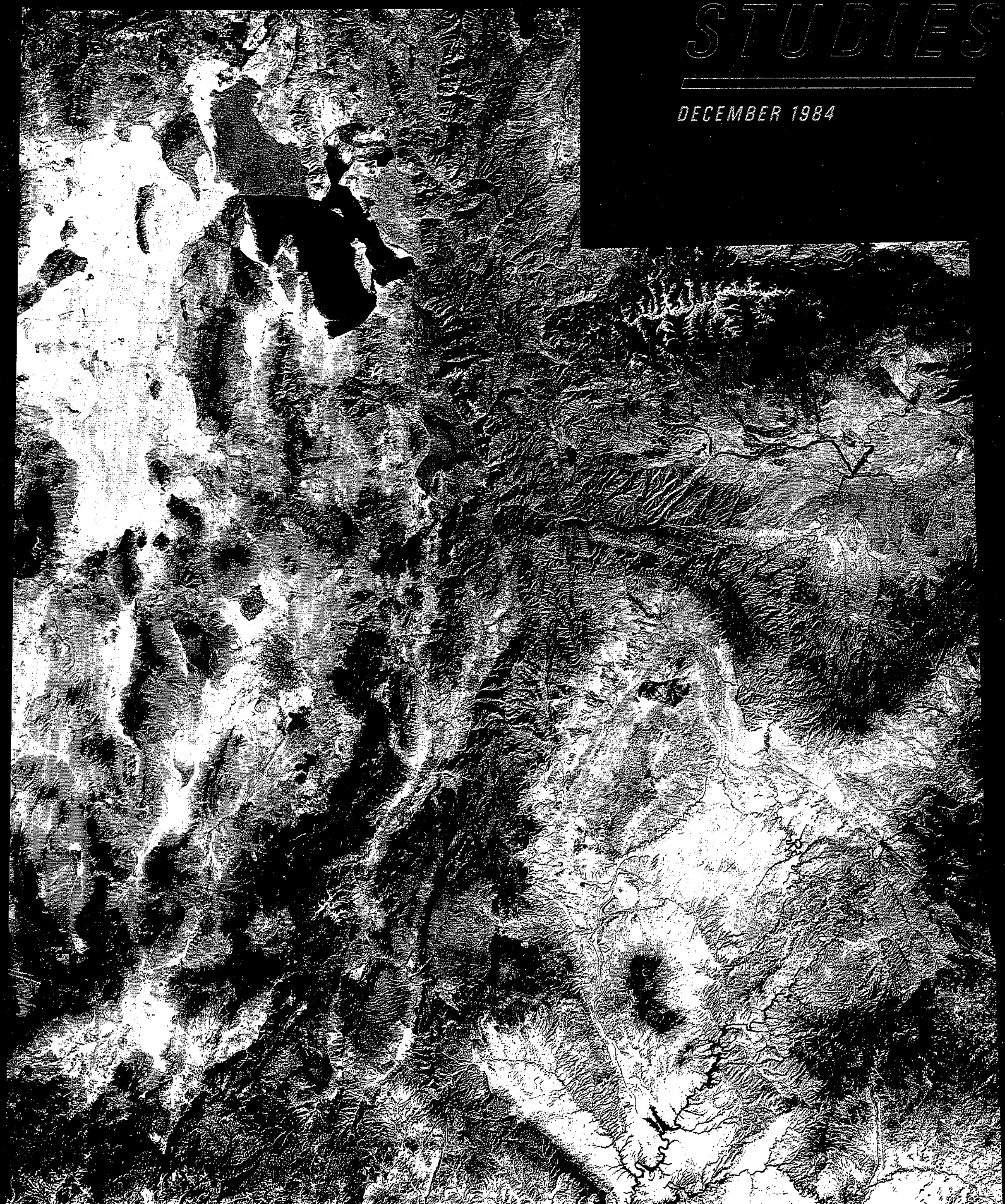
BRIGHAM
YOUNG
UNIVERSITY

GEOLOGY

STUDIES

DECEMBER 1984



VOLUME 31, PART 1

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

VOLUME 31, PART 1

CONTENTS

A publication of the
Department of Geology
Brigham Young University
Provo, Utah 84602

Brigham Young University Geology Studies is published by the Department of Geology. This publication consists of graduate student and faculty research within the department as well as papers submitted by outside contributors. Each article submitted by BYU faculty and outside contributors is externally reviewed by at least two qualified persons.

Cover: LANDSAT Mosaic of the State of Utah. Fall 1976. U.S. Department of Agriculture, Agricultural Stabilization and Conservation Service. Salt Lake City, Utah: Aerial Photography Field Office.

ISSN 0068-1016
Distributed December 1984
12-84 600 74358

CONTENTS

Figures

Depositional Environment of the Iron Springs Formation, Gunlock, Utah*

BRAD T JOHNSON
Utah Department of Health, Salt Lake City, Utah 84103

Thesis chairman: JAMES L. BAER

ABSTRACT

The Cretaceous Iron Springs Formation near Gunlock is a sequence of clastic rocks, approximately 950 m thick, exposed in extreme southwest Utah. These strata were deposited in the foreland basin of an arc-trench system near the shore of an interior Cretaceous sea. Sediments of the Iron Springs were derived from uplifted Paleozoic and Mesozoic rocks and consist of five facies which represent deposition in the various subenvironments of a braided fluvial system. The identified facies include (1) conglomerate, deposited in the bottom of stream channels; (2) sandstone, deposited in channel bars and as channel fill; (3) silty shale, deposited near the margins of the stream channels; (4) shale, deposited in topographically low areas of the floodplains; and (5) red siltstone, deposited in abandoned channels of the floodplains. The Dakota conglomerate constitutes the basal unit of the Cretaceous strata near Gunlock and probably represents a separate event in the history of Cretaceous sedimentation in the Gunlock area.

INTRODUCTION

GENERAL STATEMENT

The westernmost outcrops of Cretaceous strata in the western interior of the United States occur in extreme southwest Utah and are the last exposures of Cretaceous rocks before those in California, 600 km to the west. These exposures are at the western margin of the transition zone between the High Plateaus and the Basin and Range Provinces.

The section of strata in southwestern Utah is approximately 1,100 m thick and consists of interbedded shale, siltstone, sandstone, and conglomerate which dip approximately 25° to the northwest. These strata were deposited in the foreland basin of an arc-trench system near the shoreline of a Cretaceous sea.

The majority of the beds are friable and weather to form a series of low-lying hills, ledges, and gullies. Color of the formation is quite variable, ranging from medium gray to moderate reddish brown, but most beds are yellowish brown.

LOCATION

The area covered in this report is located in the extreme southwest corner of Utah near the town of Gunlock (fig. 1). The rock exposures cover an area of approximately 55 km^2 and are bounded on the east by the Gunlock fault and on the west by the Square Top Mountain thrust fault.

The area can be reached by going northwest from St. George about 15 km on U.S. 91 to Santa Clara Valley. Approximately 3 km up the Santa Clara Valley the road forks. The north fork follows the Santa Clara River to the town of Gunlock, about 12 km away. From Gunlock all access to the study area is by dirt road. The majority of the roads are graded and easily passable, but some remote areas can be reached only on foot or by four-wheel-drive vehicle.

Figure 2 is a detailed map of the study area, showing the locations of measured sections. These locations were chosen on the basis of optimum outcrop as shown on aerial photographs and the geologic maps prepared by McCarthy (1959) and Wiley (1963). The studied section

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

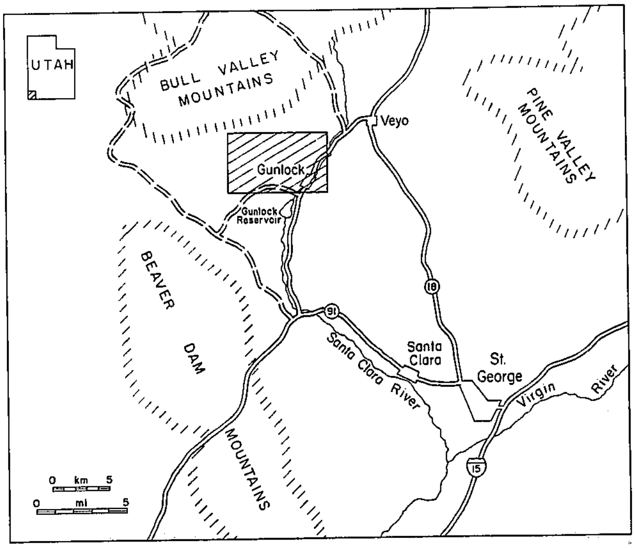


FIGURE 1.—*Index map showing the location of the Gunlock area.*

includes all the strata from the Cretaceous–Jurassic erosional contact to the base of the conglomeratic Claron Formation (Grapevine Wash Formation of Wiley 1963).

Good outcrops occur in the eastern third of the area whereas vegetation covers much of the rock in the western third. In the central third, complex geology, poor exposures, and vegetation prevented accurate measurement; therefore, this portion of the area was not measured in detail. It was, however, examined to determine the sedimentary features of the strata.

PREVIOUS WORK

Several publications cover the general stratigraphic relationships of southwestern Utah. These include Bissell (1952, 1954), Burger (1963), Cobban and Reeside (1952), Van deGraff (1963), and Warner (1949). However, there are no specific, detailed references to the Gunlock area.

In the Iron Springs mining district, approximately 45 km northeast of Gunlock, Leith and Harder (1908) identified the Cretaceous Pinto Sandstone as part of a study of the iron ores in the region. Mackin (1947), in a structural study of the same area, reevaluated and suggested changes in the nomenclature of Leith and Harder. Mackin redefined the Cretaceous–Jurassic boundary, and proposed the name Iron Springs Formation for the Cretaceous strata.

Gregory (1931, 1949, 1950a, 1950b, 1951) published many major papers on the geology of southwestern Utah. Gregory has published studies of the Kaiparowits region (1931), the Markagunt Plateau (1949), Zion Park region (1950a), eastern Iron County (1950b), and the Paunsaugunt region (1951) and is responsible for proposing much of the nomenclature of the Cretaceous strata in southern Utah. Although Gregory's work is invaluable in terms of defining formations and correlation, it is well to the east of the Gunlock area, and he makes only cursory reference to Gunlock strata.

Cook (1957) did a study of the Pine Valley Mountains, which lie approximately 10 km northeast of the town of Gunlock. His research was primarily concerned with the laccolith which makes up the Pine Valley Mountains, but he also mapped the sedimentary rocks at the southern end of the range. Although the Cretaceous outcrops between the Pine Valley Mountains and the Gunlock area are partially obscured by Tertiary volcanics, the exposures are easily correlated.

Reeside and Bassler (1921), Cook (1957), McCarthy (1959), Reber (1951), and Wiley (1963) published stratigraphic sections and descriptions of the strata near Gunlock, but they do not include any detailed work concerning the environment of deposition. Cook (1957, 1960), McCarthy (1959), and Wiley (1963) also published geologic maps which cover the Gunlock area.

A more comprehensive study of the Cretaceous rocks of southwest Utah was conducted by Moir (1974). Moir's work was concentrated in the Cedar City area, where he recognized fluvial, lagoonal–paludal, littoral, and offshore marine deposits. He then correlated his data with the strata to the east and west, constructing generalized cross sections of the entire region, but again there is only cursory mention of strata in the Gunlock area.

METHODS

A Jacob's staff was used to measure six stratigraphic sections near Gunlock. Aerial photographs, geologic maps, and visual inspection were used to determine the optimum locations for measuring. During the measurement, detailed notes covering the various characteristics (lithology, sedimentary structures, topographic expression, etc.) of the strata were recorded (the Geologic Society of America rock color chart was used to determine the colors of the strata). In addition, representative samples were collected.

Laboratory analysis of the samples included thin-sectioning, sieving, and point counts. Thin sections were analyzed microscopically for grain composition and grain-to-grain relationships. Sieving was accomplished by disaggregating the samples in water, drying the sediment, and ro-tapping 150 grams of sediment for 10 minutes. Sieves consisted of a series of 12 U.S. standard sieves ranging from 8- to 250-mesh. Point counts involved isolating 100 grains in each disaggregated sample or thin section and determining the number of quartz, feldspar, and lithic fragment grains.

ACKNOWLEDGMENTS

I wish to express my thanks and appreciation to Dr. James L. Baer for acting as thesis chairman and providing helpful suggestions on fieldwork and the manuscript, in addition to securing financial support. I am also indebted to Dr. W. K. Hamblin and Dr. H. J. Bissell for critical review of the manuscript and also for providing helpful comments. I would also like to thank Gulf Oil Company for providing financial support for the thesis. Finally, I would like to acknowledge my family and friends, who continually provide support and encouragement.

GEOLOGIC SETTING

NOMENCLATURE

The strata covered in this report have been mapped as Cretaceous undifferentiated (Cook 1957, 1960) and Iron Springs Formation (Wiley 1963, McCarthy 1959). The name *Cretaceous undifferentiated* is a valid title in that there are no identifiable horizons that would separate the rocks into mappable formations. However, this designation is too general to be of any value in correlation.

Van deGraff (1963) suggested that the Iron Springs Formation be identified as a sequence of conglomerate, sandstone, shale, and freshwater limestone. With the exception of the limestone, which is a minor member of Mackin's (1947) Iron Springs, this description fits the studied formation very well. Therefore the name *Iron Springs Formation* will be applied to the strata studied in this report.

AGE

The exact age of the Iron Springs Formation in the Gunlock area is impossible to establish because there are

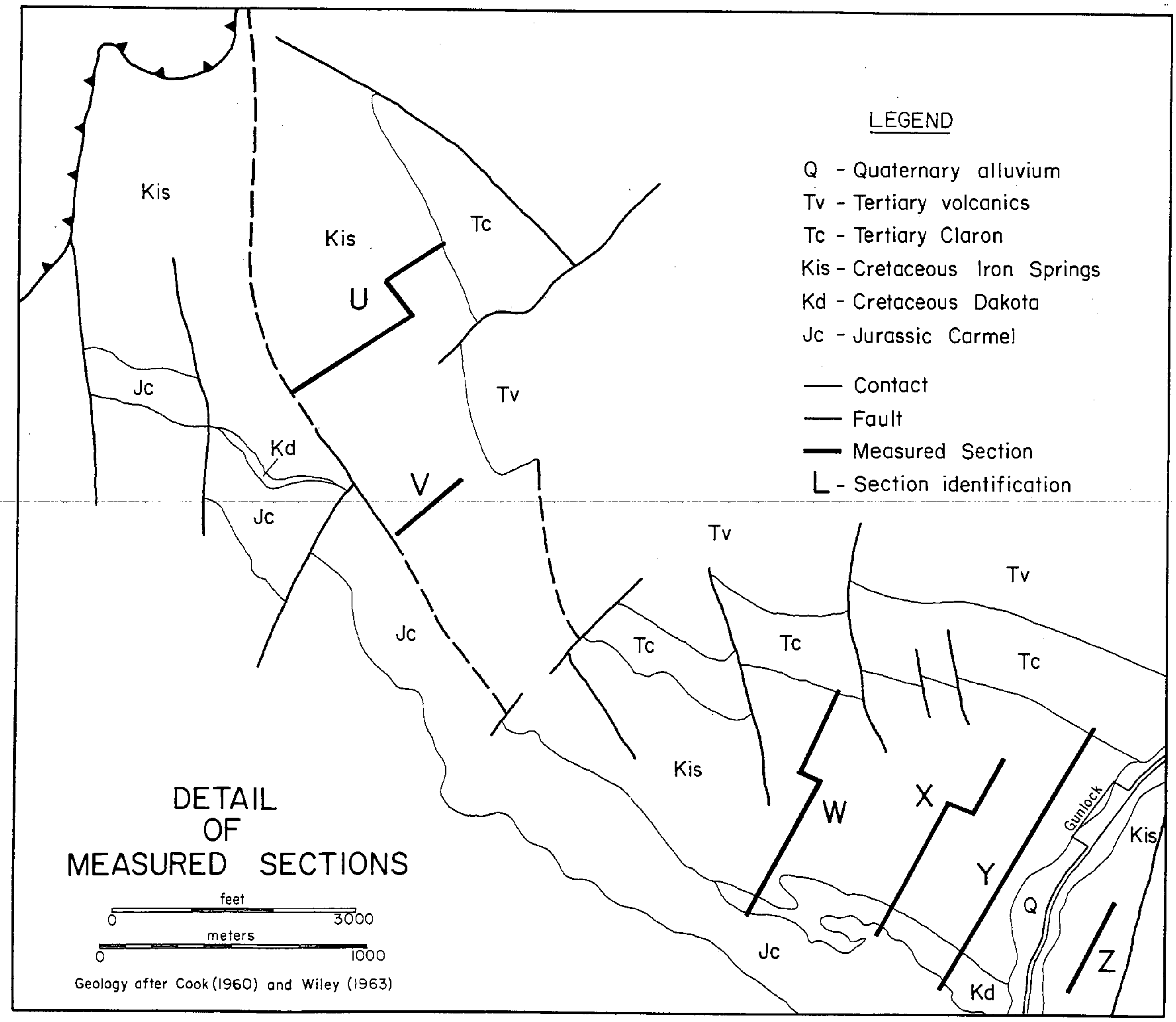


FIGURE 2.—*Geologic map showing the locations of measured sections.*

no diagnostic fossils. However, on the southeast side of the Pine Valley Mountains, part of the stratigraphic section consists of, from oldest to youngest, Tropic Formation (235 m), Straight Cliffs and Wahweap undivided (550 m), and Kaiparowits Formation (365 m). The Iron Springs near Gunlock is stratigraphically equivalent to these formations.

The Tropic Shale contains fossils of Colorado age in the Pine Valley Mountains (Cook 1957), but to the west it thins rapidly and is absent in the Gunlock area. Richardson (1927) found fossils of Montana age in the Kaiparowits Formation on the plateaus near Cedar City, but no fossils have been reported in the Kaiparowits of the Pine Valley Mountains or in the Iron Springs Formation. Therefore, the Iron Springs is probably of Colorado and Montana age (Cobban and Reeside 1952), but this is not absolutely certain due to the lack of diagnostic fossils in Iron Springs strata.

PALEOGEOGRAPHY

The tectonic setting in western North America during the Late Cretaceous consisted of an Andean-type arc-trench system (Burchfield and Davis 1972, Dickinson 1975) located between 30 and 60° north latitude (Dott and Batten 1976). Dott and Batten believe that the climate was warm and humid in this region during this time interval. Figure 3 illustrates the general boundaries of the subduction complex, orogenic highland, and foreland basin. The Gunlock area was located in the foreland basin, in close proximity to the orogenic highland.

In the foreland basin, thick sequences of marine and terrestrial sediments were deposited. During early Colorado time a sea rapidly advanced into the basin from the east (Spieker and Reeside 1926) and exerted a strong influence on sedimentation patterns of the basin. Many shale and sandstone units were deposited in the marine environment of this sea. The sea began to retreat in late Colorado time, and by the end of Montana time the region was again subaerial.

Stokes and Heylmun (1963) suggested that a topographic low existed in the area between the Mesocordilleran highland and the Mogollon Rim during Cretaceous time and termed it the Grand Canyon Bight (fig. 4). The presence of the Grand Canyon Bight prevented influx of sediment from the Mogollon Rim into the Gunlock area and also caused the arcuate form of the Cretaceous shoreline.

GEOLOGIC HISTORY

Five major events can be recognized in the history of the Cretaceous strata near Gunlock. These include (1) a period of erosion before deposition of Cretaceous rocks, (2) deposition of Cretaceous rocks, (3) the Sevier orogeny, (4) deformation due to the Laramide orogeny, and (5) basin-and-range block faulting.

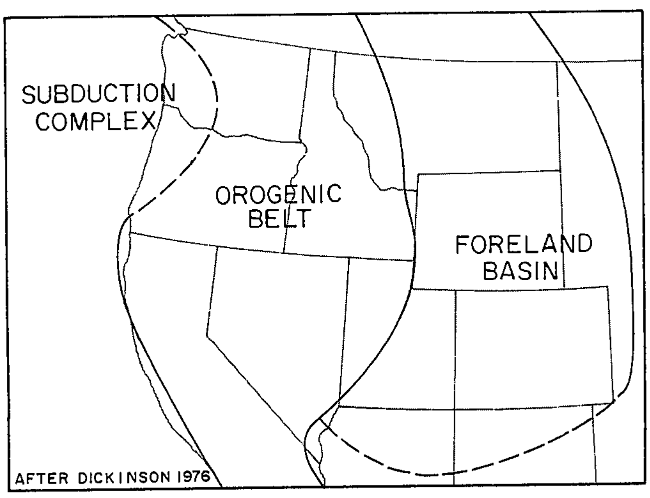


FIGURE 3.—*Tectonic setting of western North America during Cretaceous time.*

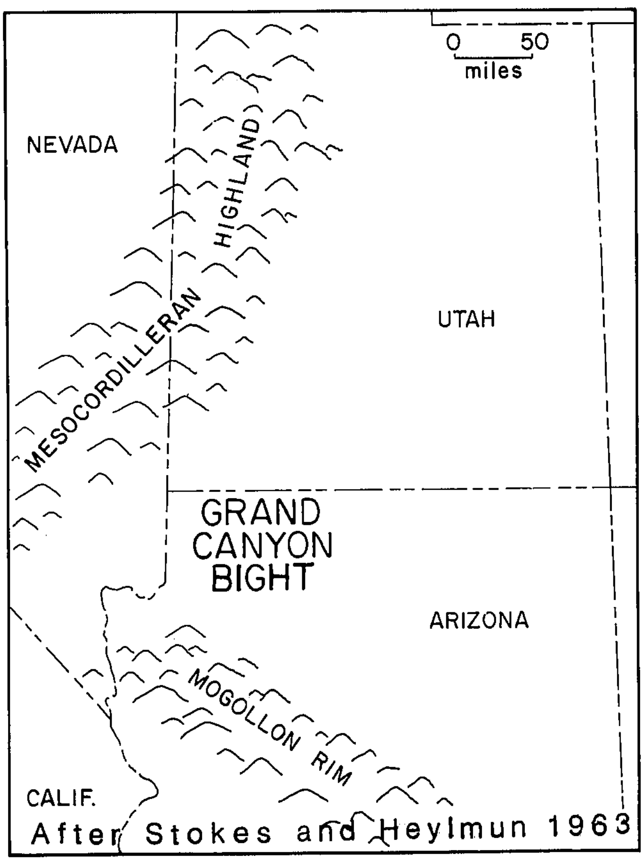


FIGURE 4.—*Detailed illustration of the tectonic setting of southwest Utah during Cretaceous time.*

A disconformable relationship exists between the underlying Jurassic Carmel Formation and the Dakota conglomerate of the overlying Cretaceous strata (Wiley 1963). This boundary is marked by an abrupt change in lithology from a silty marine shale to a coarse conglomerate. The age difference between the Late Jurassic Carmel and the Cretaceous Dakota also reflects a long period of erosion.

After the erosional interval, deposition of Cretaceous rocks occurred. In the foreland basin a complex Late Cretaceous sequence of marine and terrestrial rocks was deposited throughout eastern Utah. The Iron Springs Formation and the Dakota conglomerate represent two of the many units deposited in this basin.

The Sevier orogeny began in latest Jurassic time and continued throughout the Cretaceous (Armstrong 1967). The positive element of the Sevier orogeny was termed the Sevier arch by Harris (1959) but is referred to as the Mesocordilleran highland by Stokes and Heylmun (1963). According to Harris, the Sevier arch extended from west central Utah into southeast Nevada and was characterized by uplift and thrusting of Paleozoic and Mesozoic strata. The Cretaceous sandstones of southern Utah probably consist of reworked sandstone eroded from the Sevier arch (Harris 1959).

The Laramide orogeny began in the Late Cretaceous and exerted a strong influence on the geology of western North America until the end of the Eocene epoch (Eardley 1962). The western boundary of the study area is marked by a Laramide thrust plate called the Jackson Mountain thrust by Wiley (1963). According to Wiley (1963), the Jackson Mountain thrust moved eastward, eventually overriding its own erosional debris. Wiley believes that the conglomeratic Grapevine Wash Formation (Claron Formation of Cook 1960), which overlies the Iron Springs Formation, represents debris shed from the thrust plate. Therefore, the contact between the underlying Iron Springs and overlying Grapevine Wash would be gradational, passing from sandstone and siltstone into coarse conglomerate. However, most researchers in the surrounding region (Cook 1957, Mackin 1947) have identified a disconformable relationship between the Cretaceous sandstones and the overlying conglomerates.

Basin-and-range faulting was the last event to affect the Cretaceous rocks near Gunlock. The Iron Springs Formation, in the study area, is on the Beaver Dam Mountains fault block, which is bounded on the east by the Gunlock, Shebit, and Cedar Pocket Canyon faults, and on the west by the Beaver Dam Wash fault (Dobbin 1939). Basin-and-range faulting resulted in significant dissection of the Cretaceous formations on a regional scale, but correlation based on stratigraphic position and lithology is still easily accomplished.

STRATIGRAPHY

Cretaceous strata in the Gunlock area contain five basic facies, including sandstone, shale, conglomerate, silty shale, and red siltstone. The generalized stratigraphic column illustrated in figure 5 depicts the complex facies relationships of these strata. The remainder of this section presents a detailed description of the characteristics of each of these facies and a discussion of the provenance.

SANDSTONE FACIES

Sandstone constitutes approximately 65% of the rock volume in the area and was classified on the basis of the constituent grains, according to the system of McBride (1963). All sandstone samples fell into the quartzarenite and sublitharenite categories of this classification scheme. Because of the high percentage of monocrystalline quartz, the majority of the samples were classified as quartzarenites.

Sedimentary structures in the sandstone facies are illustrated in figures 6–8 and include horizontal bedding, deformed bedding, and cross-bedding. However, approximately 35% of the sandstone is massive, showing no indication of sedimentary structures. Massive units occur in beds 0.5 to 3 m thick and up to 150 m long and commonly form slopes with patches of outcrop.

Exposures of horizontally bedded sandstones are 75 to 200 cm thick and extend laterally for tens of meters (fig. 6). Individual layers are 0.5 to 2.0 cm thick and are continuous throughout the unit. Contacts with adjacent facies are usually sharp; however, some gradational contacts do occur.

A common deformation feature is illustrated in figure 7. The vertical extent of deformation varies from 20 to 50 cm and always occurs in parallel bedded sandstone.

Cross stratification (fig. 8) occurs in units that are 0.5 to 2.5 m thick and extend laterally up to 150 m before grading into massive sandstone or undergoing a facies change. Contacts with under- and overlying units are usually sharp. However, the upper contact sometimes grades into a massive or horizontally bedded sandstone, and lower contacts sometimes grade into an underlying conglomerate. Cross stratification ranges from 10 to 40 cm in thickness and the foreset laminae are inclined at an angle of 15° to 25°.

Representative samples of each bedding type were disaggregated and sieved to determine if a relationship exists between bedding type and grain-size distribution. Sieve analysis of the samples (appendix A) revealed size distribution curves ranging from fines (clay size) to 0.83 mm (coarse sand size). Size distribution of the sand units in the area is consistent, and the dominant size is usually in the 0.15 to 0.21 mm range; therefore, there appears to be no correlation between bedding type and size distribution. In addition, the fine fraction of the sieve analysis constitutes 0 to 9% of the total sample weight, but it too bears no apparent correlation to bedding type. However, there are two notable features of the sieve analysis. First, the cross-bedded units will occasionally contain a higher percentage of coarse constituents; and, second, there is an obvious shortage of grains in the 0.05-to-0.07-mm-diameter range.

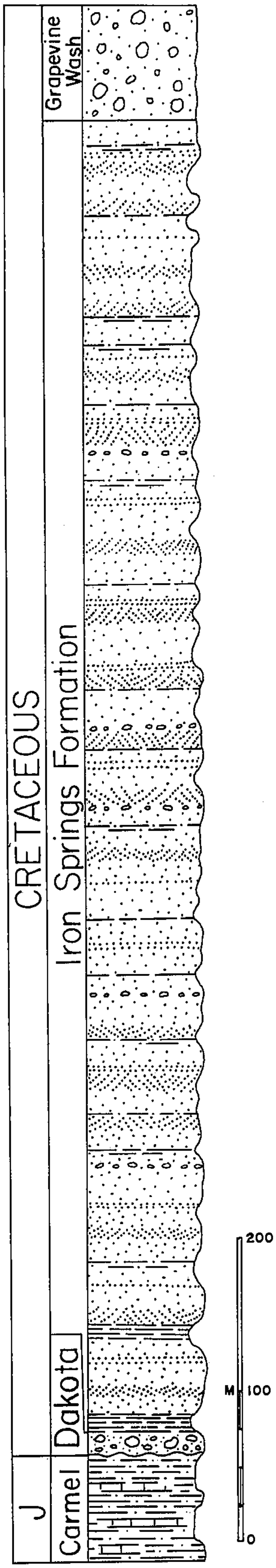


FIGURE 5.—*Generalized stratigraphic column of the Iron Springs Formation.*

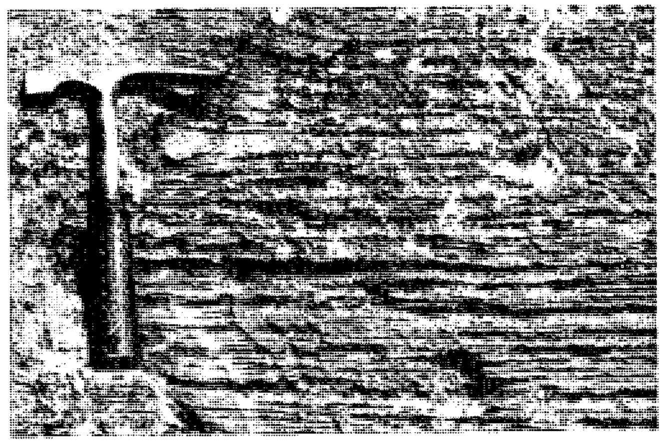


FIGURE 6.—*Laminated sandstone in the sandstone facies.*

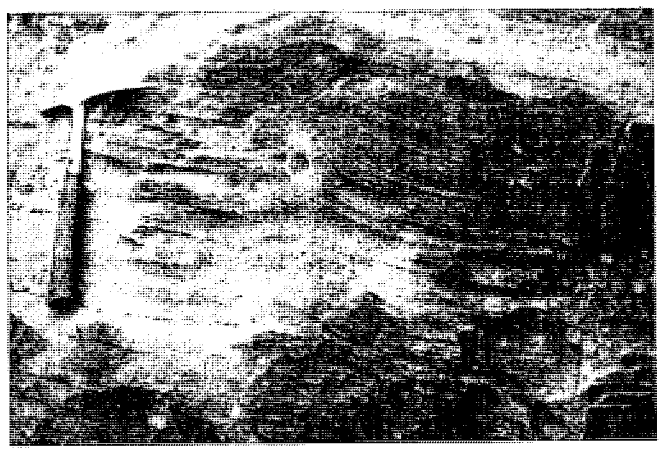


FIGURE 7.—*Deformation feature in the sandstone facies.*

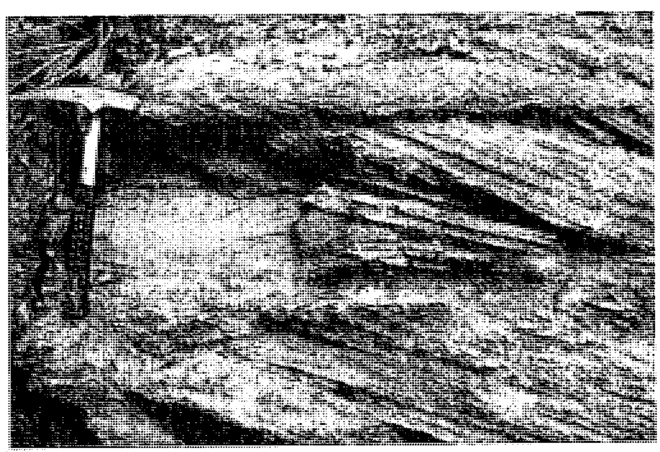


FIGURE 8.—*Cross-bedding in the sandstone facies.*

Figure 9 is a typical histogram of the samples collected from the Iron Springs Formation.

Analysis of sorting is based on Folk's (1966) criteria. The majority of the samples fall in the moderately well sorted category of Folk's classification although some samples are well sorted. Additional characteristics of the grains include high sphericity and rounding ranging from subangular to rounded, the majority being subrounded and rounded.

Variation in cementation of the sandstone results in variable topographic expression. Some of the sandstone units are very friable and form moderate slopes and valleys, and others are moderately well cemented and form ridges or ledges 1 to 2 m high. Cementation is apparently random, giving no preference to any single bedding type. However, there is an increase in the number of poorly cemented sandstones in the upper 300 m of the section.

Color of the sandstone varies from bluish white to yellowish brown, but the majority of the outcrops are yellowish brown, and the bluish white outcrops are absent in the upper 50 m of the section.

SHALE FACIES

Shale comprises approximately 10% of the total volume of the Iron Springs Formation in the study area and forms slopes and recesses among the sandstone outcrops. The shale is commonly somewhat silty and occurs in lenses 10 to 50 cm thick and 15 to 50 m long, that are usually in sharp contact with under- and overlying units.

Two prominent gullies occur in the lower 150 m of the section (each approximately 30 m thick) in the southeast corner of the study area. Examination of roadcuts at the east margin of the study area indicates that these gullies are a result of interbedded sandstone and shale. These shale breaks pinch out to the west, are absent at the western margin of the study area, and are cut off by the Gunlock fault to the east. Cook (1957) measured the Cretaceous in Diamond Valley of the Pine Valley Mountains and did not mention any shale breaks in the lower part of the Diamond Valley section. Therefore, it is assumed that the shale breaks are a local feature. Throughout the remainder of the study area the shale is irregularly distributed, and thick shale breaks are absent.

Weathering characteristics of the shale result in rare exposures of rock; therefore, descriptions of bedding and sedimentary structures are based on a limited number of outcrops. In the outcrops examined, the shale was usually in sharp contact with an overlying conglomerate or cross-bedded sandstone. The only bedding characteristic visible is the load structure illustrated in figure 10. Distortion of bedding in the overlying sandstone indicates that this deformation was probably caused by sinking of the sandstone into the shale.

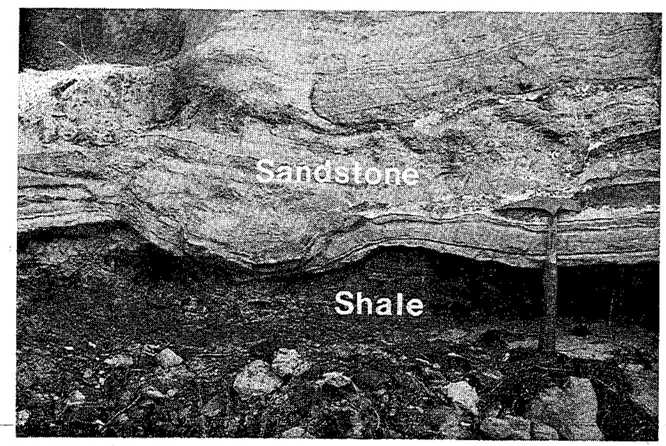


FIGURE 10.—*Shale facies with an overlying sandstone unit.*

In the strike valleys near the bottom of the section, the shale is medium gray. Higher in the section the color ranges from grayish red purple to light pinkish gray to medium gray to grayish green.

Gulf laboratories of Houston, Texas, performed pyrolysis tests on ten shale samples which were collected at various localities in the study area. The tests yielded minimal hydrocarbons, and the absence of a temperature factor indicates a very immature shale. The test results are presented in appendix B.

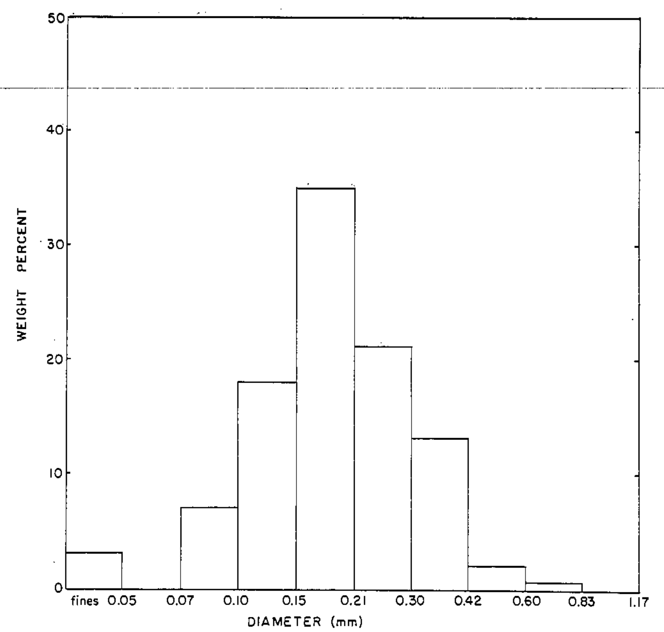


FIGURE 9.—*Histogram of a typical sand sample from the Iron Springs Formation.*

CONGLOMERATE FACIES

Conglomerate beds in the Gunlock area constitute approximately 5% of the total rock volume. Constituent clasts include sandstone (20%–60%), quartzite (20%–40%), chert (10%–20%), and limestone (0%–20%) in a sand matrix. The majority of the clasts are subrounded and have low sphericity, with a long dimension ranging from 0.3 to 10 cm. The matrix material is identical in character to the sandstone facies, and constitutes 25%–75% of the total rock volume.

The conglomerate is usually interbedded with sandstone, and the contact between the two facies is either sharp or gradational (fig. 11). Usually, the lower contact is very sharp, whereas the upper contact can be sharp, or it can rapidly grade into a cross-bedded sandstone. Cross-beds up to 30 cm thick are common in the conglomerates that have a high percentage of matrix material, but those with a low percentage of matrix material are massive.

Conglomerate units range in thickness from 20 to 150 cm and commonly occur as channels in the underlying sandstone. Unfortunately, incomplete exposures prevent precise determination of their lateral extent. The most complete exposure located is approximately 30 m long but obviously extends beyond this limit.

RED SILTSTONE FACIES

Red siltstone units stand out in prominent contrast to the typical yellowish brown sandstone of the area (fig. 12). This rock type makes up about 10% of the total rock volume and weathers to form slopes with minor protruding ledges 25 to 50 cm thick. Bedding in the siltstone is not visible, with the exception of the small ledges.

Trace fossils were located in three of the siltstone ledges in the study area. These fossils are tubular, have a diameter of approximately 2 cm, and are 10 to 20 cm in length. Orientation relative to bedding is horizontal or vertical, and they are linear or slightly sinuous. Unfortunately, they are poorly preserved and consequently could not be identified.

Contacts between the siltstone and adjacent rocks are not exposed because of the weathering characteristics of the siltstone. It was therefore difficult to precisely establish the geometry of the siltstone units. However, it appears that the siltstone is in sharp vertical contact with adjacent units, varies from 1 to 10 m in thickness, and has a lateral extent of 50 to 150 m.

SILTY SHALE FACIES

The gradational contact between the sandstone and silty shale renders estimates of the volume very difficult. However, the silty shale probably occupies approximately 10% of the total volume of Cretaceous rocks in the area.

This rock type contains 20%–50% silt and sand-size quartz grains suspended in a mud matrix, which makes up the remaining 50%–80% of the rock. Color of the rock

FIGURE 11.—*Conglomerate facies.*

varies from light greenish gray to pale red, or pale yellowish orange. The pale yellowish orange units contain the highest percentage of silt. Lithic fragments are also present but are rare.

The silty shale weathers to form slopes and is invariably in sharp contact with an overlying cross-bedded or massive sandstone (fig. 13). The lower contact is normally gradational, fining upward from massive sandstone.

There are also a number of exposures in which the silty shale facies is interbedded with the sandstone facies as illustrated in figure 14. In these exposures the individual beds are 5 to 15 cm thick and extend laterally for tens of meters.

Wavy bedding is also a common feature of the silty shale facies, and consists of an irregular pattern of small-scale laminae as illustrated in figure 15. Wavy bedded horizons are usually about 75 cm thick and extend laterally up to as much as 50 m.

DAKOTA CONGLOMERATE

The basal unit of the Cretaceous strata is a massive conglomerate which ranges in thickness from 13 m at the east

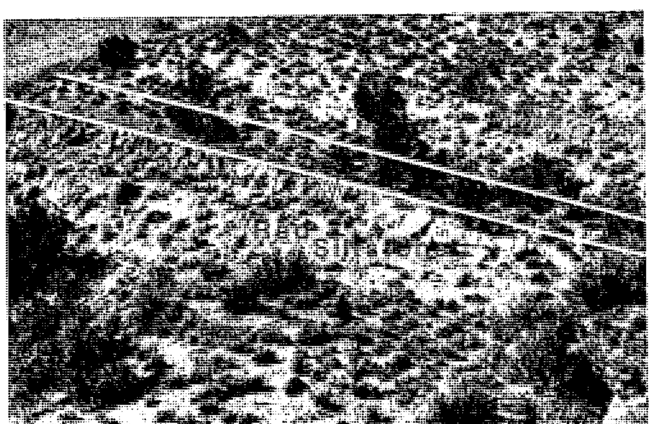


FIGURE 12.—*Red siltstone facies.*

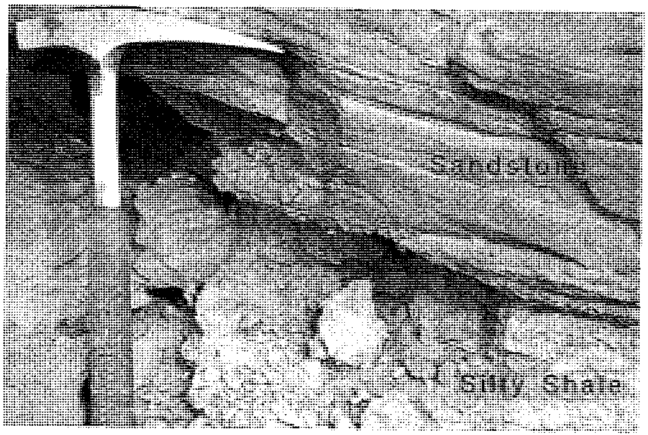


FIGURE 13.—*Silty shale facies.*

margin of the study area to 3 m at the west margin (fig. 16). This conglomerate was mapped as Dakota by McCarthy (1959) and Wiley (1963), and forms a prominent but discontinuous ridge over much of the area. In the central third of the study area the Dakota is missing, and the Iron Springs Formation is in fault or disconformable contact with Jurassic rocks.

Clasts in the conglomerate constitute approximately 70% of the total rock volume and include limestone (50%), quartzite (50%), and minor amounts of chert. Size of the clasts ranges from 1 to 25 cm in diameter, the majority being in the 4-to-10-cm category. Matrix material consists of calcareous sandstone and occupies the remaining 30% of the rock volume. Sandstone lenses up to 30 cm thick and 10 m long occur within the conglomerate but are rare, constituting only about 3% of the total unit.

The Dakota is in disconformable contact with the underlying Jurassic Carmel Formation, where an abrupt change in lithology from a marine siltstone to a coarse conglomerate reflects the erosional surface between the two formations. The contact between the Dakota and the overlying rock is not exposed on the eastern side of the study area; however, it appears that the overlying rocks consist of interbedded sandstone and shale. Near the western margin of the study area the Dakota is in direct, sharp contact with overlying sandstone.

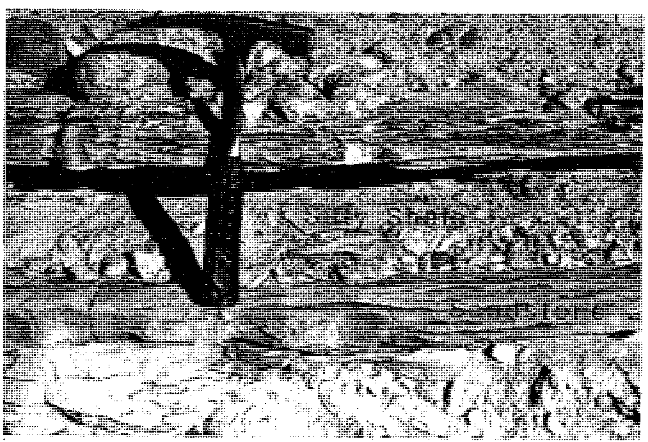


FIGURE 14.—*Interbedded silty shale and sandstone unit.*

At the type locality for the Iron Springs Formation (in the Iron Springs mining district 45 km northeast of Gunlock), Mackin (1947) described a basal conglomerate which grades into an overlying limestone. The basal conglomerate described by Mackin is very similar to the Dakota in the Gunlock area; however, in the Gunlock area the conglomerate is in sharp contact with shale or sandstone and is discontinuous. In addition, the characteristics of the Dakota and conglomerate facies are markedly different. This tends to indicate that the Dakota is a unique event in the sedimentation history of the Cretaceous strata near Gunlock.

MEASURED SECTIONS

Six stratigraphic sections were measured in the Iron Springs Formation near Gunlock. Section Y was described in detail, whereas the other sections were generally de-

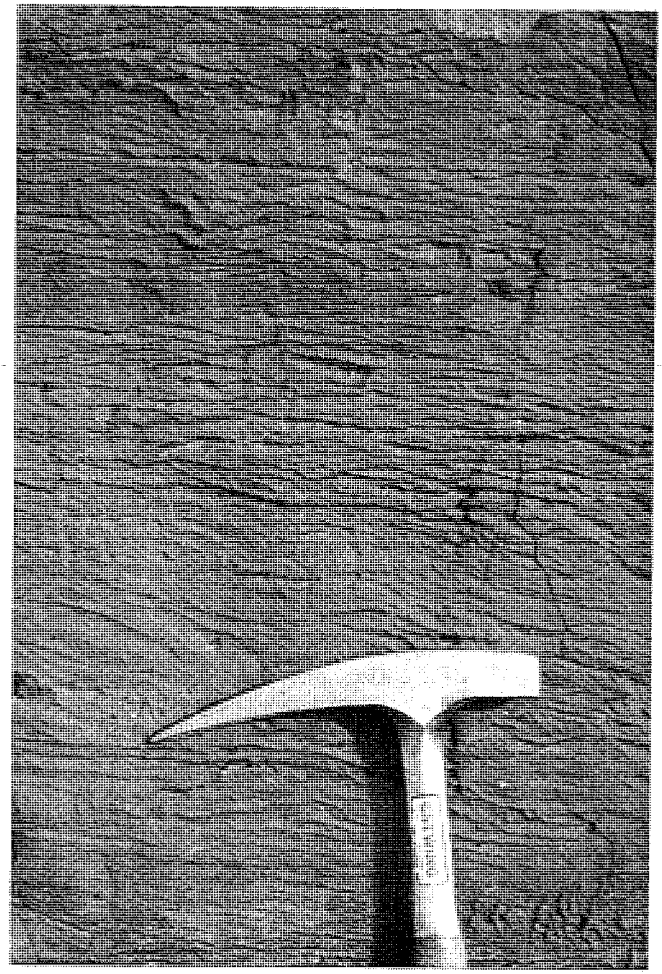


FIGURE 15.—*Wavy bedding in the silty shale facies.*

FIGURE 16.—*Dakota conglomerate at the eastern side of the study area.*

scribed; however, the best exposures of the upper fourth of the Iron Springs strata occur in section W. Overall, the strata are very complex throughout the Gunlock area. The sections were examined collectively to determine if lateral correlation was possible, but there are no laterally consistent horizons.

The following stratigraphic section represents the detailed measurement of units 8–10 of section Y and is typical of the strata throughout the Iron Springs Formation in the Gunlock area.

Unit	*Description*	*Thickness (meters)*
10	Conglomerate, massive, forms ledge, clasts consist of chert (10%), quartzite (40%), sandstone (30%), and limestone (20%) from 0.5 to 8.0 cm in diameter, contacts with under- and overlying sandstone are sharp.	1.5
9k	Sandstone, moderate yellowish brown, massive, forms ledge, sharp contacts, extends laterally approximately 50 m.	0.5
9j	Sandstone, moderate yellowish brown, massive, forms slopes with patches of outcrop, sharp contacts.	2.0
9i	Sandstone, moderate yellowish brown, cross-beds up to 25 cm thick, forms ledge, sharp vertical contacts, extends laterally approximately 100 m.	2.5
9h	Silty shale, grayish orange, forms recess below the overlying ledge.	0.5
9g	Sandstone, bluish white, massive, forms slope with patches of outcrop, sharp lower contact, gradational upper contact with silty shale.	3.0
9f	Sandstone, bluish white, horizontal bedding in units 1.5 cm thick, forms ledge, sharp vertical contacts, extends laterally approximately 125 m.	2.0
9e	Sandstone, moderate yellowish brown, massive, forms slope with patches of outcrop, grades into silty shale which is in sharp contact with overlying sandstone ledge.	2.5
9d	Sandstone, moderate yellowish brown, massive, forms ledge, sharp contacts, extends laterally approximately 50 m.	1.0
9c	Shale, moderate gray, forms slope.	0.25
9b	Sandstone, moderate yellowish brown, massive, forms slope with patches of outcrops, sharp vertical contacts.	3.0
9a	Sandstone, moderate yellowish brown, cross-beds up to 30 cm thick, forms ledge, sharp contacts with under- and overlying units, extends laterally approximately 70 m.	1.5
8	Siltstone, pale reddish brown, bedding indistinct, forms a slope with a 25-cm-thick ledge near the middle of the unit, vertical contacts with adjacent facies are apparently sharp.	2.5

Figure 17 is a diagrammatic representation of the preceding detailed section. All the various facies are demonstrated in this illustration, which shows the complexity of the Iron Springs Formation. The majority of the units are in sharp contact with over- and underlying strata, and the various bedding types are irregularly distributed throughout the area.

PROVENANCE

A general source for the Iron Springs sediment in the Gunlock area can be established by examining the tectonic history of the area and the character of the Cretaceous samples.

According to Dickinson (1975), the tectonic setting in the western United States during the Late Cretaceous consisted of an Andean-type arc-trench system (fig. 3). The orogenic highland to the west of the Gunlock area was a foreland thrust belt in which Paleozoic and early Mesozoic rocks were uplifted. These uplifted rocks were undoubtedly the source of the Iron Springs sediments.

Identifying the exact formations from which the Iron Springs Formation was derived is more tenuous. However, the sandstone units, which constitute most of the formation near Gunlock, consist of a very mature sand. Microscopic examination of 70 sandstone samples revealed that all samples contain approximately 95% monocrystalline quartz, 5% lithic fragments, and rare grains of feldspar and polycrystalline quartz. Using the roundness and sphericity scale described by Powers (1953), it was found that the grains have high sphericity and rounding ranges from subangular to rounded, the majority being in the rounded and subrounded categories. Therefore, it is very likely that the sediment in the Iron Springs consists of reworked sand grains.

Reeside and Bassler (1921) recorded approximately 2,800 m of late Paleozoic and early Mesozoic rocks underlying the Cretaceous in southwest Utah. These rocks consist primarily of shale and sandstone, with some minor limestone and conglomerate units, and were probably involved in the uplifting and thrusting to the west. Consequently, they are a very likely source for the sediment of the Iron Springs Formation.

In summary, the Cretaceous sediments near Gunlock are mature sandstones derived from uplifted Paleozoic

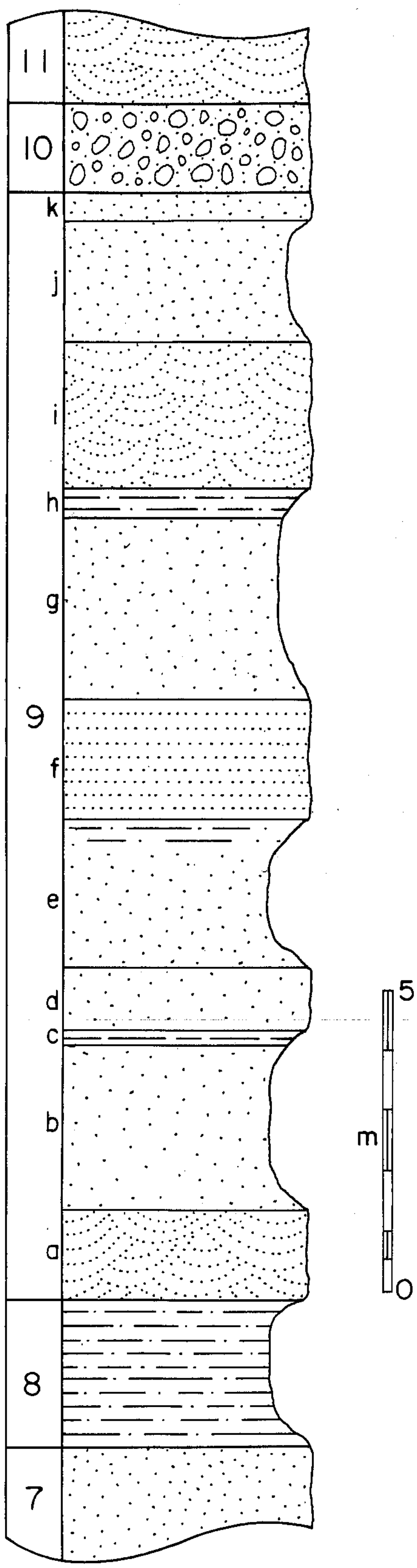


FIGURE 17.—*Detailed stratigraphic column of part of the Iron Springs Formation.*

and early Mesozoic rocks in the foreland fold thrust belt of the Mesocordilleran highland.

DEPOSITIONAL ENVIRONMENT

Reconstruction of the depositional environment involves evaluation of the physical, chemical, and biological characteristics preserved in the rocks (Gould 1972) and correlation of these characteristics with a modern analog. The five parameters most useful in establishing these characteristics are geometry, lithology, sedimentary structures, fossils, and paleocurrent (Shelly 1970).

Lithology, sedimentary structures, and bedding characteristics provide the primary data base for evaluating the depositional environment of the Iron Springs Formation. The stratigraphic column depicted in figure 17 illustrates a portion of measured section Y and demonstrates the complex facies relationships of the Iron Springs strata. Analysis of all measured sections reveals little change (vertically or laterally) in the characteristics and interrelationships of the various facies throughout the study area.

Lithologies in the Iron Springs Formation near Gunlock are exclusively clastic, ranging in texture from coarse conglomerate to shale. The total outcrop consists of approximately 5% conglomerate, 65% sandstone, 10% silty shale, 10% red siltstone, and 10% shale. Distribution of the various lithologies is complex, and the section is apparently void of any cyclic pattern.

Bedding characteristics of the Iron Springs strata consists of a complex pattern of thick to very thick bedded rock bodies ranging from 0.5 to 3.0 m in thickness. Unfortunately, the lateral extent of the beds is difficult to analyze because of incomplete exposures, lateral facies changes, and alluvial cover. Complete exposures of individual facies are generally 0.5 to 3.0 m thick, 25 to 150 m long, and usually have sharp contacts with under- and overlying units. Some contacts are gradational, and occasionally a single unit consists of a basal conglomerate grading upwards into sandstone, with silty shale on top; however, such a complete sequence is rare.

The primary sedimentary structures include wavy bedding, horizontal bedding, and cross-bedding. Cross-bedding is the most common structure, occurring in approximately 35% of the exposures of sandstone and conglomerate. Wavy and horizontal bedding are also common but are much less frequent. Distribution of bedding types in the overall study area is very complex and appears to follow no consistent pattern. The grain-size distribution of the various bedding types in the sandstone facies is consistent; however, the cross-bedded sandstones will occasionally have a higher percentage of coarse constituents, which probably reflects a higher flow regime for some cross-bedded units. In addition, there is a marked shortage of grains in the 0.05-to-0.07-mm size range. This shortage could be caused by a number of factors affecting the environment and therefore is an enigma.

Extensive field search by the author and microscopic examination of samples at Gulf's laboratories yielded no fossils in the Iron Springs Formation near Gunlock that could be used to determine the age of the strata. However, fossil evidence is present that aids in establishing the depositional environment. Pieces of petrified wood up to 25 cm long and 10 cm in diameter are common in the area. The wood is impregnated with mud and is poorly preserved. Texture of the wood is very rough, indicating extensive weathering before burial. Macerated plant fragments commonly occur as a carbon film in the shale facies, particularly in the gray shales. However, all plant fragments are very small, and species cannot be identified.

Root casts were collected at two localities. These casts are generally 5 to 10 cm long and range from 3 to 8 mm in diameter. They commonly occur in clusters of interwoven casts, and always occur in the silty shale facies. Trace fossils, described previously, were also found at three localities in the red siltstone facies.

Trends in the overall geometry of the Iron Springs Formation in the study area are difficult to analyze because of the disconformable relationship with under- and overlying strata and the limited number of outcrops. Cook measured approximately 1,100 m of undifferentiated Cretaceous in the Pine Valley Mountains. In the study area, section Y is 1,070 m thick, and section W is 835 m thick. This trend indicates a westward thinning, but this observation is tenuous. In addition, extensive faulting in the area could have resulted in repetition or deletion of part of the section. However, there is no conclusive evidence to indicate that any of the measured sections are affected by the faulting.

Unfortunately, data concerning paleocurrents in the Iron Springs Formation is scarce. The only current indicator exposed in the area is cross-bedding, and the exposures capable of yielding reliable current directions are rare. Therefore, there is no data presented here concerning paleocurrent directions.

In summary, the lithology of the Iron Springs near Gunlock is exclusively clastic; individual facies range from 10 cm to 3 m in thickness; primary sedimentary structures include cross-bedding, parallel bedding, and wavy bedding; and preserved fossils primarily consist of macerated plant fragments and petrified wood. This data corresponds well with the braided-stream model for the depositional environment.

The regional paleogeography also corresponds well with a fluvial interpretation for the Gunlock strata. Moir (1974) identified a variety of marine and nearshore deposits in the Cedar City area and noted that the marine deposits increase in frequency and thickness to the east and decrease to the west. Using Walthers law of the correlation of facies, terrestrial deposits (if preserved) should be located somewhere to the west of the beach environment described by Moir. The characteristics of the Iron Springs Formation suggest that it represents a braided fluvial sequence deposited near the Cretaceous sea that lay to the east.

DEPOSITIONAL MODEL

Modern braided streams occur in a variety of geologic settings ranging from mountainous to coastal terrain. Reineck and Singh (1980) and Cant (1982) provide excellent summaries of the voluminous literature relevant to braided-stream deposits. Miall (1977) classified braided streams into four categories based on the characteristics described in both modern and ancient deposits.

The Iron Springs Formation correlates very well with Miall's Platte-type braided model in many respects; however, it also has many characteristics that correspond with the Donjek-type model. The Platte River is dominated by sand that is deposited in units of planar cross-stratified, linguoid, and transverse sandbars. Sand also constitutes the majority of the Iron Springs Formation; however, planar cross-stratification does not dominate the sequence. In addition, the relative abundances of the various facies in the Iron Springs Formation is very similar to the Platte type.

The Donjek type has fining upward sequences, interbedded silty shale and sandstone, and abundant trough cross-stratification. The Iron Springs also has all of these characteristics; however, they are not as common or as complex as in the Donjek River. The Donjek River, Platte River, and Iron Springs Formation are represented diagramatically in figure 18.

The most obvious difference between the Platte and Donjek braided deposits and the Iron Springs Formation is the massive sandstone that dominates the Iron Springs sequence. The occurrence of massive sandstone is not documented in any studies of braided streams, yet massive units occupy approximately 35% of the rocks in the Iron Springs Formation. Hamblin (1965) determined that most homogenous sandstones actually have a definite internal structure that is too subtle to be seen with the unaided eye and requires X-ray radiography techniques to be detected. Massive units in the Iron Springs probably have internal structure, but the external manifestation of the structure has been destroyed, or is too faint to be seen. In addition, many of the massive units form slopes, which could obscure the sedimentary structure.

Deposition in a braided stream occurs both laterally and vertically, primarily in the form of channel bars, sand flats, and channel fill. Each of the facies identified in the

Iron Springs Formation represents deposition in a subenvironment of the braided sequence. Figure 19 (modeled after Williams and Rust 1969) illustrates the various realms of deposition and the associated facies of the Iron Springs strata.

Channel bars are the primary mode of deposition in a braided stream (Smith 1970). The majority of the cross-bedded units in the Iron Springs Formation represent deposition of sand in these bars. Foreset laminae of the cross-beds are a result of migrating megaripples, dunes, and sandwaves (Cant and Walker 1978, Coleman 1969) on sand flats and channel bars and in channels.

Horizontally bedded sands also occur in braided environments, but are much less common than cross-bedded units (Williams and Rust 1969, Cant and Walker 1978, Coleman 1969). Horizontal lamination occurs exclusively in channel bars and is considered a high-flow regime feature, possibly due to flooding. Coleman (1969) in an X-ray radiograph study of some laminated sands in the Brahmaputra River, found that individual laminae actually consisted of very small-scale planar cross-stratified units. Cross-stratification was not observed in the laminated sandstones of the Iron Springs Formation; however, X-ray radiograph studies were not conducted.

Fining-upward sequences in the Iron Springs are rare. They consist of channel-lag deposits about 50 cm thick, sandstone about 1.5 m thick, and silty shale about 50 cm thick. The rare occurrence of fining-upward sequences in the Gunlock strata is a result of deposition in point bars. Point bars locally occur in braided-stream deposits and usually occur at the distal margins of the stream channel (Rust 1978).

The deformation feature described in the horizontally bedded sandstone and illustrated in figure 7 was probably

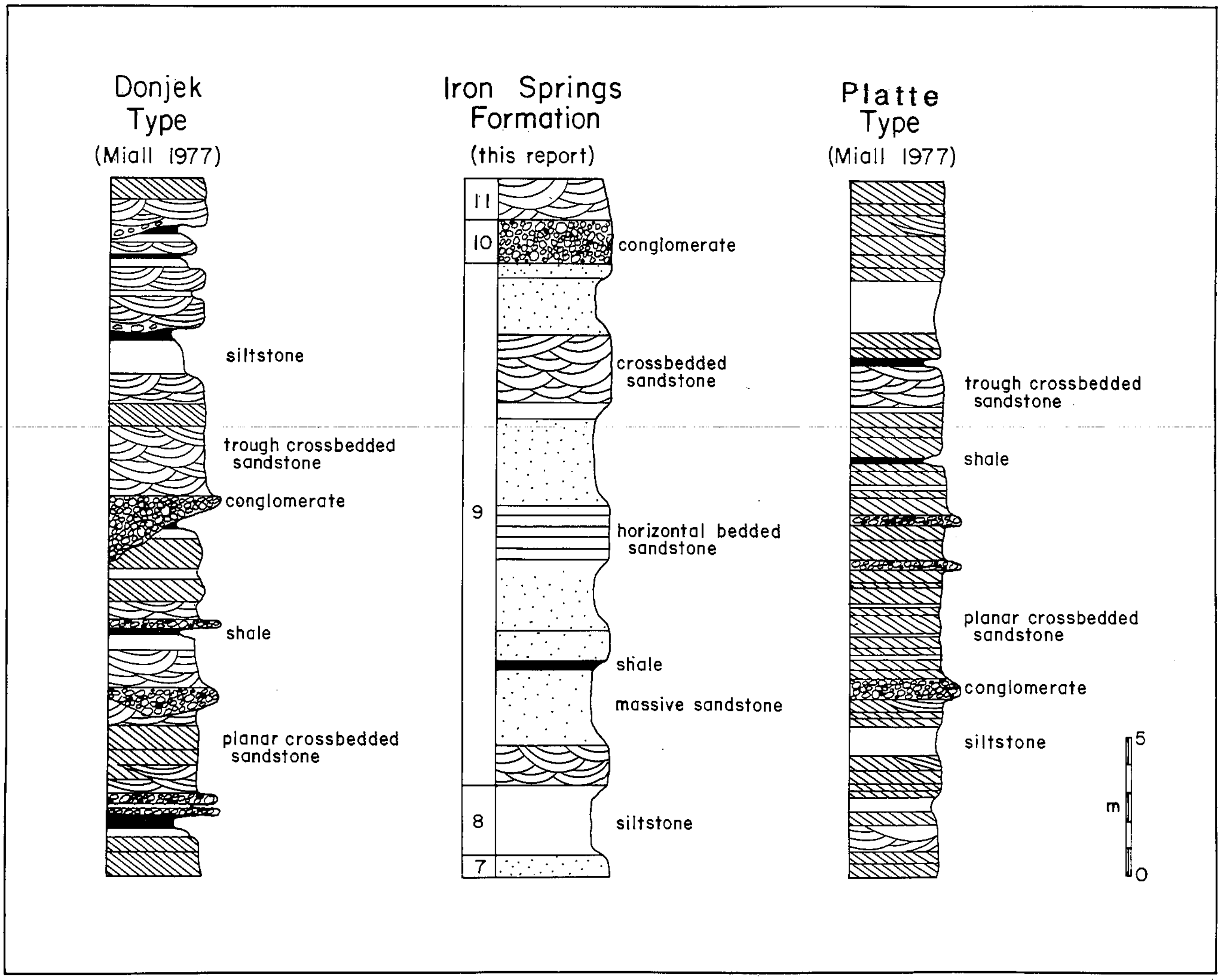


FIGURE 18.—*Comparison of the Iron Springs Formation to the Donjek and Platte type of braided sequences.*

caused by the rising of silt or mud that was trapped in the sandstone. Silt volcanoes observed by Williams and Rust (1969) in the Donjek River could result in this type of deformation. However, Williams and Rust failed to document any deformation caused by the silt volcanoes.

Wavy bedding in the silty-shale facies represents climbing-ripple lamination which is a common feature of braided deposits. This facies was deposited in the lower-flow regime near the margins of the stream channel (Coleman 1969). Some of the silty-shale beds contain root casts, which indicate deposition in a region that persisted long enough to allow plant growth. Vegetation in braided environments is well documented by Williams and Rust (1969).

Units of interbedded sandstone and silty shale are also a common feature of braided streams (Smith 1974, Williams and Rust 1969). These deposits occur in minor channels which are subject to periodic variations in current intensity. Sandstone beds are deposited during high-water phases, whereas silty shale is deposited during low-water phases.

Deposition of the shale facies probably occurred in paludal areas that were subject to occasional flooding (Smith 1974, Williams and Rust 1969) and in abandoned channels, which would also provide good basins for accumulation of this facies. The red siltstone facies also probably accumulated in abandoned channels. However, the larger grain size indicates a higher flow regime than shale. Therefore, abandoned channels filled with red siltstone were probably subject to frequent flooding, or continuous sedimentation at a low-energy level.

The interbedded shale and sandstone breaks in the southeast corner of the study area are lithologically very similar to the Tropic Formation of the Pine Valley Mountains. However, marine fossils are absent, and the breaks are apparently a local feature (see "Shale Facies" section). Therefore, they probably represent anomalous areas of low energy which received more silt and clay than other areas.

The conglomerate facies represents channel deposits in the highest-flow regime of the fluvial sequence. Deposits identical to the Iron Springs conglomerate have been re-

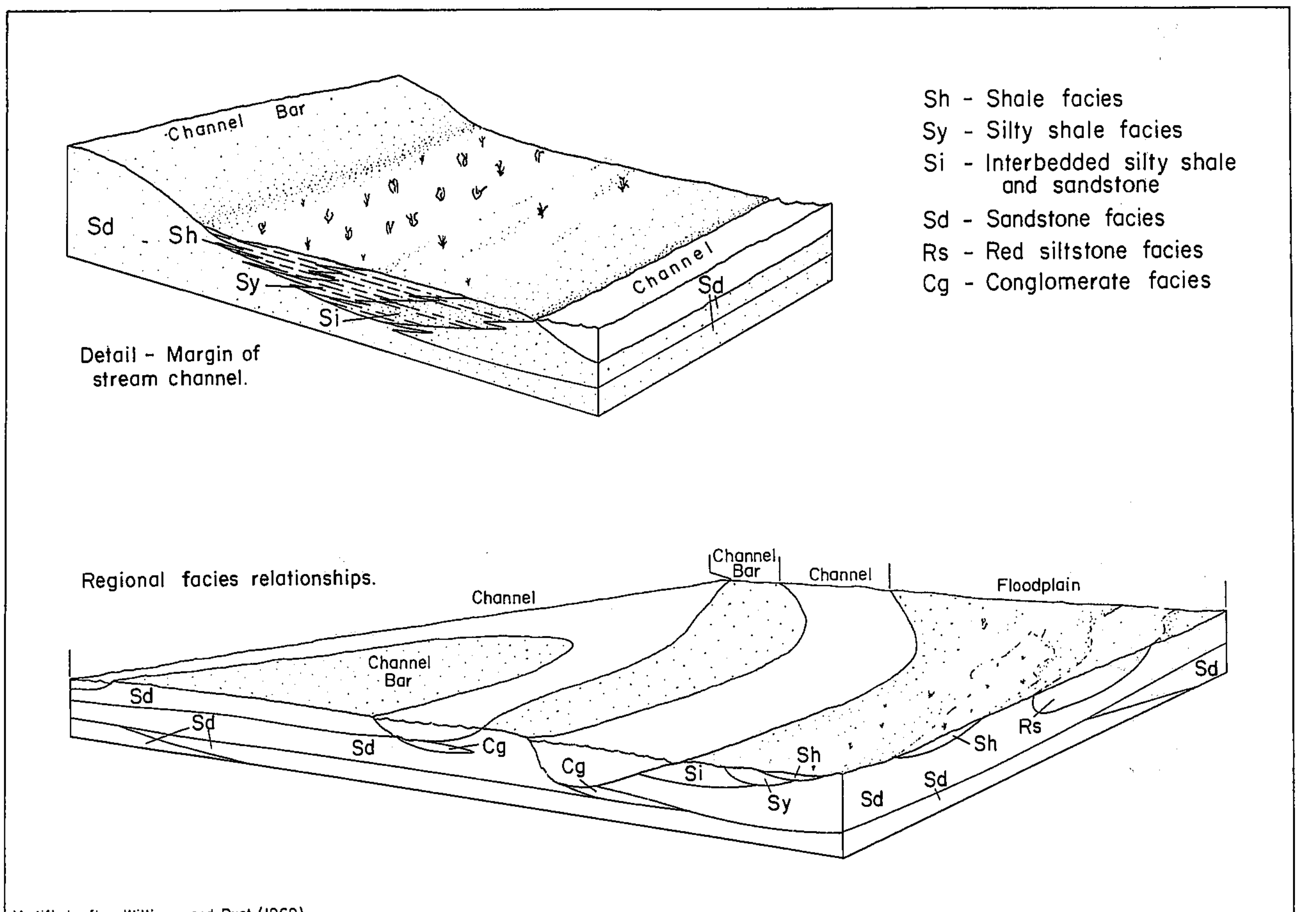


FIGURE 19.—*Depositional model for strata in the Iron Springs Formation.*

ported by Williams and Rust (1969), Smith (1974), and others in braided fluvial environments.

The Dakota conglomerate is markedly different from the conglomerate facies in the Iron Springs Formation. Clasts of the basal units are much larger, and the overall clast composition is very different. Stokes (1952) believes that the Dakota represents gravels deposited on the erosional surface which existed during Early Cretaceous time. In the Gunlock area the Dakota appears to concur with Stokes's evaluation. However, the contact between the Dakota and Iron Springs is also very abrupt, indicating that the Dakota too is an erosional surface. Unfortunately, the time gap between the Dakota conglomerate and Iron Springs Formation is impossible to establish because of the absence of identifiable guide fossils.

SUMMARY

The Iron Springs Formation was deposited in the foreland basin of an Andean-type arc-trench system near the shore of a Cretaceous sea.

Characteristics of the collected samples indicate that the grains in general are very mature and were probably derived from uplifted Paleozoic and Mesozoic strata of the Sevier orogenic highland.

Cretaceous strata in the Gunlock area were deposited in a complex braided-stream environment. The sandstone facies was deposited primarily in channel bars, sand flats, and channels in the fluvial system. Point bars are also present and are expressed as fining-upward sequences in the strata; however, they are rare. Silty shale units represent deposition in low-energy environments near the margins of the stream channel. The shale and red siltstone probably represent deposition in abandoned channels and paludal areas in the floodplain. Conglomerates of the Iron Springs Formation were deposited in channel bottoms of the braided fluvial complex. The Dakota conglomerate is in disconformable contact with the under- and overlying rocks and probably represents fluvial deposition on a pediment surface.

REFERENCES CITED

Armstrong, R. L., 1967, Sevier orogenic belt in Nevada and Utah: Geological Society of America Bulletin, v. 79, p. 429.

Bissell, H. J., 1952, Geology of the Cretaceous and Tertiary sedimentary rocks of the Utah-Arizona-Nevada corner: Intermountain Association of Petroleum Geologists, Guidebook to the Geology of Utah no. 7.

———, 1954, The Kaiparowits region: Intermountain Association of Petroleum Geologists 5th Annual Field Conference, p. 63.

Burchfield, B. C., and Davis, G. A., 1972, Structural framework and evolution of the southern part of the Cordilleran orogen, western United States: American Journal of Science, v. 272, p. 97.

Burger, J. A., 1963, The Cretaceous system of Utah: In Crawford, A. L. (ed.), Oil and gas possibilities of Utah re-evaluated: Utah Geological and Mineralogical Survey Bulletin no. 54, p. 123.

Cant, D. J., 1982, Fluvial facies models and their applications: In Sandstone depositional environments: American Association of Petroleum Geologists Memoir, v. 31, p. 115.

Cant, D. J., and Walker, R. G., 1978, Fluvial processes and facies sequences in the sandy, braided South Saskatchewan River, Canada: Sedimentology, v. 25, p. 625.

Cobban, W. A., and Reeside, J. B., 1952, Correlations of the Cretaceous formations of the western interior of the United States: Geologic Society of America Bulletin, v. 63, p. 1011.

Coleman, J. M., 1969, Brahmaputra River: channel processes and sedimentation: Sedimentary Geology, v. 3, p. 129.

Cook, E. F., 1957, Geology of the Pine Valley Mountains, Utah: Utah Geological and Mineralogical Survey Bulletin, v. 58.

———, 1960, Geologic atlas of Utah, Washington County: Utah Geological and Mineralogical Survey Bulletin, v. 70.

Dickinson, W. R., 1975, Sedimentary basins developed during evolution of Mesozoic-Cenozoic arc-trench system in western North America: Canadian Journal of Earth Science, v. 13, p. 1268.

Dobbin, C. E., 1939, Geologic structure of St. George district, Washington County, Utah: American Association of Petroleum Geologists Bulletin, v. 23, p. 121.

Dott, R. H., and Batten, R. L., 1976, Evolution of the Earth: McGraw-Hill.

Eardley, A. J., 1962, Structural geology of North America: Harper and Row.

Folk, R. L., 1966, A review of grain-size parameters: Sedimentology, v. 6, no. 2, p. 73–93.

Folk, R. L., and Ward, W. C., 1957, Brazos River bar: a study in the significance of grain size parameters: Journal of Sedimentary Petrology, v. 27, p. 3.

Gould, H. R., 1972, Environmental indicators: a key to the stratigraphic record: In Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralogists Special Publication no. 16, p. 1.

Gregory, H. E., 1949, Geologic and geographic reconnaissance of eastern Markagunt Plateau, Utah: Geologic Society of America Bulletin, v. 60, p. 969.

———, 1950a, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geological Survey Professional Paper no. 220.

———, 1950b, Geology of eastern Iron County, Utah: Utah Geological and Mineralogical Survey Bulletin, v. 37.

———, 1951, The geology and geography of the Paunsaugunt Region, Utah: U.S. Geological Survey Professional Paper no. 226.

Gregory, H. E., and Moore, R. C., 1931, The Kaiparowits Region: U.S. Geological Survey Professional Paper no. 164.

Hamblin, W. K., 1965, Internal structures of homogenous sandstones: State Geologic Survey of Kansas, no. 175, pt. 1.

Harris, H. D., 1959, Late Mesozoic positive area in western Utah: American Association of Petroleum Geologists Bulletin, v. 43, p. 2636.

Leith, C. K., and Harder, E. C., 1908, Iron ores of the Iron Springs District, Utah: U.S. Geologic Society Bulletin no. 338.

Mackin, J. H., 1947, Some structural features of the intrusions in the Iron Springs District: Utah Geological Society Guidebook to the Geology of Utah, no. 2.

McBride, E. F., 1963, A classification of common sandstones: Journal of Sedimentary Petrology, v. 33, p. 664.

McCarthy, W. R., 1959, Stratigraphy and structure of the Gunlock-Motoqua area, Washington County, Utah: Master's thesis, University of Washington, Seattle.

Miall, A. D., 1977, A review of the braided-river depositional environment: Earth-Science Reviews, v. 13, p. 1–62.

Moir, G. J., 1974, Depositional environments and stratigraphy of the Cretaceous rocks, southwestern Utah: Ph.D. dissertation, University of California at Los Angeles.

Powers, M. C., 1953, A new roundness scale for sedimentary particles: Journal of Sedimentary Petrology, v. 23, p. 117.

Reber, S. J., 1951, Stratigraphy and structure of the south-central and northern Beaver Dam Mountains, Washington County, Utah: Master's thesis, Brigham Young University, Provo, Utah.

Reeside, J. B., and Bassler, H., 1921, Stratigraphic sections in southwestern Utah and northeastern Arizona: U.S. Geological Society Professional Paper 129-D, p. 53–77.

Reineck, H. E., and Singh, I. B., 1980, Depositional sedimentary environments: Springer-Verlag, New York.

Richardson, G. B., 1927, The Upper Cretaceous section of the Colob Plateau, southwest Utah: Washington Academy of Science Journal, v. 17, p. 466.

Rust, B. R., 1978, The interpretation of ancient alluvial successions in the light of modern investigations: In Davidson-Arnott (ed.), Research in fluvial geomorphology, Guelph Symposium on Geomorphology, Proceedings, no. 5, p. 67.

Shelly, R. C., 1970, Ancient sedimentary environments: Chapman and Hall.

Smith, N. D., 1970, The braided stream depositional environment: comparison of the Platte River with some Silurian clastic rocks, north-central Appalachians: Geologic Society of America Bulletin, v. 81, no. 10, p. 2993–3013.

————, 1974, Sedimentology and bar formation in the upper Kicking Horse River, a braided outwash stream: Journal of Geology, v. 82, p. 205.

Spieker, E. M., and Reeside, J. B., 1926, Upper Cretaceous shoreline in Utah: Geologic Society of America Bulletin, v. 37, p. 429.

Stokes, W. L., 1952, Lower Cretaceous in Colorado Plateau, American Association of Petroleum Geologists Bulletin, v. 36, no. 9, p. 951–92.

Stokes, W. L., and Heylmun, E. B., 1963, Tectonic history of southwestern Utah: In Geology of southwestern Utah: Intermountain Association of Petroleum Geologists, 12th Annual Field Conference Guidebook, Utah Geological and Mineralogical Survey, p. 19–25.

Van deGraff, F. R., 1963, Upper Cretaceous stratigraphy of southwestern Utah: In Geology of Southwestern Utah: Intermountain Association of Petroleum Geologists, 12th Annual Field Conference Guidebook, Utah Geological and Mineralogical Survey, p. 65–70.

Warner, M. M., 1949, A correlation study of the Mesozoic stratigraphy of Utah and the adjacent portions of surrounding states: Master's thesis, Brigham Young University, Provo, Utah.

Wiley, M. A., 1963, Stratigraphy and structure of the Jackson Mountain–Tobin Wash area, southwest Utah: Master's thesis, University of Texas, Austin.

Williams, P. F., and Rust, B. R., 1969, The sedimentology of a braided river: Journal of Sedimentary Petrology, v. 39, no. 2, p. 649–79.

APPENDIX A

SIEVE ANALYSIS DATA

U.S. STANDARD SIEVE--MESH OPENING

SAMPLES - MEASURED IN GRAMS

	fines	250	200	140	100	60	50	40	30	20	16
1-M	4.6	1.4	11.0	42.7	83.1	4.0	0.7	-	-	-	
2-L	3.0	N	5.6	21.4	103.1	14.2	3.2	-	-	-	
3-L	N	N	4.1	16.7	74.2	37.6	15.3	1.8	-	-	
4-X	7.3	0.8	11.6	33.8	73.8	13.8	7.9	-	-	-	
5-M	1.5	N	4.5	20.5	78.6	31.0	14.2	0.7	-	-	
6-M	1.5	N	3.2	12.4	51.6	40.5	31.7	10.3	-	-	
7-M	13.0	0.4	19.4	46.5	58.4	9.2	4.8	0.7	-	-	
8-M	13.5	0.4	21.3	48.3	53.3	10.2	4.7	0.6	-	-	
9-L	1.3	N	3.0	20.1	79.3	28.5	16.8	3.4	-	-	
10-X	8.0	3.2	29.1	81.5	27.0	1.4	0.9	-	-	-	
11-M	1.0	N	1.8	13.4	75.0	33.0	21.4	4.3	-	-	
12-L	6.1	N	7.6	17.8	76.9	23.0	18.5	0.8	-	-	
13-M	7.0	N	11.4	30.8	51.8	25.5	19.5	4.2	1.4	-	
14-L	4.4	0.8	12.8	39.5	63.7	16.5	10.1	2.7	1.1	-	
15-L	4.7	N	10.1	27.0	54.0	32.8	18.9	3.5	0.6	-	
16-X	1.0	0.8	2.4	7.5	40.7	48.5	41.3	9.3	0.7	-	
17-L	4.2	0.6	4.5	15.7	98.0	21.1	8.4	-	-	-	
18-X	2.9	N	2.0	5.6	46.5	38.1	36.1	15.3	3.8	0.6	
19-M	1.4	N	1.5	8.1	71.3	33.8	22.4	11.4	2.7	-	
20-M	1.8	N	2.6	13.5	92.6	25.8	13.6	2.6	0.9	-	
21-M	1.6	N	4.2	21.8	66.1	33.5	19.8	5.5	0.9	-	
22-X	4.0	N	4.2	16.4	57.4	35.0	23.7	9.3	2.2	-	
23-X	2.9	N	2.9	11.4	69.9	32.3	23.1	7.5	3.1	0.8	
24-X	2.5	N	2.9	8.8	93.5	31.0	13.3	0.6	-	-	
25-X	5.0	N	4.5	11.5	48.6	34.2	33.2	15.0	2.9	-	
26-X	N	N	2.0	7.9	56.0	37.1	36.3	10.9	2.4	-	
27-X	0.5	N	0.8	4.0	28.1	32.7	52.7	29.2	1.0	-	
28-M	3.3	0.6	11.7	38.6	70.5	16.3	8.1	2.5	-	-	
29-X	4.7	0.9	10.4	41.7	80.7	7.9	4.5	0.3	-	-	
30-M	1.2	0.2	1.2	4.8	50.0	47.8	36.9	7.4	0.8	-	
31-M	1.0	N	1.0	6.6	77.4	43.7	18.9	2.2	-	-	
32-X	6.2	N	6.0	19.1	71.7	27.5	18.1	-	-	-	

N = negligible, M = massive bedded, L = parallel bedded, X = cross-bedded

APPENDIX B

TOTAL ORGANIC CARBON AND PYROLYSIS RESULTS
IRON SPRINGS FORMATION

Sample Number	T.O.C. (wt.%)	S mg/g rock	S mg/g rock	S mg/g rock	Tmax (°C)	H Index	O Index	Sample Location*
1-12C	0.24	0.00	0.00	0.00	-	0.0	0.0	Sec 29 SW 1/4 of SE 1/4
1-12D	0.21	0.00	0.00	0.00	-	0.0	0.0	Sec 29 NE 1/4 of SW 1/4
1-13C	1.13	0.00	0.00	0.12	-	0.0	10.6	Sec 29 SW 1/4 of SE 1/4
1-13K	0.36	0.00	0.00	0.00	-	0.0	0.0	Sec 29 NW 1/4 of SE 1/4
1-17A	2.38	0.00	0.00	1.76	-	0.0	73.9	Sec 29 SW 1/4 of NE 1/4
1-17D	2.38	0.00	0.08	3.45	-	3.4	144.9	Sec 29 SW 1/4 of NE 1/4
1-26B	0.50	0.00	0.00	0.00	-	0.0	0.0	Sec 29 NE 1/4 of NE 1/4
1-29	0.30	0.00	0.00	0.18	-	0.0	60.0	Sec 28 NW 1/4 of NW 1/4
1-31	0.23	0.00	0.00	0.00	-	0.0	0.0	Sec 21 SW 1/4 of SW 1/4
2-14	0.48	0.00	0.00	0.00	-	0.0	0.0	Sec 28 SW 1/4 of SW 1/4

* All sample locations are on the Gunlock, Utah 7 1/2 min quadrangle, R17W, T40S.