formed where the sandstones pinch out into the less permeable mudstones. These stratigraphic traps are thought to be the most favorable sites for oil accumulation.

At approximately the same time the oil seepage was encountered, fresh outflows of natural gas (methane) from the roof rocks were noticed. Methane in coal mines is very common throughout the world, and the appearance of oil in coal mines in the Book Cliffs is not uncommon; miners in the Castlegate mine in the Wasatch Plateau once encountered an oil seep that leaked enough oil to wet the haulage track (. W. Osterwald, 1908, oral communication). The methane is believed by the author to be a product of decomposition of vegetable material during diagenesis and coal formation. Sedimentary structures such as channel-fill sandstones and trace fossil horizons may have trapped the gas in a stratigraphic trap in the roof rocks.

As a result of the study described in this paper, a geologic study of a mining area would be justified <u>before</u> laying out drift or entry headings. In addition to the usual geologic information gathered, the study should focus upon types of biogenic and inorganic sedimentary structures, their magnitude, mode of occurrence, and spatial orientation. If such a study were incorporated into the framework of the mining operation, it could contribute materially to the safety and economy of the venture. Because continual creep and spalling of the coal aids mining efficiency as well as contributing to safety, a mine should be opened with the entries driven parallel to the trend of directional structures so as to take advantage of the natural creep and spalling during mining. Such a practice would lead to a safer and more economical operation.

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APPENDIX

Detailed Stratigraphic Sections

Measured section 1-67

NW$\frac{1}{4}$-NW$\frac{1}{4}$ sec. 31, T. 14 S., R. 14 E.

No. 1 Fan Canyon Section

Feet

Castlegate Formation

Sandstone, light-yellow-orange, fine- to medium-grained, calcareous, very carbonaceous, contorted bedding, log and branch impressions---

Blackhawk Formation

Sunnyside Member

Sunnyside Shale

Covered---Casltegate float---mostly carbonaceous claystone-- 37

Sandstone, medium-grey to light-grey, fine- to medium-grained, weathered to light-grey, finely divided carbonaceous trash on bedding planes only. Cross-laminae dip southeast in thin sets, tangential at base; calcareous, poorly sorted; thinly and irregularly bedded, labyrinth castings common------------------------- 14

Covered interval--thin, discontinuous stringers of: very fine-grained sandstone, noncalcareous, cross-laminae dip southeast, thinbedded, uneven, slabby; siltstone, dark-grey to red-brown, clayey; claystone, dark-grey to red-brown to yellow-brown, with gastropods, zone of fossils 22 ft above top Sunnyside Sandstone. At 75 ft from base of covered unit; sandstone, very fine-grained, thin, wavy bedded, flaggy, nonfossiliferous,

Feet

brittle, cross-laminae dip southeast and northwest. Above is carbonaceous mudstone with many plant impressions———— 102

Coal zone, burned on outcrop; coal in the mine is 12 ft thick———— 12

Siltstone, dark-grey, very carbonaceous; fresh surfaces show rootmarks perpendicular to laminae. Coaly fragments, irregular lower contact———— 2

Sunnyside Sandstone

Sandstone, light-yellow-grey to light-grey, fine- to medium-grained. Increased grain size upward. Strongly cross-laminated in tangential sets up to 8 ft long, 2 ft thick. Carbonaceous on bedding, calcareous throughout; Ophiomorpha lower; logs have labyrinth castings; ripple crests strike N 10 E, N 40 E; channels southeast and northwest. Rootmarks upper———— 49

Sandstone, light-yellow-grey, very fine- to fine-grained, carbonaceous on cross-laminated surfaces; "stairstep" beds, thin bedded sandstone interbedded with soft siltstone, very dark-grey. Sandstone cross-laminae S 75 E and N 10 W. (7 and 15 readings, respectively)———— 56

Kenilworth Member

Kenilworth Shale [redacted]

Shale-mudstone, medium-grey, slightly silty, with thin, discontinuous siltstone with ironstone layers———— 75

Sandstone, dark-yellow-brown, very fine-grained, silty, thinly laminated to laminated, evenly bedded, grades up into cross-laminae dipping S 58 E, N 65 W, S 80 E at angles of 5-10 degrees E and of 15-25 degrees W. Very few fossils. Sharp top———— 14

Covered--dark-grey mudstone in digs———— 10

Feet

Sandstone, dark-yellow-brown to brown-orange, very fine-grained, ironstained, calcareous, carbonaceous, hard, brittle, slabby---------- 4

Covered interval--colluvium---------- 22

Kenilworth Sandstone

Sandstone, light-yellow-grey, very fine- to fine-grained, some medium. Very similar lithology to upper Sunnyside Sandstone. Slightly calcareous, very carbonaceous on bedding planes; thin bedded and flaggy, uneven and discontinuous bedding; cross-laminae dip eastward, at low angle---------- 15

Sandstone, light-grey-yellow to light-yellow-orange, very fine- to fine-grained, poorly sorted; *Ophiomorpha* throughout, plural curving tubes at base, funnels at 15-18 ft. Makes big rounded bluff; bedding obscured, but some two-way cross-lamination present. Basal part is "stairstep" sand, interbedded with very thin, soft siltstone. At 18 ft is a 3-8 in. bed carbonaceous shale. Unit thickens rapidly S 50 E, thickbedded and massive, increased grain size upward, fine to medium---------- 36

Siltstone, dark-yellow-brown, very finely sandy, carbonaceous, with carbonaceous trash on laminae, some small pieces coalified. No coal streaks, no large pieces. Poorly preserved horizontal trails and burrows. Unit deeply weathered. Several sandstone stringers, very fine- to fine-grained, poorly sorted, silty, carbonaceous, long and low crossbedding---------- 38

Sandstone, medium-grey-yellow, very fine-grained, obvious cross-lamination was absent to minor in lower units; fossil population much thinner. Low-angle eastward cross-lamination dips steeper (10-15 degrees) westward. Transport direction S 25 E, S 40 E, S 65-70 E prevalent, N 10 W, N 25 W, N 15 W, N 20 W. Hard, resistant, slabby; ledge and cliff maker. Grain size increase upward to fine; more friable in upper 3 ft---------- 45

Feet

Sandstone, light-grey-yellow, very fine-grained, silty, plural curving tubes, Ophiomorpha Gyrochorte, very fossiliferous, noncalcareous; very carbonaceous in mottled beds, well sorted upward. Plural curving tubes in well sorted beds. Unit more massive than below. Thin slabby beds. Cross-laminae dip east and west, N 10-20 W, S 60-70 E---------- 15

Sandstone, medium-grey-yellow, very fine-grained, silty, very calcareous, slightly carbonaceous; trails on bedding, Cylindrichnus, Ophiomorpha, rod-shaped tubes to bedding. Interbedded at base with claystone. Heavy population trace fossils. Bedding varied. Mottled beds are very calcareous and very carbonaceous; well sorted beds have carbonaceous trash only on bedding surfaces. Some beds of well sorted sand show cross-bedding dipping at low angle (3-5 degrees) toward S 60-70 E---------- 22

Mancos Shale

Claystone, medium-yellow-brown, slightly silty, deeply weathered, shaly split, fossiliferous. Silty, sandy, nodular weathering---------- 52

Siltstone, medium-yellow-brown to dark-brown-yellow, very slightly sandy, with very fine sand; thin and flaggy, irregular discontinuous beds; interlaminated with claystone below. Woody debris on depositional surface. Teichichnus common---------- 35

Claystone, medium-yellow-brown to medium-grey, shaly split; silty stringers throughout are more resistant; very rich in plant debris. Possibly a few worms. Very few shell fragments, no whole specimens. Base covered---------- 21

Total section---------- 676

T-3350

Measured section 2-67

Center SW$\frac{1}{4}$ sec. 30, T. 14 S., R. 14 E.

Drageton Section

Feet

Castlegate Formation

Sandstone, light-grey-yellow to medium-yellow brown, fine- to medium-grained, very carbonaceous, with coalified woody debris throughout, labyrinth castings common on logs and thick sections of carbon. Bedding extremely contorted. Poorly sorted, silty, clayey, calcareous

Blackhawk Formation

Sunnyside Member

Sunnyside Shale

Covered interval--stringers and lenses of: sandstone, very fine-grained, hard, iron-stained, calcareous, very carbonaceous, irregularly bedded; digs in colluvium show mudstone, carbonaceous, dark-grey 32

Sandstone, light-grey to medium-grey, fine- to medium-grained, poorly sorted, calcareous, carbonaceous. Weathers very light-grey; cross-laminae dip mostly southeast in sets to 1.5 ft thick, tangential at base; thin, irregularly bedded, silty, with labyrinth castings and large horizontal burrows 16

Covered, colluvium slope. Digs at intervals show mudstone, very dark-grey, very carbonaceous, nodular; siltstone stringers throughout;

upper part. Conditions that governed the deposition of these sediments were not as orderly as those controlling deposition of the sandstone units, because the vertical lithologic succession in the coal-bearing unit is unpredictable, whereas the succession in the sandstones is relatively predictable. The only body fossils found in the area by the author occur from 40 to 60 feet stratigraphically above the Sunnyside coal bed in dark grey, silty, carbonaceous mudstone (fig. 23). The fauna comprises small, thin-shelled poorly preserved molluscs that were identified by W. A. Cobban of the U. S. Geological Survey (written communication, 1963) as:

Ostrea sp.

Anomia micronema Meek

Brachidontes sp.

Corbula sp.

The trace fossils most common in the unit are large horizontal burrows, which occur locally in carbonaceous siltstones overlying coal seams and are known as "fingers in the roof" by miners. Trace fossils are rare in the argillaceous beds.

Many of the sedimentary rocks in the Blackhawk Formation at Sunnyside are calcareous; most of these effervesce actively in cold dilute hydrochloric acid, indicating that the calcareous material is calcite. The carbonate has been postulated to be a weathering product of primary dolomite by Sabins, who recognized dolomite rhombs in the Blackhawk sandstones from the Wasatch Plateau (1962, p. 1194). Dolomite may be the source of calcareous cement at Sunnyside; X-ray powder diffraction studies indicate varying amounts of dolomite in rocks from selected horizons (table 2). The carbonate also may be contained in either water of deposition or percolating groundwater, or it may result from feldspar degeneration in the sands, in which calcium combines with carbon dioxide derived from organic-rich sediments during diagenesis.

Kenilworth Member

The Kenilworth Member is the lowest stratigraphic unit of the Blackhawk Formation at Sunnyside. The member was named and was defined by Young (1955, p. 184) to consist of

> ... a massive, cliff-forming, basal sandstone, an overlying series of coal-bearing rocks, and the offshore bar sandstones behind which they were deposited.

Young's definition derives from lithology, topographic expression and inference of origin. Detailed field investigations by the author show, furthermore, that the basal unit of Young's defined Kenilworth is the upper bed of an orderly upward succession of interbedded siltstone and sandstone, thinbedded sandstone, and thickbedded sandstone. All these units combine to make up a mappable unit of similar lithology. The author here proposes that the base of the Kenilworth Member be placed at the base of the sandstone sequence (fig. 23). It is further proposed by the author that the Kenilworth Member be divided into [redacted] the Kenilworth Sandstone (lower) and Kenilworth Shale (upper).

Sample No.	Stratigraphic Horizon	Quartz	Clay Kaol. + Illite	Calcite	Dolomite
M_7-25	Upper Kenilworth Sandstone	50%	40%	10%	-
-26	Upper Kenilworth Sandstone	50%	25%	25%	-
-27	Upper Sunnyside Sandstone	60%	25%	15%	-
-30	Sandstone Channel Sunnyside Shale	60%	25%	-	15%
-34	Upper Kenilworth Sandstone	50%	35%	15%	-
-35	Upper Sunnyside Sandstone	30%	25%	35%	10%
-37	Sandstone Channel Sunnyside Shale	20%	-	40%	40%
-38	Sandstone Channel Sunnyside Shale	20%	-	35%	45%
-40	Upper Sunnyside Sandstone	50%	35%	15%	-
-52	Middle Kenilworth Sandstone	45%	15%	15%	25%
-54	Upper Sunnyside Sandstone	55%	30%	---15%--- (Calcite + Dolomite)	

(E. E. McGregor, analyst)

Table 2. X-ray powder diffraction data from selected rocks of the Blackhawk Formation at Sunnyside, Utah.

Feet

at 50 ft from top of coal is 7 ft sandstone, yellow-brown, very fine-grained, noncalcareous, slightly carbonaceous, cross-laminae dip southeast, slabby, discontinuous. Above is claystone, medium-yellow-brown, burned, with gastropods. At 75 ft above top of coal is 4 ft sandstone, yellow-brown, very fine-grained, calcareous, carbonaceous, well sorted, cross-laminae dip southeast and northwest, thin wavy bedded, nonfossiliferous, silty---------- 81

Coal zone, burned on outcrop---------- 16

Siltstone, dark-grey, coaly, uneven thickness, rootmarks---------- 2

Sunnyside Sandstone

Sandstone, light-grey-yellow, fine-grained, calcareous, cross-laminae dip southeast and northwest (70 dip readings average S 70 E, N 15 W). Thinbedded and slabby lower, interbedded with dark-grey siltstone; bedding grades upward to thin and blocky to thick and massive in upper unit, beds to 15 ft thick. Thin carbonaceous mudstone splits at various intervals. Carbonaceous throughout with carbonaceous trash on bedding planes; logs, sticks on many bedding surfaces, where are labyrinth castings. Bleached zone is fine- to medium-grained, 11 ft thick, starts at 53 ft; above is 9 ft fine- to medium-grained, calcareous, very felspathic sandstone, carbonaceous and jarositic, with few burrows and fossils of any kind. Burrows and mottled sandstone to siltstone zones throughout. <u>Cylindrichnus reptilis</u> in mudstone stringers, <u>Ophiomorpha</u>, large horizontal burrows in upper; plural curving tubes in more fine-grained part at base. Forms vertical cliff---------- 74

Kenilworth Member

Kenilworth Shale

Mudstone, grey-brown, medium-grained, silty, clayey, carbonaceous. At 23 ft above base

Feet

is interbedded sandstone, light-grey-yellow to yellow-orange, very fine-grained, silty, slightly very finely carbonaceous, calcareous, thinbedded and slabby. Interbeds increase in number upward to make single bed 9 ft thick at 45 ft. Covered above, digs show mudstone as above-- 115

Kenilworth Sandstone

Sandstone, light-grey-yellow, very fine- to fine-grained, poorly sorted, calcareous, silty, clayey, carbonaceous. Burrowed and mottled throughout. <u>Ophiomorpha</u> of varying sizes very common. Plural curving tubes, <u>Arenicolites</u>, smooth tubes abundant. Honeycomb weathering. Bedding poorly preserved, thick to very thick, massive, ledge former. "Whitecap" base at 30 ft, 9 ft thick, fine- to medium-grained, very light-grey, poorly sorted, noncalcareous, porous, very permeable. Sandstone above whitecap is extensively channeled, ripple cross-laminated, with very few large fossils. Top of unit is very fine- to medium-grained, very poorly sorted, silty------- 67

Mudstone, medium-grey, silty, clayey, with siltstone stringers throughout. Unit mostly covered-- 23

Sandstone, light-grey-yellow, very fine- to fine-grained. Unit has massive appearance. Grain size increases upward, thinbedded to laminated, flaggy to slabby split. Calcareous, few fossils, cross-lamination prominent. Megaripples, amplitude 4-6 in.; length 3-4 ft. Strike of crests N 40 E. Some units of thinly laminated, ripple cross-lamination with channels on top of unit. Channel axes strike S 85 E. Transport direction S 45-50 E. Crests of oscillation ripples on channel base strike N 40 E. Clay galls very common, especially in channels------------------------ 35

Sandstone, light-grey-yellow, very fine-grained, very calcareous, mostly quartz, high grain-to-matrix ratio. Well sorted, carbonaceous only on depositional surfaces. Some more carbonaceous, thinner beds interbedded, giving

Feet

ledge-and-cut cliff. Well sorted units have thumb-sized *Ophiomorpha*, with plural curving tubes, *Cylindrichnus* funnels, *Cylindrichnus*, *Arenicolites*. More carbonaceous units have chevron trails, *Teichichnus*, *Ophiomorpha*, smooth tubes, *Cylindrichnus*. Prominent low-angle cross-laminae dip mostly S 40-60 E, steeper (to 25 degrees) northwest. Cross-laminated sets 4-14 in. Smooth, planar base------------------------------------ 17

Sandstone, medium-brown-grey, very fine-grained, very carbonaceous with detritus and "coffee-grounds" trash on bedding and throughout beds. Intensively burrowed and mottled. Chevron trails, *Teichichnus*, *Ophiomorpha*, smooth tubes, *Cylindrichnus*, all very common. Very thin-bedded, laminated, sets 8-10 in. thick, irregular but continuous. Sharp upper and lower contacts. Poorly exposed cross-lamination. Horizontal *Ophiomorpha* in well-sorted units. Some siltstone interbeds, very finely sandy, very mottled------------------------------------ 28

Mancos Shale

Mudstone, dark-grey to black, carbonaceous, with carbonaceous claystone lenses and pods at odd intervals. Upper 3 ft is medium-grey-brown siltstone, sandy, carbonaceous, very calcareous------------------------------------ 58

Interbedded mudstone, siltstone, and sandstone. Mudstone: dark-grey to black, very fossiliferous, silty, slightly calcareous, clayey. Woody debris, shell fragments (no whole fossils). Siltstone: dark-yellow-brown to medium-grey-brown, sandy, shaly split. Sandstone: brown-orange, very fine-grained, calcareous, laminated in beds 4-8 in. thick. Ripple cross-laminated, building southeast. Laminae are uneven and discontinuous, sets are long and even with sharp upper and lower boundaries. Heavy limonite staining. Very few bedding surface tracks and trails. Base covered------------------------------------ 74

Total section------------------ 638

Measured section 3-67

SE$\frac{1}{4}$-SW$\frac{1}{4}$ sec. 31, T. 14 S., R. 14 E.

Sunnyside Section

Feet

Castlegate Formation

Sandstone, light-yellow-grey, fine- to medium-grained, calcareous, carbonaceous, silty; very uneven, irregular base. Logs, branches, carbonaceous debris throughout. Contorted bedding------------------------------------

Blackhawk Formation

Sunnyside Member

Sunnyside Shale

Mudstone, dark-grey, carbonaceous, with carbonaceous trash throughout. Worm trails on laminae. Fresh pieces are structureless, but weathered pieces have shaly split---------------- 21

Sandstone, light-yellow to light-grey, very fine- to fine-grained, silty, carbonaceous, calcareous, nonfossiliferous. Thinbedded and slabby, uneven beds-- 4

Covered---colluvial slope with siltstone and resistant sandy claystone stringers cropping out at odd intervals. Digs between beds show dark-grey carbonaceous mudstone------------- 102

Coal zone, burned and slumped on surface. Thickness from mine workings--------------------------- 17

Siltstone, dark-grey to black, sandy, with much coalified material throughout, root marks in

Feet

solid pieces. Shaly split, nonfossiliferous, noncalcareous-- 2

Sunnyside Sandstone ~~~~~~

Sandstone, light-grey-yellow to medium-grey-yellow, fine- to medium-grained, with siltstone stringers as interbeds, containing Cylindrichnus reptilis, coaly material, much carbonaceous matter. Large horizontal burrows in siltstone beds. Sandstone grain size grades to larger upward. Thickbedded, blocky, forms rounded cliff, friable. Ophiomorpha uncommon. Beds in upper 17 ft stained yellow by jarosite. Root marks with more carbon content in upper 10 in., also in top of bed 4 ft from unit top-- 32

Sandstone, light-grey-yellow, very fine- to fine-grained, thinbedded and slabby, makes ledges with stringers and thin beds of very carbonaceous sandy siltstone. Sandstone moderately well sorted and clean. Cross laminae dip at low angle S 75 E, some dip northwest N 15 W; sets 10 in. to 2 ft thick, tangential at base. Plural curving tubes common, Ophiomorpha, Cylindrichnus escape burrows and C. funnels, Arenicolites, Teichichnus, labyrinth castings. Ripplemarks on base of beds, crests strike N 10-20 E-- 23

Sandstone and siltstone, interbedded: sandstone, light-grey-yellow, very fine-grained, thin and regularly bedded, blocky, clay galls, ironstone concretions, honeycomb weathering. Siltstone, light-grey, carbonaceous, soft, very mottled. Cross laminae dip S 75-85 E at 4-7 degrees------------ 20

Kenilworth Member

Kenilworth Shale ~~~~~~

Mudstone, dark-grey, to black, with coal streaks and pods, most numerous near base. Stringers of grey-brown siltstone at odd intervals, discontinuous. At 60 ft is 2-ft zone of interlaminated siltstone and mudstone, carbonaceous, coaly, with oscillation ripplemarks on bases of

	Feet
beds. Above this is interbedded mudstone and medium-grey carbonaceous siltstone ----	112
Coal, hard, bright, brittle, jointed, no bone, mostly vitrain, fresh, rests on siltstone and sandstone below ----	6

Kenilworth Sandstone [illegible]

Sandstone, light-grey, very fine- to fine-grained, carbonaceous on bedding, noncalcareous. Thin-bedded in beds to 1.5 ft thick. Organic tracks and trails on bedding. Cross laminae dip mostly N 30 W at 25 degrees near top of beds, tangential at base, tabular sets, 27 in. maximum length of laminae. Upper 2.5 ft weathered white, is dark-grey and very carbonaceous, very silty, finely mottled, root zone. Papery split, thinly and unevenly laminated. Continuous with sandstone below, grades medium- to fine-grained. Large horizontal burrows in silty, carbonaceous sandstone, mottled in siltstone ----	9
Sandstone, light-grey-yellow, very fine- to fine-grained, carbonaceous, very slightly calcareous, poorly sorted, mica; silty, thickly and unevenly bedded, beds to 4 ft thick, blocky. Friable. Plural curving tubes common, <u>Ophiomorpha</u>, smooth tubes, <u>Teichichnus</u>, miscellaneous tracks ----	31
Sandstone, light-grey-yellow, fine-to medium-grained. Bleached zone, grain size gradation very apparent. Cross laminated and cross-bedded, noncalcareous, carbonaceous, poorly sorted, slightly silty. Uneven base. Few large <u>Ophiomorpha</u> (diam. to 1.5 in.) only fossils ----	22
Sandstone, light-grey-yellow, very fine- to fine-grained, poorly sorted. Silty, noncalcareous, clayey, carbonaceous, finely mottled. Cross-laminae dip southeast at low angle (7-10 degrees). Wedge-shaped sets, tangential at base. Some honeycomb weathering. Thick-bedded (5-10 ft), massive ----	30

Feet

Mudstone, medium-grey to dark-grey, carbonaceous shale streaks. Mostly covered--colluvium---------- 45

Sandstone, light-grey-yellow to yellow-orange, very fine- to fine-grained moderately well sorted, thinly and evenly bedded in beds to 10 in. Calcareous, carbonaceous only on bedding. Silty, minor clay. Very low-angle dipping cross-laminae, ripple cross-laminated. Honeycomb weathering. *Ophiomorpha*, plural curving tubes, *Arenicolites*, *Cylindrichnus* escape burrows-- 32

Mancos Shale

Mudstone, dark-grey, silty, very finely sandy, with discontinuous very fine-grained sandstone lenses.

Total section---------------- 503

Measured section 4-67

NW¼-SE¼ sec. 32, T. 14 S., R. 14 E.

Slaughter Canyon Section

Feet

Castlegate Formation

Sandstone, light yellow-grey, fine- to medium-grained, angular grains, poorly sorted----------

Blackhawk Formation

Sunnyside Member

Sunnyside Shale [illegible]

Covered--thick cover with Castlegate float---------- 17

Sandstone, yellow-brown, fine-grained, silty, noncalcareous, carbonaceous, cross-laminated and crossbedded in wedge-shaped, southeastward dipping sets that thicken and thin rapidly laterally. No fossils seen. Poorly sorted, no ripples--some sole marks indicate transport S 70 E---------- 22

Shale, red, baked; and claystone, light-grey, carbonaceous, mottled, silty, with woody debris; Teichichnus, Cylindrichnus, labyrinth castings--- 17

Sandstone, light-grey to medium-grey-yellow, very fine- to fine-grained. Poorly sorted, carbonaceous, calcareous, cross-laminated foresets; Ophiomorpha, Teichichnus, large horizontal burrows, Cylindrichnus and funnels. Interbedded with siltier, more carbonaceous sandstone, clean to mottled---------- 22

Feet

Shale and siltstone, carbonaceous claystone; woody debris, siltstone layers. Labyrinth castings on carbonaceous debris ---------- 21

Sandstone, medium-grey, very fine-grained, silty, well sorted, some very silty carbonaceous beds. Clean beds have Ophiomorpha and Cylindrichnus. Thinly laminated, shaly; cross-laminae dip southeast ---------- 14

Shale, burned and clinkered; light-grey at base, grading upward to bright-grey-yellow, some burned-red places, chippy. Capped by 6 in. band light-grey sandstone ---------- 8

Covered--sandstone pieces in float ---------- 12

Sandstone, burned-red to light-grey, fine-grained, well sorted, carbonaceous, silty; ripples cross-laminated, woody debris on bedding; bedding planes very irregular, show erosion, fills, small trought, worm trails, snails trails; logs, branches and twigs on bedding in no particular orientation. Small channels all directions; many clay galls. Upper 6-8 ft has large Ophiomorpha burrows ---------- 28

Covered--coal interval--slope, only burned sandstone beds exposed, 2 ft thick at 14, 21 and 38 ft, with oscillation ripplemarks, crests striking N 75 E, ripple-laminated, with woody debris; at 49 ft, 6 ft thick fine- to medium grained, ripple cross-laminated, rib-and-furrow laminated, woody debris ---------- 61

Sunnyside Sandstone

Sandstone, yellow-brown to light-grey, very fine-grained, thinly laminated, shaly; few scattered Ophiomorpha; finely cross-laminated; silty, clayey, carbonaceous; labyrinth castings; ripple cross-laminae dip southeast; ripple cross-laminated on bedding surface, clay galls ---------- 23

Sandstone, light-grey, fine- to medium-grained, sugary, whitecap; bedding surfaces have woody debris, contain Teichichnus, labyrinth castings, large horizontal burrows, Cylindrichnus with funnels. Uneven surfaces, much undulation; sandstone beds have Cylindrichnus and Ophiomorpha ---------- 36

Feet

Sandstone, light-grey-yellow, very fine-grained well sorted, carbonaceous on bedding, calcareous, strongly cross-laminated, even and thick-bedded. Four beds, separated by very carbonaceous, burrowed, silty sandstone with large burrows. Cliff contributor. Top of each bed is ripple cross-laminated———— 32

Sandstone, light-grey-yellow, very fine- to fine-grained, well sorted, slightly carbonaceous mostly on bedding. Base is ball-and-pillowed into lower bed. Ophiomorpha, Cylindrichnus, plural curving tubes, thin-bedded and blocky to slabby; cliff maker. Cross-laminated in long sweeping foresets, wedge-shaped, dip southeast and northwest. Penecontemporaneously deformed beds. Honeycomb to cannonball weathering, ledgy weathering. Ripple cross-laminated in many beds———— 42

Sandstone, medium-yellow to medium-grey-yellow, very fine-grained, silty, clayey, thinbedded, flaggy; plural curving tubes, few Teichichnus, some Ophiomorpha, not overly fossiliferous; appearance may be due to jointing or shear, or due to clay content. Different appearance from units below and above. Has interbeds of grey, silty, carbonaceous sandstone. Thinly laminated at top. Makes cliff———— 9

Interbedded sandstone and black, carbonaceous shale: sandstone, light-yellow, very fine-grained, calcareous, clean, well sorted; Ophiomorpha, Arenicolites, Cylindrichnus, plural curving tubes; steeply cross-laminated in places; same beds are evenly thinbedded to north. Ophiomorpha beds directly overlain by black coaly carbonaceous shale. Makes cliff or slope depending on exposure and erosion———— 48

Kenilworth Member

Kenilworth Shale [illegible]

Interbedded sandstone and siltstone: sandstone, very fine-grained to fine-grained, poorly sorted, silty, very carbonaceous, mottled. Siltstone, grey, very carbonaceous, clayey, mottled. Sandstone often bleached in spots. At 13 ft is a bleached sandstone 1.5 ft thick, with Ophiomorpha and Cylindrichnus, overlain

	Feet
by coaly, carbonaceous shale. Other sandstone ledges are thin, discontinuous, brown. Much black, coaly, carbonaceous, silty shale	90
Covered interval--digs at odd intervals yield dark-grey, silty mudstone; ledges of discontinuous sandstone beds common throughout. Colluvial slope	115

Kenilworth Sandstone

Sandstone, medium-grey-yellow, fine- to medium-grained, very poorly sorted, silty, with carbonaceous debris and trash, some feldspar. Small Ophiomorpha, Cylindrichnus funnels, Teichichnus. At 2 ft is a 3 in bleached zone, white, sugary; above 2 ft is sandstone as above, but cross-laminated and with clay galls on bedding. Thinbedded, blocky. Entire unit above 2 ft is whitecap	6
Sandstone, light-grey-yellow, very fine- to fine-grained, poorly sorted, silty, clayey, slightly carbonaceous mostly on bedding, with labyrinth castings. Very calcareous--mud cracks (?) common on base of bedding--polygons lined with carbonaceous shale, about size of quarter. Horizontal Ophiomorpha burrows, other plain burrows may be Cylindrichnus. Bedding obscured. Fractures into small pillows, makes rounded cliff	28
Sandstone, soft, silty, carbonaceous; slope maker, covered. Appears to be a softer, sugary sandstone	7
Sandstone, light-yellow-grey, very fine- to fine-grained, poorly sorted, well cemented, hard, calcareous, thickbedded, makes massive, rounded cliff. Ripple drift laminated, very uneven lower surface. Some honeycomb weathering; Thalassinoides, Ophiomorpha, Cylindrichnus, helicoid funnels; grain size grades upward to medium; unit contains some thin beds of laminated, very carbonaceous, mottled, silty sandstone. Over these beds are zones of clay galls on bedding, then more clean massive sand. Crossbedding in sandstone alternately northwest and southeast, foreset bedding dips 12-20 degrees. Upper portion (grain-size change) is sugary-textured	55

Feet

Sandstone, light-yellow-grey to grey-yellow, very fine-grained, poorly sorted, very carbonaceous with woody debris on bedding and carbonaceous trash throughout, burrowed and mottled slightly; Cylindrichnus escape burrows, Thalassinoides. Very thinly and unevenly bedded but no apparent cross-lamination. Papery in some beds. Upper 4 ft has channels 3 ft thick of thickbedded, cross-laminated sandstone. Slabby sandstone beds are cut out, more massive channel sandstones are laid in. Channels have many Cylindrichnus escape burrows, some horizontal Ophiomorpha ---------- 14

Covered--colluvium; dig at 18 ft showed medium-grey carbonaceous shale, silty; top of unit is grey-brown, sandy, clayey, carbonaceous siltstone with carbonaceous trash throughout. Dig at 12 ft showed siltstone ---------- 27

Sandstone, light-grey-yellow, very fine-grained, well sorted, mostly ironstained quartz; silty, very calcareous; carbonaceous trash on bedding planes; thin to medium bedded, grading thicker bedded upward, in beds 10 in. to 3 ft thick; cross-laminae dip S 65-85 E, to N 65-85 W, in wedge-shaped sets that are mostly 5-7 ft long, 6-10 in. thick; basal angle to 12 degrees, tangential at base, filling-in of scour to become horizontal laminae at top. Cross-laminated sets dip S 85 E. Horizontal and vertical Ophiomorpha, plural curving tubes, few Arenicolites. Top covered, but appears to grade to thinner, slabby beds ---------- 20

Mancos Shale

Mudstone, dark-grey, silty, structureless ----------

Total section ---------- 754

Measured section 5-67

NW$\frac{1}{4}$-NW$\frac{1}{4}$ sec. 5, T. 15 S., R. 14 E.

No. 2 Canyon Section

	Feet
Castlegate Formation	
Sandstone, medium-grey, medium-grained, carbonaceous, irregular base	
Blackhawk Formation	
Sunnyside Member	
Sunnyside Shale	
Covered slope	57
Sandstone, light-yellow to light-yellow-orange, very fine- to fine-grained, very calcareous, very clean and well sorted. Weathers to smooth, rounded ledge, blocky, thickbedded. Bedding details obscured. Relatively soft and friable. No fossils. Clay galls common. Upper surfaces weather sugary texture	38
Sandstone, light-yellow-orange, very fine- to fine-grained, silty, very slightly carbonaceous, very calcareous, poorly sorted. Very thin to thinbedded, wavy, irregular and uneven. All ripple-laminated, no observed foreset or festoons. Makes ledge and slope unit. Lowest ledge 5 ft thick at base section	37
Covered slope--outcrops of sandstone, light-yellow-grey, very fine- to fine-grained, wilty, calcareous to very calcareous, silty and dirty, cross-laminated and channeled in all directions.	

Feet

Forms ledges up to 5 ft thick that go under cover within short distance laterally---------------- 98

Sandstone, red, very fine-grained, very silty, dirty, carbonaceous, very calcareous; shows bedding in every mode from chaotic to evenly laminated, mostly festoon crossbedding in short cross-laminae 2-6 in., in 2-6 in. thick sets, most sets tabular. Direction of transport mostly S 25-40 E. Clay galls, nonfossiliferous. Thinly laminated basal 2.5 ft, interlaminated with grey-brown siltstone, grades upward to 2.5 ft of sandstone, as above, in 2-3 in. thick beds, separated by up to 2 in. dark-grey, shaly, sandy siltstone. Entire unit sits on dark-grey silty shale (burned red here). Above 12 ft unit is ripple-laminated, ledgey, 4-8 in. beds varying from friable to resistant. Next ledge maker begins at 35 ft.------------------------- 69

Covered--Sunnyside coal interval at base, steep slope, much burn------------------------------------ 41

Sunnyside Sandstone

Sandstone, light-grey, fine-grained, salt-and-pepper, sugary texture, noncalcareous. Thickens southeast. Crossbedding dips mostly southeast; no fossils, very irregular upper and lower surfaces---------------------------------- 3

Sandstone, light-grey to light-yellow-orange to brown-red (burnt), very vine- to fine-grained, hard, resistant, forms sharp to rounded ledge, sugary texture when fresh, fair sorting. Cross-stratified in long (6-8 ft) wedges up to 1 ft thick, low angle, 10-15 degrees ESE. Calcareous, few fossils, horizontal Ophiomorpha common, filled often with ironstone------------------------------------ 17

Sandstone, light-yellow-orange, very fine-grained, very calcareous--dogtooth spar fills cracks--cross stratified in wedges, mostly southeast. Ophiomorpha, Cylindrichnus with funnels, fecal pellets (common on tops of beds), Teichichnus, Gyrochorte. Beds usually separated by up to 2 in. of very carbonaceous, fissile, silty sandstone that weathers away to give ledges formed by beds. These small

Feet

units contain large horizontal burrows, labyrinth castings, tracks and trails. Base of most units ripplemarked. Unit contains concretions of clay-ironstone that weather to stairstep beds ---------- 32

Interbedded sandstone and siltstone: sandstone, yellow-orange, very fine-grained, weathers light-yellow-orange to light- yellow-grey, very calcareous, noncarbonaceous, slightly silty. Very thin bedded to laminated, flaggy to platy split. Cross-stratified, mostly surfaces of accretion but some foreset southeast and northeast. Load casts in some current markings on bottoms of sandstone beds indicate transport S 40 E, S 60 E, N 70 E. Ophiomorpha, Cylindrichnus, plural curving tubes; siltstone, medium-grey-brown, very carbonaceous, mottled, somewhat sandy, calcareous ---------- 57

Kenilworth Member

Kenilworth Shale

Siltstone, medium-grey to dark-grey to black, shaly, carbonaceous, silty with sandy siltstone stringers. Stringers are usually burned, have burrows and tracks and trails. Sandier toward top ---------- 67

Covered interval--mostly dark-grey mudstone, with thin, discontinuous, very fine-grained sandstone lenses ---------- 112

Interbedded sandstone and siltstone: sandstone, very fine-grained to silt-size, silty, carbonaceous, calcareous, pitted weathering surface due weathering-out of carbonaceous material. Ophiomorpha in upper layers, Cylindrichnus, Gyrochorte, many tracks-and-trails type fossils. Very thinbedded, 2-6 in., evenly laminated. Siltstone, dark-grey-brown, mottled, carbonaceous, calcareous. Thoroughly reworked by burrowings. Upper sandstone units crossbedded and evenly laminated, burrows. Upper 6 ft is all siltstone as above ---------- 16

Interbedded sandstone and siltstone: sandstone, yellow, fine-grained, carbonaceous, clayey, soft and friable; siltstone, dark-grey,

Feet

sandy, carbonaceous, Rock Canyon Coal (1 ft) at base -- 10

Kenilworth Sandstone

Siltstone, light-grey to light-brown-grey, shaly, very carbonaceous, sandy, fine at base to very fine-grained at top, noncalcareous, not conspicuously reworked. Stringers and lenses of sandstone, very fine- to fine-grained, silty, very carbonaceous, mottled -- 16

Sandstone, light-grey to grey-yellow, very fine- to fine-grained, noncalcareous, pitted surface, carbonaceous bedding planes, crossbeds steeply bipolar. Thin, crossed and often contorted bedding, massive cliff. Rare large *Ophiomorpha*, no other observed fossils. Whitecap where light grey. Colors discontinuous laterally ---------- 27

Sandstone, light-yellow to grey, very fine-grained, well sorted, intensively churned, burrowed and mottled. Slightly carbonaceous, very calcareous. Honeycomb weathering, bedding details obscured. Thickbedded, massive, makes rounded cliff -- 20

Mancos Shale

Mudstone, dark-grey, slightly sandy, silty, calcareous --

Total section ---------------- 725

Measured section 6-67

NE$\frac{1}{4}$-SW$\frac{1}{4}$ sec. 5, T. 15 S., R. 14 E.

Coke Oven Section

Feet

Castlegate Formation

Sandstone, light-grey-yellow, medium-grained, calcareous, very carbonaceous, with labyrinth castings common------------------------------

Blackhawk Formation

Sunnyside Member

Sunnyside Shale

Covered--lenticular sands and siltstones throughout, thickest is a poorly sorted very fine-grained sand from 86-94 ft; thins to zero or is covered within 10 ft either side------ 128

Sandstone, light-grey-yellow, very fine-grained, well sorted. Thin bedded in sets of beds that give massive cliff. Clay galls on bedding surfaces; bedding details very badly contorted. Churned, looks like organic reworking, but no organsim traces seen. Very well sorted within beds-- 28

Sandstone, very fine-grained, crossbedded, lenticular; siltstone, sandy, coaly, discontinuous, in carbonaceous shale; carbonaceous claystone; mudstone------------------------------- 85

Siltstone, claystone and carbonaceous shale, black (grey-brown claystone) all coaly---------- 11

	Feet
Sandstone, all colors from brown-yellow to red-brown, most yellow-orange, very fine-grained. Very thinbedded to laminated, flaggy to platy. Ripple laminated, worm and snail trails on accretion surfaces. Evenly to wavily bedded. Bedding grades upward to thinbedded. Poorly sorted, silty, very calcareous, slightly carbonaceous. Current ripplemarks, long axis N 20 E-------------------------------------	25
Siltstone, brown to dark-grey, sandy, structureless, clayey, weathered light-grey to white, carbonaceous------------------------	8
Sandstone, burnt, red-orange to brown-red, very fine- to fine-grained, has much very fine iron-stained feldspar, giving a speckled look. Few widely scattered large horizontal burrows, but very uncommon. Crossbedded mostly northwest, some southeast. Thinbedded, slabby to blicky, makes discontinuous ledge------------------------	5
Covered--Sunnyside coal, burned at this location. Several lenticular beds dark-grey siltstone, nonfossiliferous, sandy. Most of rest grey shale with claystone----------------	56
Sunnyside Sandstone [illegible]	
Sandstone, light-yellow to light-grey-yellow, very fine-grained, grades upward to fine-grained, poorly sorted, silty, very calcareous, noncarbonaceous except on bedding. No fossils seen. Slump structures common. Crossbedding dips low angle, 10 degrees or less; tangential. Clay-ironstone pellets scattered throughout. Upper 4 ft is light-grey, sugary, salt-and-pepper whitecap, overlain by 2 ft fine- to medium-grained, medium-grey salt-and-pepper sandstone, crossbedded cut-and-fill festoon types. Overlain in turn by 4 ft bed of sandstone, light-grey as above----------------------------	30
Sandstone, whitecap, light-grey, weathered white, medium-grained, silty, sugary, with much clay. Clay galls filled with ironstone.	

Feet

Ophiomorpha burrows filled with ironstone. Crossbedded in steep foresets; dips northwest and southeast, wedge-shaped sets, tangential at base, all dip 10-20 degrees. Makes rounded ledges. Thinbedded, blocky, very calcareous---------- 11

Sandstone, alternating beds of (1) soft and clayey, friable, laminated, carbonaceous, mottled and contorted, and (2) harder, silty, very fine-grained, very calcareous, carbonaceous bedding. Beds mostly very thin to thin, with one 3-ft bed in upper. *Ophiomorpha*, *Cylindrichnus*, *Arenicolites* in cleaner beds---------- 28

Sandstone and siltstone interbedded: sandstone, light-yellow-orange to red-brown (much baked), very fine-grained, silty, *Cylindrichnus* escape burrows. Some *Ophiomorpha* in cleaner beds, mostly upper. Siltstone, medium-grey to grey-brown, carbonaceous, sandy, mottled---------- 50

Kenilworth Member

Kenilworth Shale

Covered--scattered lenticular beds of siltstone, red-brown, nonfossiliferous, noncalcareous, sandy; none greater than 8 in. thick. Digs at odd intervals show medium-grey to grey-brown claystone and mudstone---------- 92

Kenilworth Sandstone

Sandstone, mostly light-grey-yellow, with some light-grey beds, very fine-grained to fine-grained, very calcareous, carbonaceous trash on bedding. *Ophiomorpha*, big plural curving tubes, *Teichichnus*, *Cylindrichnus*. Some lenticular masses of very well sorted, very fine-grained very light-grey sand, very calcareous quartz and little else. Grain size grades upward to fine, well sorted. Rest of unit is very fine-grained, poorly sorted, mostly very effectively reworked by organisms. Almost no bedding details present. Makes rounded ledges. At 27 ft and at 36 ft are very light-grey whitecap type zones of variable thicknesses. Fill irregularities in

	Feet
upper sandstone beds, have been eroded. Makes terraces. Topmost 6 ft unit is sandstone, very fine-grained, very poorly sorted, silty, very carbonaceous, mottled, light-grey-brown, weathered light-gray to white, very calcareous	57
Covered--break in slope--may be soft very fine-grained sandstone	9
Sandstone, light-yellow-orange, very fine-grained, poorly sorted, silty. Iron staining. Calcareous, noncarbonaceous. *Ophiomorpha*, *Arenicolites*, scattered others (*Cylindrichnus*). Massive, makes high cliff. Pitted surface (weathered). At 21 ft it changes: sandstone, fine-grained, same color, with white "splotches" due feldspar weathering (?) Glauconitic, very calcareous; well sorted, ripple-laminated, no apparent crossbedding; clean to burrowed in alternating beds 8-10 in. thick. Burrows of *Ophiomorpha*, *Arenicolites*, *Cylindrichnus*	33
Sandstone, light-grey-yellow, very fine-grained, silty and poorly sorted; calcareous, porous. Slightly carbonaceous within beds, much carbonaceous trash on bedding planes; alternating clean, thin (2 ft) beds and carbonaceous, shaly laminated beds. Much trough-set crossbedding. Many track-and-trail fossils on bottoms of sandstone beds, with *Ophiomorpha* in bedded, clean parts. Laminated units have mostly horizontal to low-angle smooth tubes. Forms series of step-ledges. At 13 ft is the base of a well sorted sandstone bed, fine-grained, light-grey-yellow, that goes from 5.5 ft thick on point to zero going around northward. Base is even, thickening occurs at top. Crossbedding, burrows. Atop this unit is a thin wash of iron-stained red sand, with rillmarks indicating current direction of S 80 E. Above the sandstone, medium-grey to medium-grey-yellow, poorly sorted, silty, clayey, very carbonaceous, noncalcareous, laminated (cross-laminated) bedding, variable hardness, making ledge-and-slope in (average) 10 in. beds	21

	Feet
Covered--break in slope at 17 ft, top 2 ft is siltstone, brown-grey, mottled	32
Sandstone, light-grey-yellow to light-yellow, very fine-grained, weathers same, very calcareous, very slightly carbonaceous; thin-bedded (2-3 ft thick), blocky. Each bed makes ledge, due weathering. Burrowing moderate below, intense in upper 2 ft. Poorly sorted, silty, clayey, iron staining. Much trough-set crossbedding--probably not mega-ripples. Fossils mostly finger-sized *Ophiomorpha*	14
Covered--slope break at 72 ft; interval from road to base is covered	88
Total section	811

Measured section 7-67

NE¼SW¼ sec. 5, T. 15 S., R. 14 E.

Quarry Section

Feet

Castlegate Formation

Sandstone, light-yellow-grey, carbonaceous trash throughout, chaotic bedding--------------------

Blackhawk Formation

Sunnyside Member

Sunnyside Shale

Covered--all digs show dark-grey carbonaceous silty mudstone-- 36

Sandstone, dark-red-brown, fine- to medium-grained, very silty, carbonaceous. Very poorly sorted. Irregularly bedded, bedding surfaces uneven. Nonfossiliferous-------------- 12

Covered interval--digs show dark-grey mudstone, clayey, silty, structureless. Coal in mine nearest this point is 14 ft thick, rests on 1.5 ft dark-grey siltstone. Thin discontinuous, ironstained sandy siltstone beds throughout interval-------------------------------- 175

Sunnyside Sandstone

Sandstone, "whitecap" overlies 2 ft siltstone, dark-grey, very carbonaceous, mottled, contorted, with large horizontal burrows. Sandstone, light-grey to light-yellow-grey, fine-grained, thinbedded to thickbedded, makes massive cliff. Very calcareous, well

Feet

sorted. Current ripplemarks indicate N 85 E transport direction 52

Sandstone, light-grey-yellow to yellow-gray, very fine- to fine-grained, very calcareous, carbonaceous, abundant burrows, *Ophiomorpha*, *Cylindrichnus*, few plural curving tubes. Crossbedded; many very contorted and chaotic areas due to slump, organisms and current action. Thinbedded (to 16 in.), beds separated by 2-3 in. carbonaceous siltstone, dark-grey, with large horizontal burrows. Most beds friable, make rounded ledges. Upper contains many clay pellets, ironstained concretions 48

Interbedded sandstone and siltstone: grey to dark-grey, mottled, sandy, clayey, sandstone, light-grey-yellow to red-orange, very fine-grained, well sorted, abundant *Ophiomorpha*, *Cylindrichnus*, small (5 ft wide, 6-8 in. deep) troughs; thinbedded and blocky; load casts on bases; low angle crossbedding, crosslaminated. Sets to 8 in. thick 49

Kenilworth Member

Kenilworth Shale

Covered--digs show badly weathered coal (Rock Canyon) at base. At 18 ft is a 7-ft thick bed of very silty sandstone. *Ophiomorpha* in this bed. Brown-orange to yellow-green, limonite cement, calcareous, highly burrowed by *Ophiomorpha*, *Cylindrichnus* and *Teichichnus*. Carbonaceous throughout, streaks of carbonaceous dark-grey claystone. Very thinbedded to laminated, platy to shaly. Top 7 ft is interbedded siltstone and claystone; siltstone, red-brown (burnt) to dark-grey, burrowed intensively, carbonaceous, very calcareous, structureless, in very thin beds; claystone, dark-grey to black, silty, shaly, very carbonaceous, slightly very finely sandy. Siltstone has *Ophiomorpha* and *Cylindrichnus* escape burrows 85

Feet

Kenilworth Sandstone [illegible]

Sandstone, light-grey to light-yellow-grey, fine-grained, well sorted, clean, very calcareous, crossbedded, thin and irregularly bedded, pitted weathering surface, scattered *Ophiomorpha* burrows only 23

Claystone, dark-brown, silty, sandy, grades upward to siltstone, dark-grey, carbonaceous, sandy 10

Sandstone, interbedded with: siltstone, very fine-grained, sandy, calcareous, yellow-brown to grey-brown) very fine-grained, grey-yellow to light-yellow-orange, matrix grain size very fine to silt-size. Very calcareous, carbonaceous throughout, woody debris on beds; *Ophiomorpha*, *Cylindrichnus* common, very thin-bedded to laminated, platy to shaly split. Most laminae are even, some wavy. Sandstone beds vary in thickness--some thicken from a wedge edge to 1.5 ft in 10 ft laterally. Interbedded part is 9 ft thick, gives way upward to all sandstone, well sorted, burrowed, crossbedded; crossbeds dip 10-12 degrees S75 E; this grades upward to a whitecap, fine-grained light-grey to white, calcareous, slightly carbonaceous, burrowed. Top 45 ft is whitecap 129

Covered slope--top 1.5 ft is black calcareous mudstone (exposed in stream) 32

Sandstone, light-grey-yellow, very fine-grained, well sorted, thickbedded to thinbedded; thick beds are crossbedded in wedge-shaped 6-in. sets dipping southeast and northwest, base planar, upper surfaces ripple-laminated, lenticular and discontinuous laminae. Unit clean, calcareous, noncarbonaceous, *Ophiomorpha*, *Cylindrichnus*, plural curving tubes, woody debris on bedding, funnels. Base covered 20

Total section 671

Measured section 8-67

NE¼-NW¼ sec. 5, T. 15 S., R 14 E.

Rifle Range Section

	Feet
Castlegate Formation	
Sandstone, light-yellow-orange, fine- to medium grained, uneven lower contact	
Blackhawk Formation	
Sunnyside Member	
Sunnyside Shale	
Covered-- colluvium and rocks	27
Sandstone, light-yellow-orange, fine-grained, moderately calcareous, noncarbonaceous, trough-set crossbedding, with some flow-rolls, all long axes oriented east-southeast. No observed fossils. Thin- to thickbedded (1.5-4.5 ft). Thickbedded from 7-30 ft, thin and unevenly bedded above and below. Lower surface very uneven	40
Carbonaceous shale, dark-grey, coaly throughout, and siltstone, clayey, sandy, iron cement, yellow-brown	35
Sandstone, light-grey-yellow to yellow-orange, very fine- to fine-grained, thinly interbedded with grey carbonaceous siltstone at base (7 ft) intricately crossbedded, cross laminated, next upward is thickbedded sandstone, cross-laminated, very fine-grained, as above, 9 ft thick; siltstone, carbonaceous, with sandstone interbeds, completely reworked, 13 ft. upper	

	Feet
7 ft thinbedded, sugary. No certain fossils seen--clay galls common throughout	35
Covered--carbonaceous shale, dark-grey, and siltstone, carbonaceous, clayey, sandy, grey-brown with resistant siltstone (light-grey weathering, carbonaceous) at 6 ft, 1 ft thick; siltstone, yellow-orange, silty, carbonaceous, clay galls, 19 ft thick at 20 ft, soft, friable, slope maker, carbonaceous debris, no fossils. Upper part mostly covered. Upper 60 ft is a succession of: sandstone, very fine-grained, silty, carbonaceous, calcareous, nonfossiliferous, approximately 12 in. thick; siltstone, grey-brown, sandy, carbonaceous, structureless 3-ft; coal, approximately 1-2 ft thick; carbonaceous shale and siltstone, plant debris, approximately 4 ft thick. (succession repeated 6 times)	95
Sandstone, light-grey-yellow to yellow-orange, very fine- to fine-grained, lenticular, very calcareous, unidirectional crossbedding, wedge shaped, transport direction S75-85 E, current ripplemarks, very carbonaceous	7
Siltstone, light-grey-brown, weathers light-grey, very carbonaceous, plant fragments, structureless, shattered. Grades upward to grey-yellow. Shaly top 1 ft, 2 in. coal on top. Many spores	7
Coal, split, top 5 in. dirty	3
Siltstone, medium-yellow-brown, very carbonaceous, woody debris throughout. Hard, resistant, thin, lenticular bedding, no observed fossils, noncalcareous	2
Coal, Sunnyside	12
Siltstone, dark-brown to dark-grey, very carbonaceous, crinkly, irregular thickness	1

Sunnyside Sandstone [illegible]

Sandstone, light-grey-yellow to very-light-grey, very fine- to fine-grained, some

Feet

medium-grained, very calcareous, nonfossiliferous, thickbedded and massive, crossbedded in wedge-shaped sets dipping 10 degrees southeast and 20 degrees northwest. Blocky, makes high rounded cliff. Burned areas throughout, discontinuous whitecaps from 32 to 37 ft, 47 to 54 ft---------- 57

Sandstone, light-grey-yellow to yellow-orange, very fine- to fine-grained, very calcareous, slightly carbonaceous on bedding planes, with woody debris and carbonaceous trash. Burrows, Ophiomorpha, Cylindrichnus escape burrows, Arenicolites, tracks and trails. Ripplemarks on bases of some beds, transport direction S 75 E, thinbedded, blocky continuous beds, cross-laminated, dip S 75 E at 7 to about 20 degrees---------- 41

Sandstone and siltstone, interbedded: sandstone light-grey to yellow, very fine-grained, moderately well sorted, thinbedded, slightly silty, intensively burrowed; Ophiomorpha, Teichichnus, Cylindrichnus, Arenicolites abundant in sandstone units. Crossbedded, dipping 10 degrees S 65 E. Siltstone, purple-grey to dark-grey, sandy, very carbonaceous, calcareous and mottled---------- 53

Kenilworth Member

Kenilworth Shale

Covered interval--digs at odd intervals reveal dark-grey carbonaceous mudstone with brown carbonaceous claystone stringers. Mudstone is structureless and slightly sandy, calcareous. At 24 ft above base is a 2 ft sandstone ledge containing Ophiomorpha. Rock Canyon coal measured at 3.5 ft in draw---------- 129

Kenilworth Sandstone

Sandstone, light-grey to yellow, very fine- to fine-grained, very calcareous, well sorted, very thickbedded and massive, makes high, abrupt cliff. Intensively burrowed lower; upper 24 ft unburrowed. Woody debris on bedding planes; lower 8 ft has scattered

Feet

carbonaceous material in it--no concentrations. Ripplemarks indicate transport S 70-80 E. *Cylindrichnus* escape burrows, *Ophiomorpha* very abundant, *Arenicolites* common, plural curving tubes and some feathered funnels at carbonaceous zones, top 15 ft is whitecap, fine- to medium-grained, very calcareous, nonfossiliferous, rootmarks on top of unit ---------- 72

Covered--digs indicate dark-grey carbonaceous silty, clayey shale ---------- 11

Sandstone, light-grey to yellow, very fine- to fine-grained, well sorted, very calcareous. Alternating beds of thin to thick, resistant, crossbedded, irregular thickness, burrows, *Ophiomorpha* and *Cylindrichnus*; with some organically-disturbed laminae and very thin to laminated beds, cross-laminated, platy (almost fissile), and carbonaceous trash on bedding. Few thin beds of very carbonaceous, silty, very fine sandstone, mottled, in upper portion. Above 32 ft becomes thick to very thickbedded (beds 4-6 ft thick), with thin sandstone interbeds as above. Thick beds blocky, resistant, form series of ledges, Whitecap 40-46 ft. Top of unit is like base lithologically, fewer fossils, same crossbedding ---------- 60

Covered--digs in lower 5 ft show grey silty shale ---------- 35

Sandstone, grey-yellow to yellow-orange, very fine-grained, very calcareous, noncarbonaceous. Fossil population conspicuously reduced, only a few small burrows. Small channel (8 ft wide, 1 ft deep) in base, bedding details obscured by blasting and weathering. Thick-bedded, blocky. Burrow population increased again upper 2 ft. Bedding seen is high angle (greater than 10 degrees) cross-stratification dipping ESE. Thin wedges (to 6 in. thick) in a small channel in top of unit near south end of outcrop 21 ft wide, 3 ft deep. Sharp, slightly irregular upper surface ---------- 12

	Feet
Sandstone, light-grey to yellow, very fine-grained, weathered yellow-orange to yellow-brown, abundant trace fossils, *Ophiomorpha*, *Teichichnus*, *Cylindrichnus*, *Gyrochorte*, *Ruh[illegible]*, tracks and trails. Some beds completely mottled by reworking. Very thin-bedded and laminated, platy, very calcareous, well sorted generally, carbonaceous. Ripple cross-lamination dominant, some suggestion of megaripples. Very irregular upper surface, base covered	52
Total section	733

Measured section 9-67

NW$\frac{1}{4}$-NW$\frac{1}{4}$ sec. 8, T. 15 S., R 14 E

Monday Wash Section

Feet

Castlegate Formation

Sandstone, light-grey, fine- to medium-grained, chaotic bedding--

Blackhawk Formation

Sunnyside Member

Sunnyside Shale

Covered---Castlegate Formation float------------------ 34

Sandstone, light-yellow-orange, very fine- to fine-grained, very calcareous, not carbonaceous, may be due weathering. Thickbedded, rounded blocky ledge. Crossbedding dips 10-15 degrees ESE------------------------------------ 14

Covered---dark-grey shale bloom------------------------- 19

Sandstone, light-yellow-grey, very fine- to fine-grained, weathers yellow-orange, very calcareous, bedding carbonaceous, no observed fossils, crossbedding dips 20-25 degrees S 65 E. Thickbedded, clay galls. Thinbedded and less resistant above 14 ft, makes receding ledge-- 30

Shale, dark-grey to black, coaly throughout--------- 34

Sandstone, yellow-orange, very fine-grained, well sorted, thin- to thickbedded, blocky, makes sheer cliff. Some contorted laminae,

Feet

due penecontemporaneous deformation. Clay galls, some shale chips, small, thin, poorly preserved burrows. Steep angle crossbedding and cross-lamination within beds. Bedding plane carbonaceous, some thin, laminated units are carbonaceous throughout ---------- 23

Shale, black, carbonaceous, coaly ---------- 7

Sandstone, light-grey-yellow, very fine- to fine-grained, weathers yellow-orange, well sorted, calcareous cement, burrowed. No complete fossils, badly weathered. Cross-bedded in wedge-shaped beds 0-6 ft thick. Some parts mottled, others merely occasional burrows. Trough-set cross-stratification common. Thickbedded and blocky, makes sheer cliff, erodes and is covered in washes. Cliff maker unit is 33 ft thick; above the unit is as described, except very thinbedded to laminated for 13 ft, then a thickbedded ledge caps the unit ---------- 51

Covered (by burn)---Sunnyside coal near base. At 42 ft is a 1-ft ledge of burned, calcareous, sandy siltstone; at 50 ft is a 5-ft sandstone, light-yellow to yellow-brown, very fine-grained, calcareous cement, well sorted, with coal fragments (very fine), thinbedded, cross-laminated mostly northwest, few southeast. No observed fossils. Blooms and resistant units above the 50 ft sandstone indicate a thin sandstone-carbonaceous shale-siltstone-coal-sandstone sequence ---------- 111

Sunnyside Sandstone ~~Member~~

Sandstone, light-yellow-orange, very fine- to fine-grained, burned pink to red-orange, very calcareous cement, few (reworked?) fossils, generally thickbedded and massive, with carbon on bedding planes where organisms disrupted it. Cross-laminated in sets from 0 tp 18 in. thick, dipping 7-12 degrees S 70 E. Makes bold, high, sharp cliff. Whitecap zones at intervals, but hard to trace laterally ---------- 67

Sandstone, red-orange to light-yellow-orange, very fine- to silt-size grains, very

Feet

calcareous, well sorted, slightly carbonaceous, well reworked by organisms: Ophiomorpha, Cylindrichnus, Arenicolites. Deeply weathered, alternating thick beds with thin beds of more carbonaceous, friable sandstone, as above. Forms rounded ledges and overhangs. Tangential cross-stratification dips ESE, all less than 10 degrees. Upper 20 ft more thickbedded and resistant, no friable beds. Bleached zones are discontinuous but scattered throughout vertical section ---------- 52

Kenilworth Member

Kenilworth Shale submember

Covered--base is a few inches of clay overlain by 15 in. Rock Canyon coal. Few lenticular beds of sandstone, very fine-grained, grey-brown, silty, slightly calcareous, carbonaceous, iron cement. Exposed lower 20 ft. Rest completely covered. Includes the interbedded sandstone and siltstone of the lower Sunnyside and the base of the thin-bedded unit of the Sunnyside Sandstone submember ---------- 148

Kenilworth Sandstone submember

Sandstone, very light-grey, very fine- to fine-grained, (whitecap), very calcareous cement. Pitted upper surfaces--due weathering-out of carbonaceous material. Thinbedded and cross-bedded, dipping at steep angles northwest, low angle to flat southeastward. Softer, more friable than unit below, forms receding ledge. Thin and slabby to thick and blocky---- 22

Sandstone, light-grey-yellow, very fine- to fine-grained, some scattered very fine bits of coaly material. Very calcareous cement. Friable, accumulations of carbonaceous debris at scattered intervals, discontinuous; where present, Cylindrichnus, labyrinth castings, other organisms have reworked. Elsewhere Ophiomorpha is abundant, Arenicolites and Cylindrichnus escape burrows

Feet

common. Thickbedded and massive, forms rounded bluff weathered to thick ledges in draw. Cross-bedded but details obscured by weathering---- 34

Covered interval--seems to be yellow-brown, silty claystone---- 16

Sandstone, light-yellow-grey, very fine- to fine-grained, thin- to thickbedded, makes rounded bluff, very calcareous, very slightly carbonaceous--mostly on bedding planes, well sorted. Fossils very rare, very irregular base, sharp and even top surfaces. Some *Ophiomorpha*, plural curving tubes in upper, Forms rounded bluff on faces, overhangs in draws---- 36

Sandstone, light-yellow to light-yellow-orange, very fine- to fine-grained, well sorted, slightly carbonaceous, some friable beds--thinbedded-- crossbedded fairly high angle (5 to 10 degrees) southeast and northwest. Some crossbedding looks like truncated megaripples but not enough section to tell. *Ophiomorpha*, *Arenicolites*, *Cylindrichnus*, plural curving tubes---- 34

Interbedded sandstone and siltstone: sandstone, light-grey-yellow, very fine-grained, silty, and poorly sorted, very fossiliferous, *Cylindrichnus*, *Ophiomorpha*, *Teichichnus*, pellets, *Thalassinoides* common. Carbonaceous, very calcareous, cross-laminated at low angle, thinbedded. Siltstone, very finely sandy, calcareous, carbonaceous, mottled---- 9

Covered--colluvium and boulders. Top is medium-yellow-brown, carbonaceous silty claystone---- 28

Sandstone, light-yellow-orange to light-grey-yellow, very fine- to fine-grained. Very calcareous, well sorted, some carbonaceous material, crossbedded at generally low angle northwest and southeast. Small troughs as described above. Friable, thick-bedded, caps middle Kenilworth cliff. Few fossils, *Ophiomorpha* only---- 20

Feet

Sandstone, light-yellow-orange, very fine-grained, well sorted, carbonaceous with coaly bits, thinbedded in alternating layers of resistant sandstone, as above, and very fine-grained, very carbonaceous, silty, friable sandstone. Continuous beds, thinly laminated within bedding. Much less fossiliferous than sandstone beds below, mostly *Gyrochorte*, *Ophiomorpha*, and *Arenicolites*. Weathers slabby to blocky. Bottoms of beds have fecal pellets, tracks and trails. Interbeds have *Cylindrichnus*. Laminae of accretion only, no steep laminae in lower. Above 18 ft there is low-angle bedding (less than 10 degrees) dipping northwest and southeast in small sets, some very small cut-and-fill structures on tops of beds, channels 6-8 ft long, about 1 ft deep. More friable upward------------------------------ 19

Interbedded sandstone and siltstone: sandstone very fine-grained, silty, carbonaceous bits, very calcareous, very thin to thinbedded, evenly continuous beds, very small-scale ball-and-pillow structures on bases. Very fossiliferous, *Cylindrichnus*, with helicoid funnels, *Ophiomorpha*, *Teichichnus*, *Arenicolites* in undisturbed beds. Siltstone, dark-grey, weathers tan, knobby, mottled, calcareous, sandy, beds from 1 in. to 6 ft thick, very carbonaceous, siltstone beds thin upward, sandstone beds increase in number, but keep same thickness. Base covered------------------------------ 42

Total section-------------- 850

Measured section 10-67

Base of section in SE¼-NW¼ sec. 8, T. 15 S., R. 14 E.

Water Canyon Section

	Feet
Castlegate Formation	
Sandstone, light-yellow-grey, fine- to medium-grained, lower contact very uneven----------------	
Blackhawk Formation	
Sunnyside Member	
Sunnyside Shale [illegible]	
Covered--light-yellow-orange sandstone in float---	72
Sandstone, light-grey-yellow, very fine- to fine-grained, calcareous, poorly sorted, sugary weathered surface, thinly crossbedded in wedges, most thickening east-southeast. Upper surfaces show ripple cross-lmainae transport direction east-southeast. Covered 15 ft above base, but unit total is----------------------------	50
Siltstone, dark-grey to black, very carbonaceous with bits of coalified plant debris throughout. Sandy in discrete rounded grains throughout. Two 6 in. beds of sandstone, very fine- to fine-grained, yellow-orange, silty, carbonaceous, lenticular------------------------------------	15
Covered--alluvium------------------------------------	18
Sandstone, light-yellow-orange, very fine- to fine-grained, well sorted, good rounding. Thickbedded and blocky to slabby, festoon	

	Feet
crossbedding prominent, penecontemporaneously deformed. Unit discontinuous----------------	36
Siltstone, black, very carbonaceous, laminated, contorted, transport direction S 80 E, 18 in. coal at 6 in. from base------------------------	6
Sandstone, light-grey-yellow to yellow-grey, very fine-grained, silty, with shale laminae throughout, hard, resistant, overlies coal. Calcareous, carbonaceous, thinly crossbedded, transport to east-southeast. Some mottling, burrows, poorly preserved----------------------	5
Mixed interval--carbonaceous shale, siltstone, both dark-grey to black, coaly, siltstone sandy. Coal on the top 1.5 ft----------------	22
Sandstone, very fine- to fine-grained, some medium. Ripplemarks show transport direction S 75 E--	6
Siltstone, light-grey, with roots present in upper 6 in., carbonaceous, slightly sandy, noncalcareous. Top 3 in. is very coaly shale---	2
Sandstone, light-yellow-orange, very fine- to fine-grained, well sorted, well rounded, unconformably overlies shaly coal. <u>Arennicolites</u>, <u>Cylindrichnus</u> escape burrows. Tracks and trails on bedding planes. Carbonaceous debris on bedding planes. Ripplemarks laminated. Top 3 ft is whitecap. Upper surface has root impressions-----------------	11
Mudstone, dark-brown-grey, silty, carbonaceous debris------------------------------------	15
Sandstone, dark-brown, very fine-grained, very carbonaceous, slightly calcareous, nonfossiliferous---------------------------	16
Mudstone, dark-grey, massive, silty, structureless----------------------------	11
Sandstone, light-yellow-brown, very fine- to fine-grained, silty, clayey, nonfossiliferous---	4

	Feet
Mudstone, with sandstone, siltstone, and carbonaceous shale stringers	48
Covered interval--colluvium	8
Sunnyside coal, upper seam. Bone split 1 ft thick at 17 in. above base	7
Interval of carbonaceous shale, siltstone. Ball-and-pillow structures in 2 ft siltstone ledge	10
Siltstone, dark-grey, forms big knobs on fresh surface, buckshot weathering, very calcareous	7
Carbonaceous shale, dark-grey to black, grading upward to siltstone, dark-grey, shaly, very carbonaceous	7
Sunhyside coal, lower seam. Taped, 15 ft inby north portal	7
Interval of carbonaceous shale, dark-grey to black, sandy, and siltstone, dark-grey to grey-brown, very sandy, wavy laminated	4
Coal, sandy, overlies 1 ft dark-grey siltstone	2
Sunnyside Sandstone [illegible]	
Sandstone, medium-grey-brown, very fine- to fine-grained, siliceous cement. Ophiomorpha, root zones with fossilized roots, rootlets and root hairs. Thinly and evenly bedded, well sorted. Upper surface very irregular, weathered. Vertical ledge	7
Sandstone, light-grey to very-light-grey, fine- to medium-grained, weathered same to light-yellow-orange. Calcareous, grains well rounded, most frosted. Feldspars are angular and sharp. Steep angle cross-laminated sets 10 in. to 2 ft thick, tabular, noncarbonaceous, nonfossiliferous. Sugary texture. Cliff maker, rounded	18
Sandstone, light-grey-yellow to light-yellow-orange, very fine- to fine-grained, very	

Feet

calcareous, forms rounded ledge. Few fossils, *Ophiomorpha* only within beds, *Gyrochorte* and tops of *Ophiomorpha* burrows and woody debris common on bedding planes. Cross-laminated and thin to thick bipolar crossbedding that dips 5-10 degrees. Well-sorted, transport direction S 70 E to N 85 E. Ironstone concretions numerous, honeycomb weathering------------------------ 35

Sandstone, yellow-orange, very fine-grained, poor to moderate sorting, thinbedded, evenly cross-laminated, all low angle (less than 5 degrees) in southeast and northwest directions. Very low carbonaceous material in these beds, *Ophiomorpha* and *Arenicolites* common. Few *Cylindrichnus* escape burrows. Very calcareous. Interbedded with sandstone as above, and *Cylindrichnus* trails. thoroughly reworked by organisms. Forms ledges in unit. Upper 4 ft has alternating sandstone (10 in.) and dark-grey carbonaceous mottled siltstone (4 in.)---------------- 46

Sandstone and siltstone, interbedded: sandstone, light-yellow-grey, very fine-grained, fair sorting. Well sorted with laminae of dark-grey carbonaceous siltstone at intervals. Thinbedded and blocky; low angle cross-laminae lower part, majority southeast. Upper part cross-laminated with some trough-set crossbedding that dips 10 degrees to ESE. *Ophiomorpha*, *Cylindrichnus* escape burrows, *Arenicolites* in upper. Carbonaceous debris on bedding planes. Siltstone, dark-brown-grey, weathered purple-grey, slightly calcareous, very carbonaceous, with sandstone laminae in the beds. *Cylindrichnus*, other organisms, mottled. Sandstone laminae disturbed. Ripplemarks on base of sandstone units, long axis N 12 E, asymmetrical to southeast-- 40

Kenilworth Member

Kenilworth Shale [redacted]

Exposure in creek bottom along road: 35 ft covered (from top of Kenilworth sandstone) 43 ft siltstone, grey-green, clayey, slightly

Feet

very finely sandy, slightly calcareous, carbonaceous, very thinbedded, slightly shaly weathering. Concretionary bands of iron-cemented siltstone at intervals. Woody debris (amber?), no observed fossils, 38 ft covered -- 116

Kenilworth Sandstone [illegible]

Sandstone, light-grey to very light-grey, fine-grained, well-sorted, conspicuously few fossils, woody debris on bedding is only carbonaceous material. Numerous concretions. Festoon cross-laminated in base and top. Crossbedded throughout. Pitted on upper surface -- 40

Sandstone, medium-yellow-orange, very fine- to fine-grained, very calcareous, carbonaceous in discontinuous bodies within beds, woody debris on bedding planes, moderately well sorted at base. Whitecap in various places, but hard to trace laterally due weathering. Thinbedded and blocky, burrowed intensively, cross-lamination dips 10 degrees S 90 E; becomes thickbedded and massive upper 15 ft. Pitted surfaces common on many beds. Makes rounded cliff, massive -- 24

Siltstone, dark-grey to black, very fine-grained, sandy, very calcareous, mottled, carbonaceous -- 16

Sandstone, as above, except very low carbon, mostly Ophiomorpha (very numerous), thin-bedded, cross-laminated, moderately well preserved, slabby ledge -- 8

Sandstone, light-grey-yellow, very fine-grained, very calcareous, very carbonaceous, with shale laminae at all orientations throughout and separating sandstone beds. Very thin laminae in very thin beds, intensively burrowed, mottled. Weathered to rubbly ledges. Ophiomorpha (small), Cylindrichnus, Teichichnus, numerous burrows -- 6

Sandstone, light-grey-yellow, very fine- to fine-grained, very calcareous, more carbonaceous.

	Feet
Notable increase in fossil population. Thinbedded, containing *Ophiomorpha*, *Cylindrichnus concentricus*, *Arenicolites*, *Gyrochorta*, *Aulichnites*, Clay galls on bedding------------------------------------	19
Sandstone, medium-grey-yellow to yellow-orange, very fine- to fine-grained, very thickbedded and massive, very calcareous, fossil population small, *Ophiomorpha*, *Arenicolites* and plural curving tubes. Bedding planes have woody debris, and organic traces more abundant. Whitecap from 18-23 ft------------------	27
Sandstone, grey-yellow, very fine-grained, very calcareous, well sorted, plural curving tubes, *Ophiomorpha*, *Arenicolites* and *Cylindrichnus*. Woody debris on bedding planes, with large and long pieces oriented S 80 E. Thickbedded and blocky with thin separating beds of very fine-grained carbonaceous, fissile, friable sandstones that have coaly laminae containing labyrinth castings------------	21
Interbedded sandstone and siltstone: sandstone with *Ophiomorpha*, *Arenicola*, *Teichichnus*, *Cylindrichnus*. Siltstone mottled, carbonaceous--	9
Covered--dark-grey carbonaceous shale in digs------	20
Sandstone, thinbedded, light-grey, very fine, calcareous, with *Ophiomorpha* and *Teichichnus* abundant, woody debris------------------------------	31
Interbedded sandstone and siltstone; sandstone light-yellow-grey, very fine-grained, silty, very thinbedded. Siltstone, mottled, medium-grey. Base covered------------------------------	23
Total section------------------	886

Measured section 11-67

SW$\frac{1}{4}$-NE$\frac{1}{4}$ sec. 8, T. 15 S., R. 14 E.

Fan Canyon Section

Feet

Castlegate Formation

Sandstone, light-grey-yellow, fine- to medium-grained, massive, calcareous, carbonaceous, thickly and chaotically bedded-----

Blackhawk Formation

Sunnyside Member

Sunnyside Shale

Sandstone, very-light-grey to very-light-yellow. Very fine-grained, crossbedded in thin, tangential trough sets. Carbonaceous splits throughout, are coaly with labyrinth castings very common----- 10

Covered interval--three major resistant units at 7, 19 and 23 ft, all less than 3 ft thick, all overlie thin coals. Digs between units show dark-grey carbonaceous mudstone----- 35

Sandstone, medium-grey-yellow, fine- to medium-grained, chaotic bedding, lenticular units. Plant debris common, labyrinth castings with larger pieces----- 25

Mudstone, dark-grey-silty, sandy, structureless. Few thin discontinuous sandstone beds. No observed fossils----- 22

Sandstone, medium-red-brown, fine-grained, thickbedded and blocky, wedge-shaped sets to

	Feet
1.5 ft thick, thin toward ESE. Unit lenticular, pinches out east and west. Carbonaceous debris throughout	50
Covered colluvium slope, with few thin, discontinuous siltstone beds. Digs at odd intervals show dark-grey mudstone	94
Coal section, burned and clinkered. Mine section is, top to bottom: coal, 2 ft; siltstone 3 ft 10 in.; coal 7 ft 10 in.; siltstone 2 ft	16
Sunnyside Sandstone ([illegible] ft)	
Sandstone, light-yellow-grey, fine- to medium-grained, calcareous, carbonaceous fines. Thickbedded, with interbeds of dark-grey, carbonaceous siltstone containing *Cylindrichnus reptilis* and large horizontal burrows. Top beds of sandstone contain abundant rootmarks, are poorly sorted and carbonaceous. Middle 20 ft of unit is well sorted, very calcareous, with scattered, uncommon *Ophiomorpha*. Lower 30 ft is zone of intense weathering at outcrop due poor sorting (?). *Ophiomorpha*, *Gyrochorte*, *Cylindrichnus*, chevron trails, *Arenicolites*, *Aulichnites* common in lower	60
Sandstone, light-yellow-grey to yellow-orange, very fine- to fine-grained, moderately well sorted, thinbedded. Prominent low-angle crossbedding, transport direction S 85 E. (10 measurements). Slightly silty, very carbonaceous and calcareous. *Ophiomorpha* (small), *Cylindrichnus* with funnels on depositional surfaces, *Thalassinoides*, plural curving tubes, *Ruhespuren*	58
Interbedded sandstone and siltstone: sandstone light-grey to brown, very fine, silty, clayey, very thinbedded, *Cylindrichnus*, *Teichichnus*, small *Ophiomorpha*, *Thalassinoides*. Siltstone, dark-grey, sandy, mottled and reworked, contorted. Much apparent organism activity, none identifiable	55

	Feet
Kenilworth Member	
Kenilworth Shale	
Covered--colluvium slope. Mudstone, dark-grey, silty, sandy, very carbonaceous, shows in digs throughout interval. 2 ft coal dug out at base of unit	92
Kenilworth Sandstone	
Sandstone, light-grey, yellow, fine- to medium-grained. Top 10 ft is whitecap. Thickbedded, crossbedding dips 10-17 degrees, inclined toward east. Few flute casts on base of beds indicate transport direction S 75 E. Below whitecap unit is fine-grained, moderately well sorted, slightly carbonaceous, calcareous, fossiliferous, thin- to thickbedded, thoroughly burrowed and mottled in lower 40 ft. Some siltstone interbeds in the lower part	71
Interbedded sandstone and siltstone: sandstone thin, very calcareous, fine-grained, thin and evenly cross-laminated, fossiliferous. Siltstone dark-grey, sandy, shaly, carbonaceous, coaly	25
Sandstone, light-yellow-grey, fine- to very fine-grained, well sorted, calcareous cement, non-carbonaceous. Upper surface intensively burrowed, crossbedding in long wedges, cross-laminated within wedges. Ophiomorpha, Cylindrichnus, Arenicolites. Top 1.5 ft is mottled, burrowed, intricate low-angle cross-laminated, with some troughs	8
Interbedded sandstone and dark-grey, carbonaceous, shaly siltstone. Sandstone part of covered interval elsewhere. Burrows abundant, cross-laminated and crossbedded in wedges, thin sets, low angle	13
Sandstone, light-yellow-orange, very fine- to fine-grained, calcareous, carbonaceous, thin-bedded, honeycomb weathering, alternating blocky and thinly laminated	21

	Feet
Sandstone, light-yellow-grey, very fine-grained, carbonaceous, with *Ophiomorpha*, *Teichichnus*, *Cylindrichnus*, *Arenicolites*	39
Covered--dark-grey to black, carbonaceous, siltstone, shaly, coaly at top and bottom	24
Sandstone, light-yellow-grey, very fine-grained, thin beds, blocky and laminated, cross-laminae, *Ophiomorpha*, *Teichichnus*, *Cylindrichnus*, *Arenicolites* in upper, *Gyrochorte* on planes, moderate honeycomb weathering upper	30
Sandstone with *Ophiomorpha*, *Teichichnus*, *Arenicolites*, exposed upper; *Cylindrichnus*. Crossbedded, cross-laminated in wedge-shaped beds; siltstone, mottled, dark-grey. Base covered	45
Total section	711

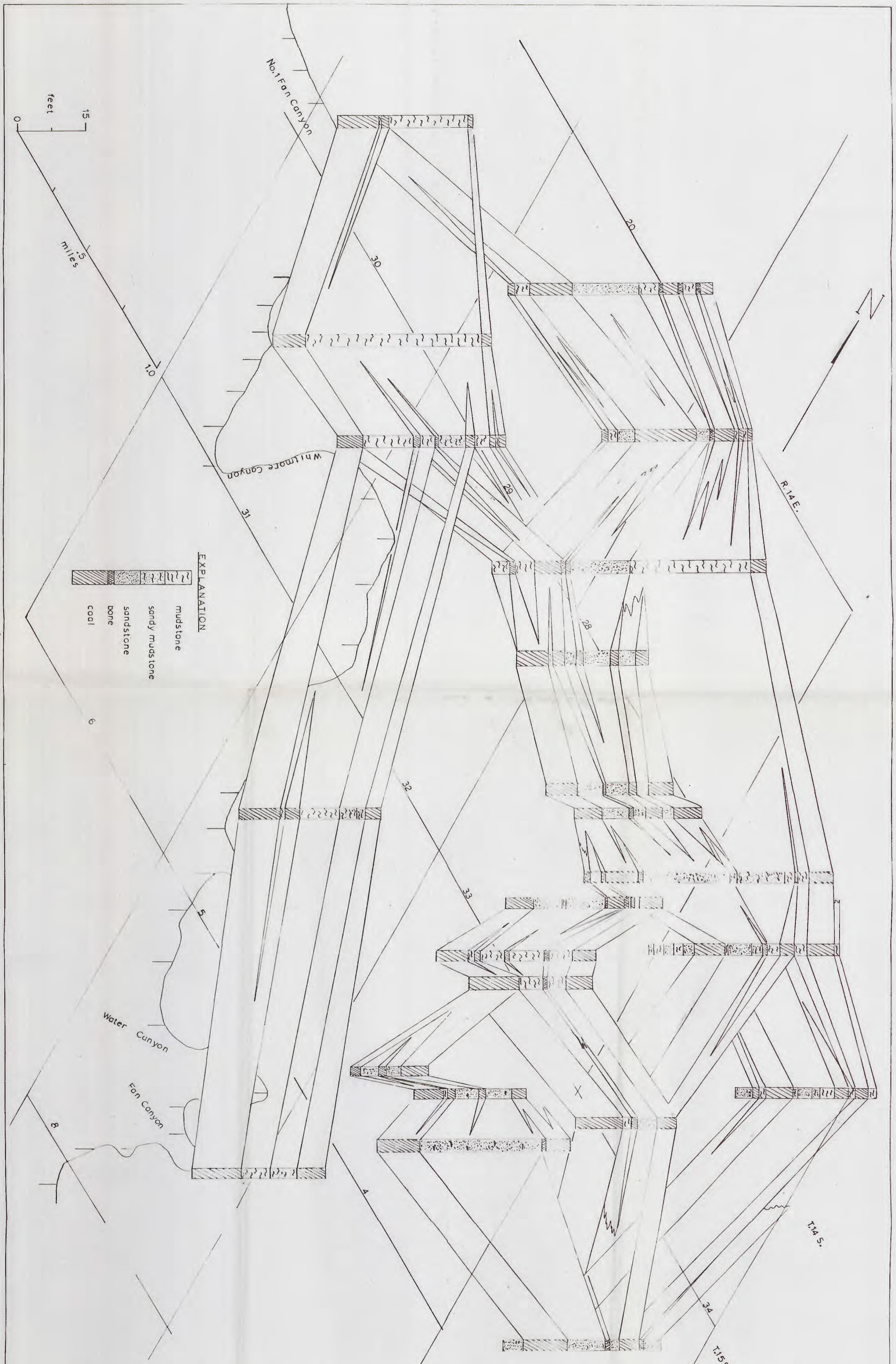

Figure 27. Isometric panel diagram, illustrating stratigraphic relationships of the Sunnyside coal bed.
(modified from Brodsky, 1960)

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GEOLOGY OF THE BLACKHAWK FORMATION AT SUNNYSIDE, UTAH

by
JOHN O. MABERRY
1968

68-170

Explanation

HOLOCENE
a/c/g — alluvium, colluvium, gravel

K-T — Cretaceous and Tertiary

CRETACEOUS — Mesaverde Group

Kc — Castlegate Formation

Blackhawk Formation — Sunnyside Member

Kbsu — Sunnyside Shale

Kbss — Sunnyside Sandstone

Blackhawk Formation — Kenilworth Member

Kbku — Kenilworth Shale

Kbks — Kenilworth Sandstone

Km — Mancos Shale

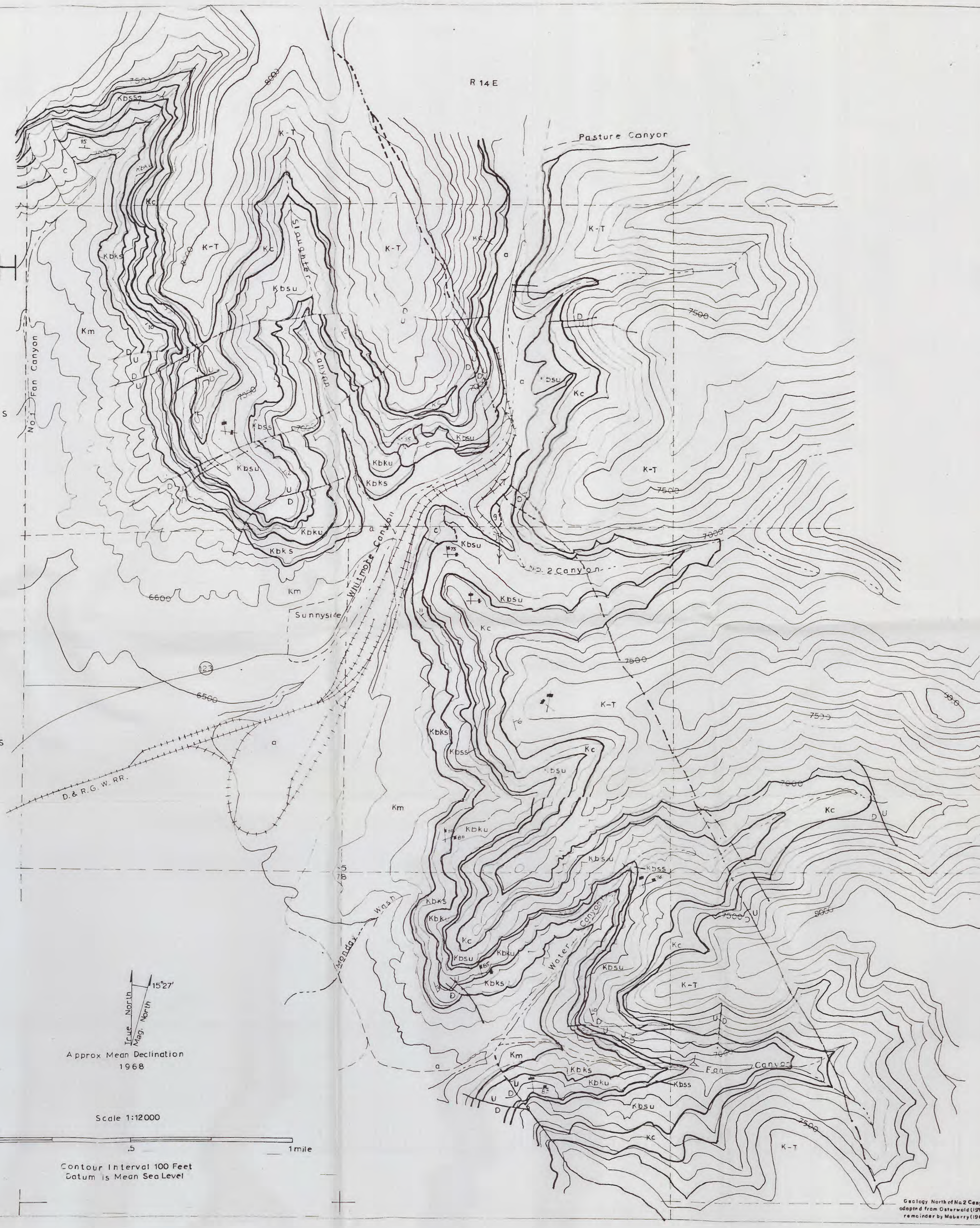
Faults
dashed where approximately located

Coal Mine Portal

Strike and dip of beds

Strike and dip of joints

Contact



Topography North of No. 2 Canyon adapted from Osterwald (1962), remainder adapted from U.S. Geological Survey Sunnyside Quadrangle (1918)

Geology North of No. 2 Canyon adapted from Osterwald (1962) remainder by Maberry (1967)

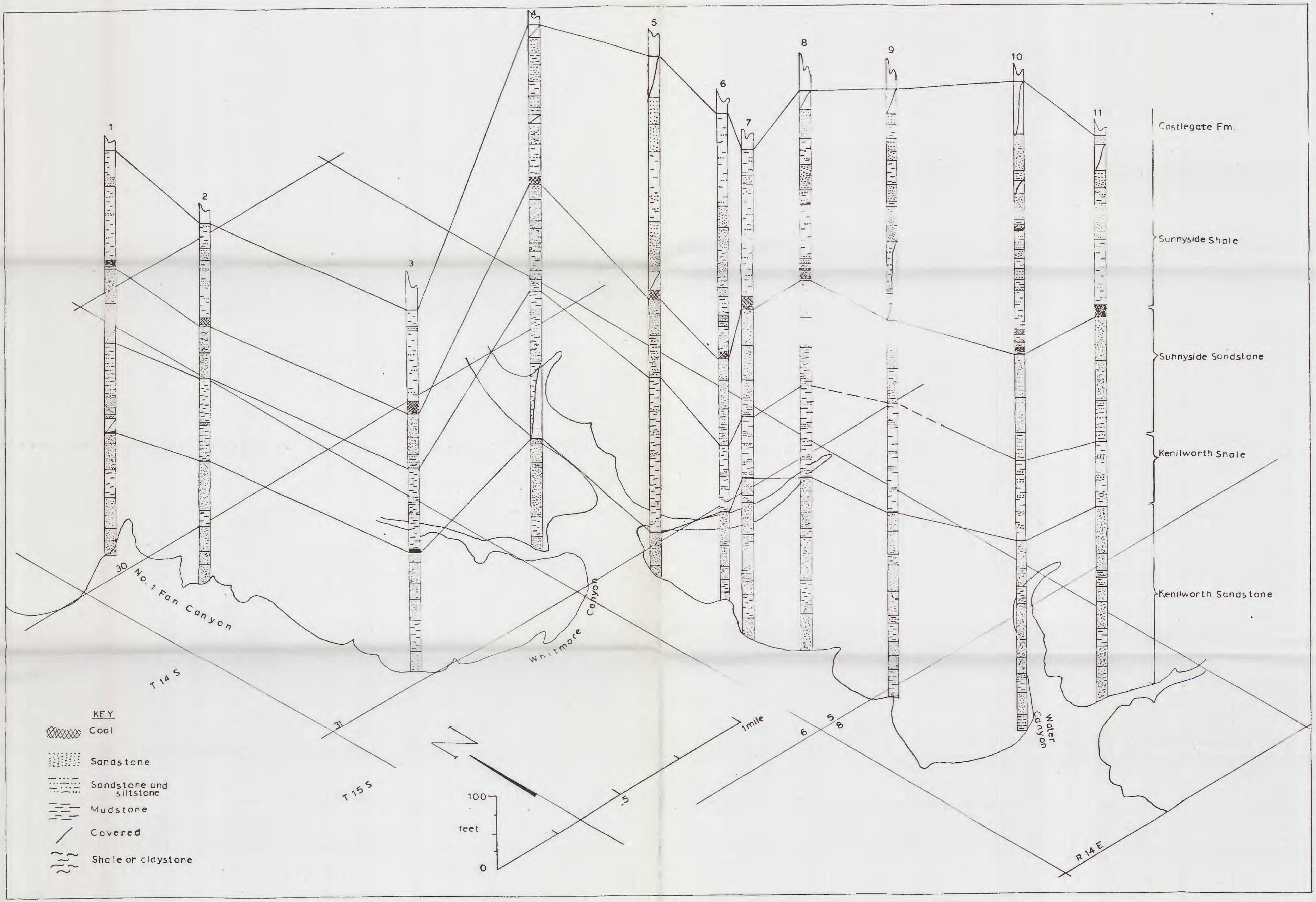


Plate 2. Correlation of measured stratigraphic sections of the Blackhawk Formation at Sunnyside, Utah, illustrating facies relationships.

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