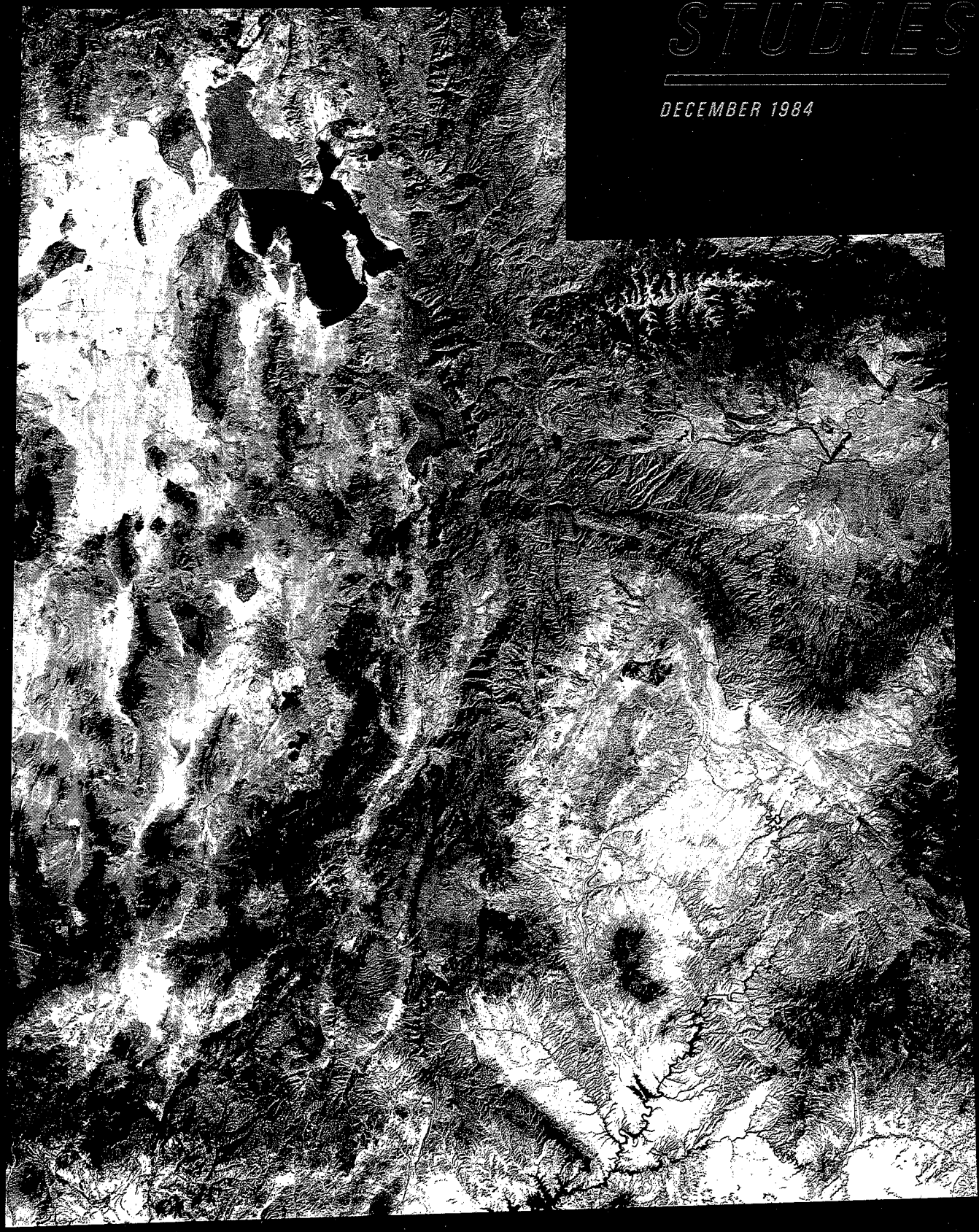
BRIGHAM YOUNG UNIVERSITY

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

Editors

W. Kenneth Hamblin
Karen Seely

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

Shnabkaib Member of the Moenkopi Formation: Depositional Environment and Stratigraphy near Virgin, Washington County, Utah*

RALPH E. LAMBERT
Chevron USA, Concord, California 94520

Thesis chairman: HAROLD J. BISSELL

ABSTRACT

The Shnabkaib Member of the Triassic Moenkopi Formation near Virgin, Utah, records a shallow, fluctuating transgression eastward and subsequent withdrawal of the sea across a very broad shelf. Shallow water, warm arid clime, and restricted circulation due to low relief and shoal areas combined to cause hypersaline waters and the formation of coastal sabkhas.

Subtidal and lagoonal sediments are represented by gray, burrowed, and slightly fossiliferous silty ooid-peloidal limestone, structureless or laminated mudstone or shales, and pyritic siltstone. Thick gypsum beds formed from the evaporation of restricted ponds in the lagoonal area.

Widespread flat algal mats grew near the high-water line of the intertidal zone and are now represented by the muddy cryptalgal laminated gypsum. Also, representative of intertidal sedimentation are light gray or greenish gray laminated siltstone, peloidal micrite, and pyritic argillaceous siltstone. Parallel and symmetrical ripple marks, flaser and lenticular bedding, small-scale graded bedding, and mudcracks help to identify intertidal deposition.

Layers of gypsum nodules and associated laminated and contorted bedding help identify the sabkha/supratidal environment. Moderate brown horizontally laminated siltstones and silty mudstones or shales, combined with disrupted bedding, mudcracks, cusp ripple marks, and a lack of fossils also represent the supratidal/floodplain environment.

The Shnabkaib is significant since it represents the last transgression of the Cordilleran sea from the miogeosyncline eastward onto the craton. Contributions of this study are several; to the writer's knowledge this study has (1) the most detailed stratigraphic sections and more sections of the Shnabkaib than any other study in southwest Utah; (2) first attempted correlation of different Shnabkaib sections; (3) first description of cryptalgal laminated gypsum in the Shnabkaib; and (4) the only detailed depositional environmental analysis of the Shnabkaib.

INTRODUCTION

The Shnabkaib Member is the second youngest of the six members of the Moenkopi Formation of Early and (?) Middle Triassic age in southwest Utah. This member forms a conspicuous banded series of red and white siltstone, mudstone, gypsum, and minor amounts of sandstone, limestone and dolomite. Thick mats of stromatolites also accumulated during the time of deposition. The Shnabkaib Member represents a shallow, evaporitic marine transgression of the Cordilleran sea eastward across the Las Vegas-Wasatch hingeline onto the craton.

Excellent exposures of this member occur on the steep slopes which are protected by the overlying cliff-forming Shinarump Conglomerate Member of the Chinle Formation in the vicinity of Virgin, Washington County, Utah. These exposures afford a three-dimensional study of the stratigraphy, lithology, and sedimentary structures, thereby permitting an interpretation of the depositional environments of the sediments. Few detailed stratigraphic sections of the Shnabkaib have been published, nor has any correlation between sections or detailed paleoenvironmental analysis been found by this writer.

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

LOCATION

Eight sections were measured within a radius of 30 km of the town of Virgin (fig. 1). Sections 1 and 2 are on the southern flanks of Hurricane Mesa (Pioneer Mesa on some maps). Section 3 is to the west of North Creek road and 1 km past the Virgin Oil Field. Section 4 is on the south side of Gooseberry Mesa adjacent to Utah 59. Fair dirt roads pass near sections 5 and 7, which are on the flanks of Little Creek Mountain. Section 6 was measured near Utah 15 in Zion Park, and section 8 was measured a few kilometers south of the type section on the east flank of the Washington Dome, a part of the Virgin anticline. This last section is near an auto wrecker's lot.

METHODS OF STUDY AND NOMENCLATURE

Field Methods

A steel tape, Jacob's staff, Abney hand level, and Brunton compass were used to measure eight stratigraphic sections which total approximately 900 m. Different lithologies may be interbedded or very gradational, and hence many large units were divided by color. Lithology, composition, grain size (almost exclusively silt size or finer), color, sedimentary structures, and topographic expression were noted for each. Where possible, paleocurrent directions were measured and a search for fossils was undertaken. Approximately 100 hand samples were collected and analyzed in the laboratory. In each section studied, the gradational lithology between the Shnabkaib and the middle and upper red members makes selecting definite member boundaries and comparing overall thickness between different studies impractical. Stewart and others (1972, p. 19) state that there is a 30–100-m transition zone between the middle red and Shnabkaib members on the Colorado Plateau. The top of the Shnabkaib is much easier to determine than the base. Therefore, it is difficult to accurately compare total thickness with sections from different researchers. Sections in this paper compare favorably with nearby sections by Gregory (1950), but section 8 is much thinner than the type section of Bassler and Reeside (1921).

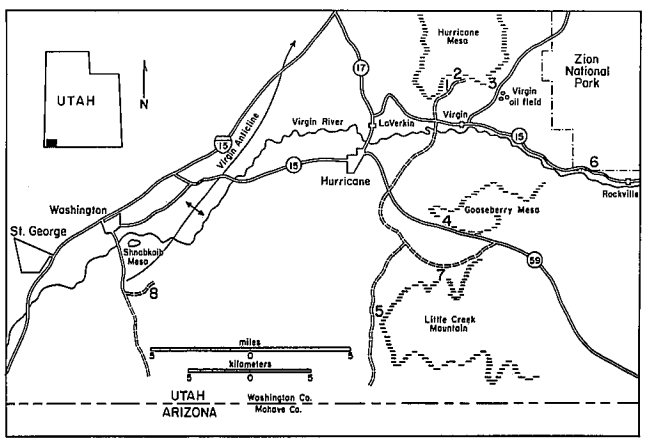


FIGURE 1.—*Index map showing location and access of measured sections.*

Laboratory Methods

Hand samples were studied under a binocular microscope, and 90 thin sections were made and studied with a petrographic microscope. Composition, texture, cement, microsedimentary structures, and fossil content were studied. Alizarine Red S stain was used on some samples but mostly unsuccessfully because of the high percentage of clastic material and extremely fine grain or crystal size. Some rocks were dissolved in dilute HCl to determine the percentages and composition of the insoluble residue. Two samples of mudstone were crushed and sieved; particles smaller than 43 microns were subjected to X-ray diffraction analysis to determine composition. Energy dispersive X-ray analysis was used to help determine the composition of four samples.

Nomenclature

Color nomenclature of lithologic units follows the color chart published by the Geologic Society of America (1979). Grain-size nomenclature is the modified Wentworth Grade Scale of Dunbar and Rodgers (1957, p. 161). Terminology for bed and laminae thickness is that of Ingram (1954).

REGIONAL SETTING

The study area lies at or very near the Colorado Plateau and Basin and Range physiographic province boundary as well as near the Las Vegas-Wasatch hingeline. Geology of the region consists generally of essentially flat-lying Mesozoic sedimentary rocks and Cenozoic volcanic rocks. There are two major structures, the Hurricane fault and the Virgin anticline. Stratigraphically, the Moenkopi Formation rests disconformably on the Permian Kaibab Limestone and consists of six members in southwest Utah. These members are, in ascending order, Timpoweap Limestone (also termed Rock Canyon Conglomeratic Member), lower red, Virgin Limestone, middle red, Shnabkaib Shale, and upper red members. Overlying the Moenkopi is the Shinarump Conglomerate Member of the Triassic Chinle Formation. The Shinarump forms the resistant caprock of the mesas and the chocolate cliffs of the Grand Staircase of the Grand Canyon. In areas where the Shnabkaib is protected by the Shinarump, it forms steep slopes, but where unprotected it forms low rounded hills (fig. 2).

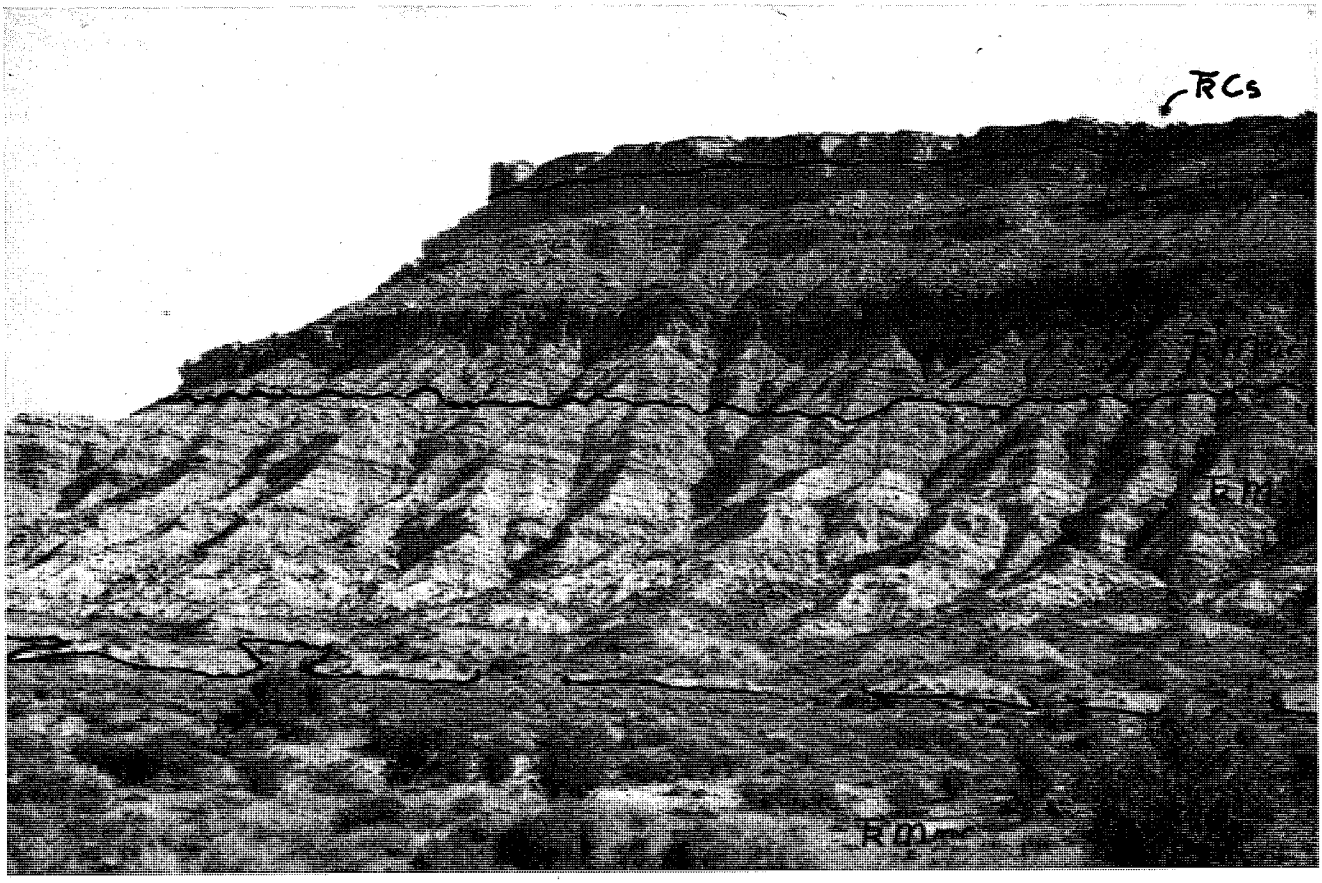


FIGURE 2.—*Outcrop at section 4 showing approximate boundaries of Triassic Shinarump Conglomerate Member of the Chinle Formation, and the upper red, Shnabkaib, and middle red members of the Moenkopi Formation.*

The Virgin Oil Field has historical interest since it is the oldest oil field in Utah, having been discovered in 1907, but economically it is unimportant (Gregory 1950, p. 190). What little oil is produced comes from shallow (180 m ±) wells in the Timpoweap Limestone. Two shallow wells were drilled while fieldwork for this study was being undertaken but had not yet been placed in production when last visited in summer of 1981.

PREVIOUS WORK

Much work has been done on the Moenkopi Formation as a whole and especially on its limestone members, but very little detailed work has been published on the Shnabkaib Member. Ward (1901) named the Moenkopi Formation, and, from its type locality in the Grand Canyon east of Arizona, it was traced to southwest Utah by Huntington and Goldthwait (1904). Bassler and Reeside first used the name "Shnabkaib Shale Member" in 1921, but they actually proposed the name a year later (Reeside and Bassler 1922). The member was named for an isolated mesa 5 km southwest of the town of Washington on the west flank of the Virgin anticline. On the USGS (1954) Hurricane, Utah, quadrangle topographic map, the mesa is called Shinob Kibe, whereas on their map, Bassler and Reeside (1921) spelled it Shnabkaib. Reeside and Bassler (1922) reported that the name *Shnabkaib* is probably the corruption of an old Indian name meaning *Coyote Mountain,* but Gregory (1950) reported that it is a corrupted Indian name meaning *Mountain of the Lord* and that the mesa has an interesting legend behind it.

The two most helpful papers that deal in part with the Shnabkaib are by McKee (1954) and Stewart and others (1972). These papers are helpful since each describes the stratigraphy, lithology, and depositional environments of the Moenkopi Formation. Poborski (1954) and Baldwin (1973) each offered good information on environmental interpretation based on the lithology and sedimentary structures of parts of the Moenkopi, but neither dealt with the Shnabkaib Member. Cadigan (1971) dealt with the petrology of the formation and discussed the tectonic history and source rock areas during Moenkopi time. Gregory (1950), Wilson (1965), and Bissell (1970) gave helpful general information of the area, age, tectonic and depositional history, petrology, and fossil life of the Moenkopi For-

mation. Only three detailed measured sections of the Shnabkaib in southwest Utah were found (Gregory 1950). No detailed Shnabkaib stratigraphic columns were found.

ACKNOWLEDGMENTS

I wish to thank my thesis adviser, Dr. Harold J. Bissell, for guidance and help. Thanks are also given to Drs. J. R. Bushman and M. S. Petersen for their work on my committee. To E. W. Christensen of Chevron USA go thanks for petrographic help. I wish to thank the Garrett and Kahle families of St. George for their free room and board during most of the fieldwork. Finally, thanks to friends, family, fellow students, and co-workers for encouragement and suggestions. This thesis was funded in part by the Quey C. Hebrew Memorial Award, for which I am grateful.

LITHOLOGIES

CLASTIC ROCKS

In the measured sections, clastic rocks make up approximately 55% to 70% of the total lithology. No pattern of percent increase in clastics was seen in the sections measured, but further eastward clastic content does increase, as noted by the writer. This eastward increase of clastics is also reported by Stewart and others (1972, p. 20) and can be explained by shallower water and an eastward source area. Most of the clastic rocks are calcareous (or dolomitic) and gypsiferous to some extent. Figure 3 illustrates the stratigraphic columns of the measured sections.

The main rock type of the Shnabkaib, comprising approximately 65% of the member, is quartz siltstone, with various admixtures of sand, clay, gypsum, and limestone or dolomite. The writer divides the siltstone into two general categories, (modified after Stewart and others 1972), which are the ripple-laminated siltstone and the structureless or parallel laminated siltstone. Colors of the siltstones follow the pattern of the member as a whole, namely moderate brown, medium to very light gray, yellowish gray, greenish gray, and pinkish gray. The grayish siltstones tend to have more gypsum and carbonate and frequently stand out in relief more than the brownish variety.

Ripple-Laminated Siltstone

Included in the ripple-laminated siltstones are the ripple-marked or cross-laminated sandstone and siltstone. Frequently quartzitic siltstones have gypsum or calcite as either matrix or cement. Very fine textured greenish mica is often visible, especially on some bedding planes in this siltstone group. Some plagioclase is occasionally seen, as well as some tiny lathlike high-birefringent crystals which are most likely the hornblende that was mentioned by Stewart and others (1972, p. 61). Other rock fragments and some heavy minerals are also found. Throughout the member, the quartz grains are angular to subrounded and fairly well sorted. These rocks could be classified as low-rank graywacke siltstones.

When seen in plain view, the ripples are small parallel ripples. The ripples themselves will be discussed in the section on sedimentary structures. Stewart and others (1972, p. 52–53) remarked that ripple-marked sediments are commonly in close association with mudcracks, salt crystal casts, and raindrop impressions. In the sections measured for this study, no salt casts or raindrop marks were found, but in sections 3, 4, and 7, ripple marks were found closely associated with mudcracks. Frequently, the ripple-marked strata seem to be closely associated with gypsum or stromatolitic gypsum beds. Usually the ripple-marked siltstones are light in color though they do occur in the brown sediments.

Structureless or Horizontally Stratified Siltstone and Siliceous Mudstone

The writer believes that the structureless or horizontally stratified siltstones and mudstones are genetically related, since they are interbedded and have similar sedimentary features. Thus, these types of siltstone and mudstone are grouped together in this discussion. These lithologies are the most abundant in the Shnabkaib of the area studied. Some ripple marks are found in silty mudstones and form what Reineck and Singh (1975, p. 98) call lenticular bedding. Lenticular bedding is similar to flaser bedding except that mud, rather than silt, dominates because of lower energy and less silt input. Stratification mainly forms thin lamina (1–3 mm) but ranges from very thin to thick lamina, or structureless beds. Individual beds usually seem fairly persistent, but on a microscopic level the lamina may be seen to be discontinuous laterally. Some of these lamina are formed by stringers/layers of mud or coarser silt (fig. 4). Structureless siltstones tend to be finer grained and softer than siltstones that are ripple marked and often break into pieces less than 3 cm thick or, if massive, may weather into slightly rounded chunks.

Soft crumbly mudstone is fairly common in beds up to a few meters thick and frequently occurs in beds less than 1 m thick. The mudstone weathers to form recesses on slopes between more resistant lithologies. The mudstone is commonly moderate brown or greenish gray in color. These two colors of mudstone often occur adjacent to each other and have gradational contacts with one another. Sometimes there is a blob of mudstone of one color completely surrounded by mudstone of the other color. X-ray diffraction analyses were run on one mudstone (marl may be a better term) sample of each color from samples

1 m apart. They each contain quartz, dolomite, plagioclase, and a clay mineral. No reason for the color difference has been found. The mudstone appears to be structureless, but its crumbly nature would make it hard to preserve any internal structure. The mudstone falls apart when wet, and so it was impossible for the writer to make petrographically useful thin sections.

CHEMICAL PRECIPITATES

Gypsum

Gypsiferous rocks average 28% of the total lithology. There is no apparent pattern of increase or decrease in the percentage of gypsum among the eight sections, but the amount of massive pure gypsum tends to decrease eastward. In section 6 (the easternmost section) the thickest massive gypsum bed is only 20 cm thick as compared with up to 3 m in section 7. Stewart and others (1972, p. 20) reported a gradual thinning of the amount of gypsum as well as carbonates east of St. George. The writer confirmed this finding in field studies east of Zion National Park. Gypsum occurs as beds, ranging from several centimeters to several meters in thickness, layers of nodules, cement, and secondary crystals or crosscutting veins.

Bedded Gypsum. Beds of gypsum in the Shnabkaib are typically massive, internally structureless, finely crystalline, and white in color. The beds may be stained grayish pink, light brown, or pale green from slope wash or included muds. Gypsum beds range from several centimeters to 3 m thick, with 1–2-m beds common. Occasional thin layers of clear selenite are found. Selenite is often found as millimeter thick layers in the laminated gypsum. Massive gypsum beds, and in particular the laminated gypsum, are somewhat more resistant than most of the other rock types, thus forming erosional shoulders and ledges. Locally gypsum is underlain by a thin limestone (section 4—unit 5 and section 5—unit 2), but usually gypsum is underlain by horizontally laminated gypsiferous siltstone and silty mudstone. The beds tend to be fairly regular and continuous, though McKee (1954) reports lenticular gypsum. Gregory (1952, p. 61) reports that many beds extend for as much as a mile. The great majority of the crystalline gypsum beds occur in the light-colored sediments (light gray or yellowish gray). It is believed that many of these beds are too thick and regular to have formed from the coalescence of nodules. Also, there is an inverse relationship between how common nodules are in a section and gypsum bed thickness. No nodules are found in section 8 though it has the thickest beds of gypsum.

Nodular Gypsum. Gypsum nodules are finely crystalline and tend to occur along bedding planes and form both flat and rounded nodules up to 20 cm in size (fig. 5). Kendall and Skipwith (1969, p. 858) and Friedman and Sanders (1978, p. 180) state that gypsum or anhydrite nodules grow in place from brines within the water table or capillary zone and above the high-water mark. Displaced sediments surrounding many nodules evince their growth in situ. When formed, nodules are usually anhydrite but upon hydration convert to gypsum (compare with modern examples, i.e., Reading 1979, p. 187).

Nodules are found in all sections except the westernmost (section 8) and are associated with both gray and brown horizontally laminated siltstones and mudstones. Nodules may have inclusions of greenish gray mud and small pyrite cubes and are often associated with massive beds of gypsum. Though nodules are secondary in origin, it is believed that they are helpful in determining environment since, as will be pointed out later, nodules are characteristic of a sabkha environment.

Replacement or Secondary Gypsum. Gypsum has apparently replaced some sediment, especially micrite and siliceous mud. Where well-developed crystals are found growing in mud, it is likely syngenetic since it would be difficult to form crystals and displace sediments after lithification (fig. 6). These sediments were still below the water table or at least within the capillary zone of the brine waters when the gypsum was introduced, since there must be some water circulation to concentrate the salts. There is much secondary gypsum which often occurs as veins of selenite or satin spar, up to 1 cm thick and found throughout the member. This gypsum occurs along bedding planes as crosscutting veins, and as large sheetlike deposits filling fractures. Secondary gypsum is essentially pure and often coarsely crystalline. Since this occurrence of gypsum is diagenetic, it is not seen as being important to the depositional environment.

Laminated Gypsum. Finely laminated gypsum beds are common in the Shnabkaib, comprising about 20% of the measured sections. Lamina of gypsum alternate with mud, wispy algal filaments, and minor amounts of dolomite or high Mg calcite (as indicated by energy dispersive X-ray analysis). Thin laminations occur in fairly clean gypsum, muddy or silty gypsum, and silty and/or gypsiferous mudstone. These beds are either grayish or brownish in color depending on the included mud. This lithology forms the most resistant of the thick units in the Shnabkaib. Ledges of algal (?) laminated gypsum are more common in the top half of the sections and are often as much as 5 m thick. Frequently, two or three of these ledges occur together, separated by 1–2 m of silty mudstone. The sediment is usually light in color, though much of it may have a brownish stain from slope wash.

Locally the gypsum in these beds occurs as millimeter-size lamina of selenite or clear gypsum, but more commonly it is a softer muddy gypsum. Laminated gypsum

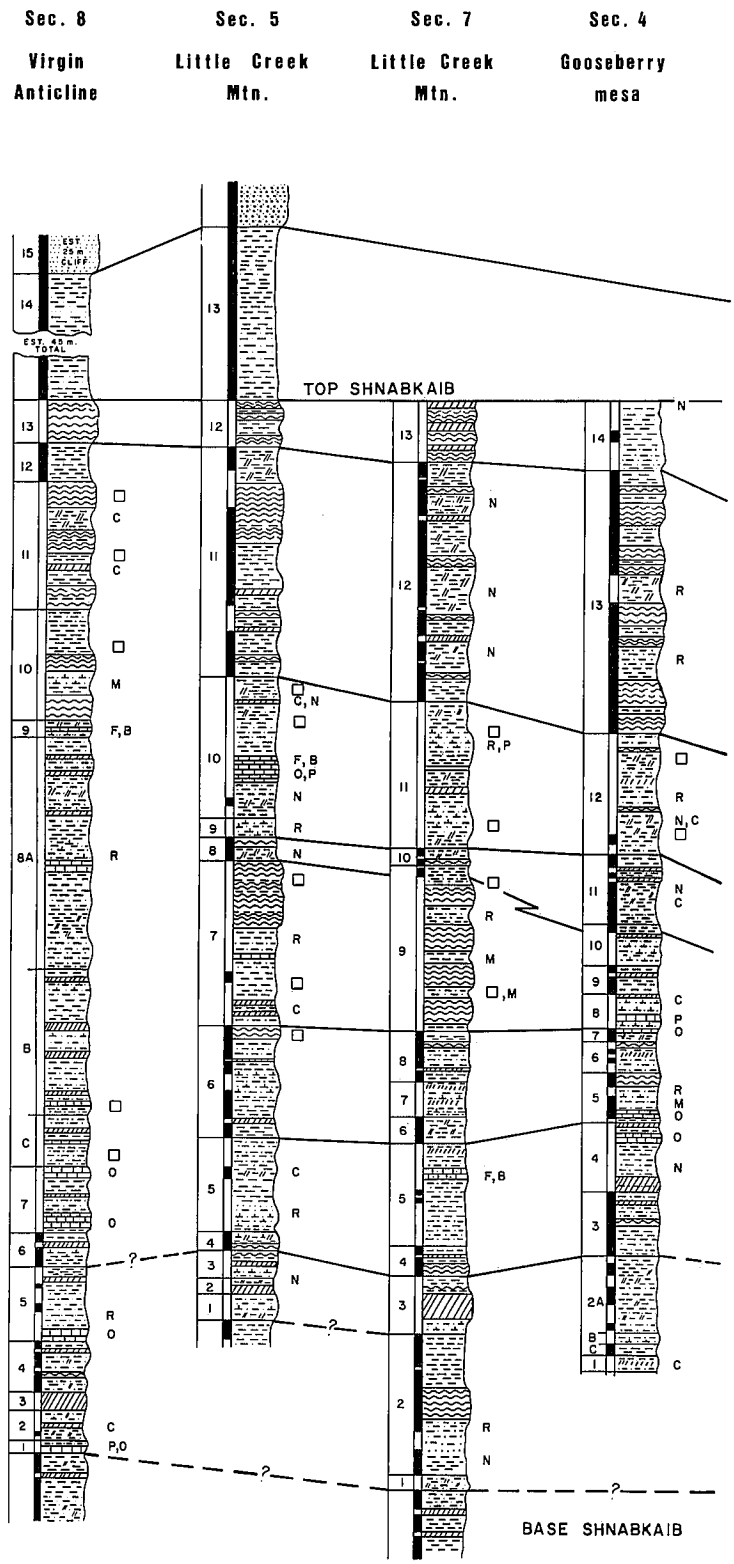
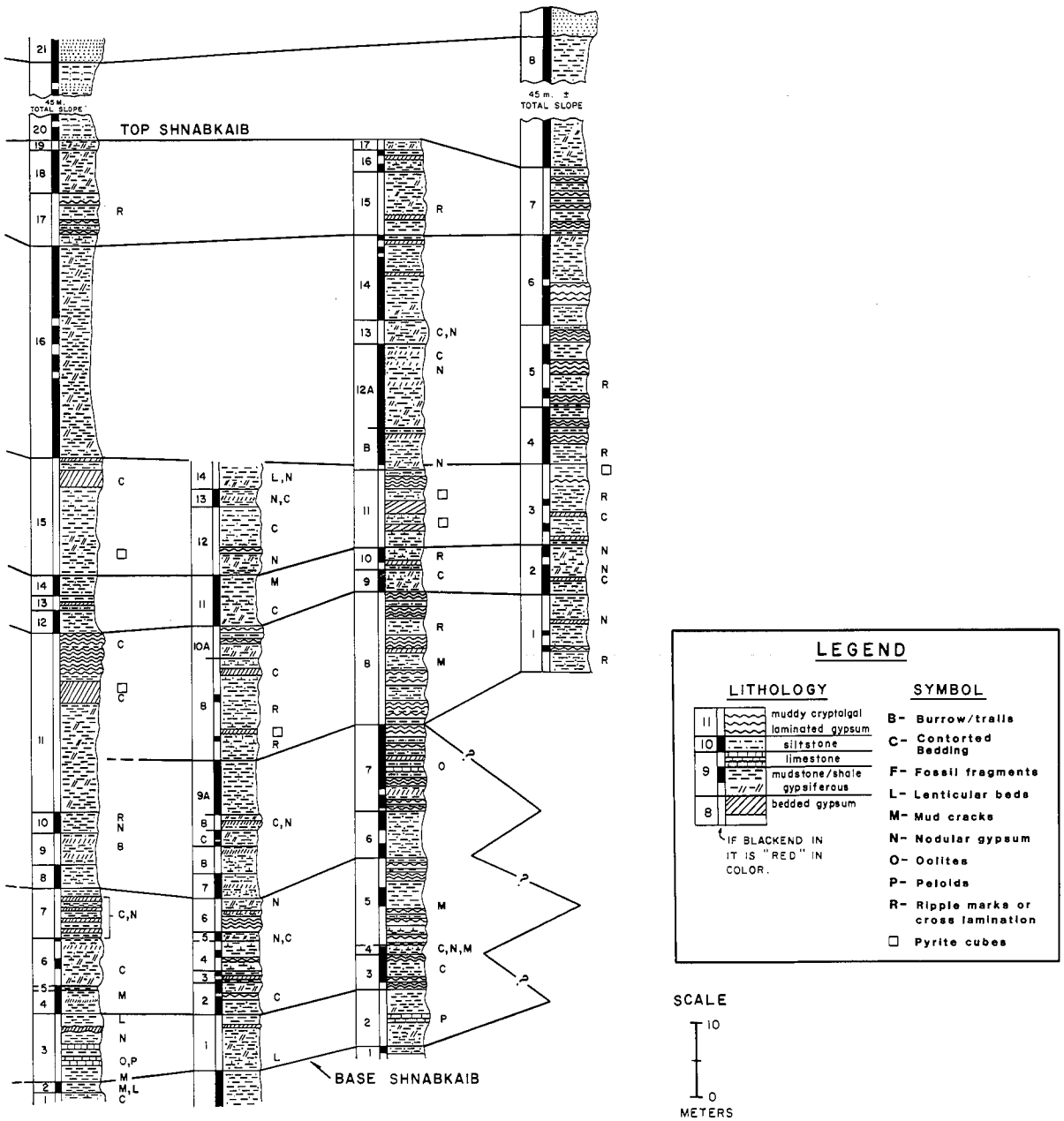


FIGURE 3.—*Measured sections with suggested correlations. Correlations are based mainly on major color changes.*


Sec. 1
Hurricane mesa
Sec. 2
Hurricane mesa
Sec. 3
North Creek
Sec. 6
Zion's Park.
45 M. TOTAL SLOPE
45 m. ± TOTAL SLOPE
TOP SHNABKAIB
BASE SHNABKAIB
LEGEND
LITHOLOGY
muddy cryptalgal laminated gypsum
siltstone
limestone
mudstone/shale gypsiferous
bedded gypsum
IF BLACKEND IN IT IS "RED" IN COLOR.
SYMBOL
B- Burrow/trails
C- Contorted Bedding
F- Fossil fragments
L- Lenticular beds
M- Mud cracks
N- Nodular gypsum
O- Oolites
P- Peloids
R- Ripple marks or cross lamination
Pyrite cubes
SCALE
10
0
METERS

beds are not very calcareous, possibly because of replacement of carbonates by gypsum. Laminae in these extensive units are wavy, parallel, discontinuous, and clearly seen in weathered outcrop (fig. 7). Very fine to medium laminae are seen in thin section (fig. 8). Frequently the laminations are seen to be ripped up or distorted. This deformation is due to desiccation, current action, burrowing or grazing animals, growing algae, growing gypsum/anhydrite crystals, or the swelling due to the hydration of anhydrite to gypsum. A few mudcracks and burrows were found in associated sediments.

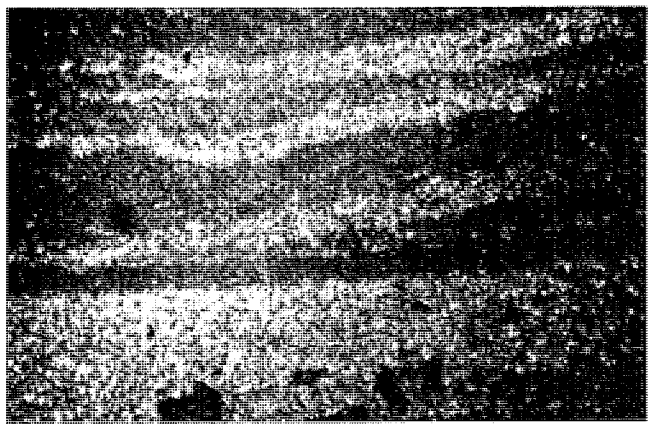


FIGURE 4.—*Photomicrograph showing lenticular bedding with silt and mudstone, section 5, unit 5, crossed nicols; field of view is 8mm, X6.*

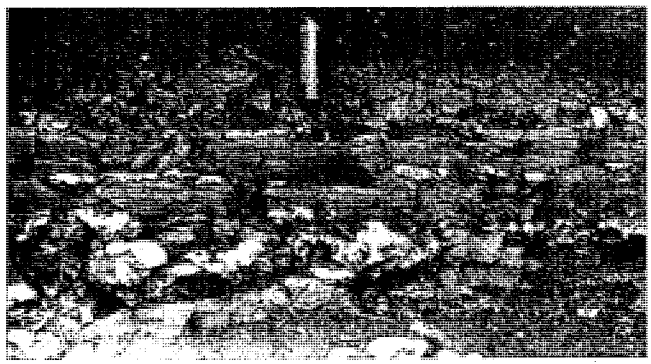


FIGURE 5.—*Layer of white gypsum nodules in medium light gray siltstone, immediately below a thin layer of grayish brown mudstone, section 4, unit 4.*

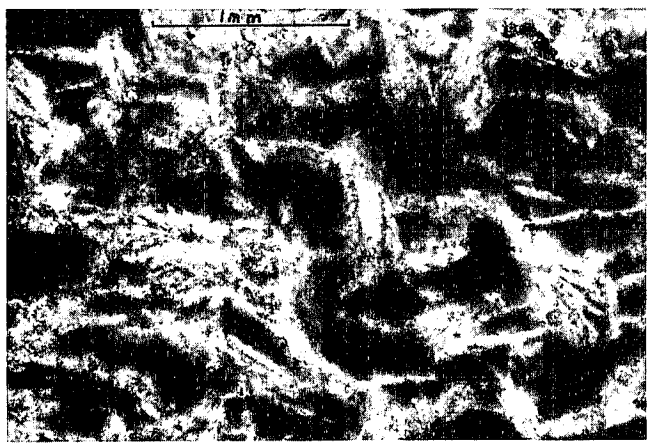


FIGURE 6.—*Photomicrograph of secondary gypsum crystals in micrite, section 5, unit 5, crossed nicols, X15.*

It is very difficult to distinguish mud lamina and cryptalgal filaments from each other. Indeed some of the so-called mud may be "algal dust." In any case mud and cryptalgal structures occur together, and it is believed that they formed in the same environment. Hereafter in this paper when algae are referred to, it should be understood that it is mostly laminated gypsum in outcrop, even though not all the lamina may be due to algae.

On the Abu Dhabi Coast in the Arabian Gulf, Park (1977, p. 493) has estimated that algal mats accrete at the rate of 2–5 mm per year. Gunatilaka (1975, p. 290) recorded 15 cm of mat growth in 12 weeks on the northwest coast of Sri Lanka. This second coastline has much more clastic input than the Abu Dhabi region. Park (1977, p. 493) states that after compaction and fluid loss the appar-

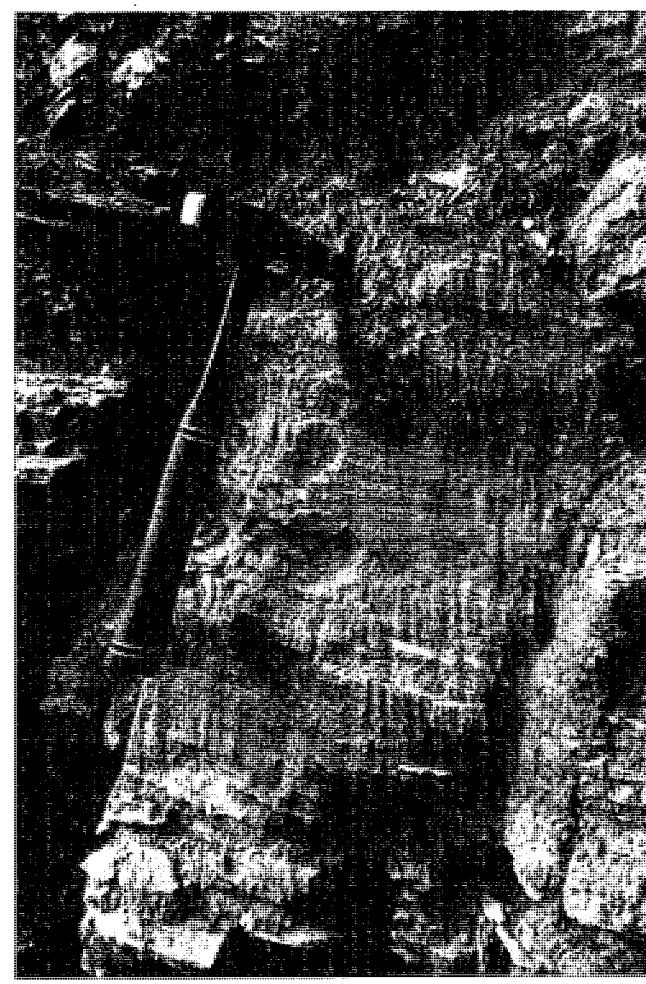


FIGURE 7.—*Outcrop of soft laminated gypsum, section 2, unit 12.*

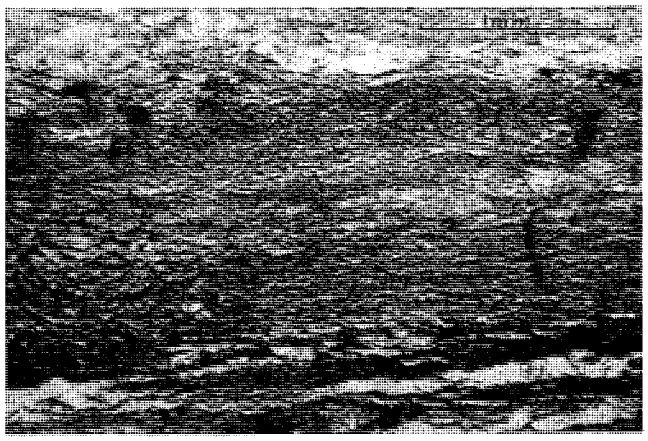


FIGURE 8.—*Photomicrograph of very finely laminated gypsum with some disrupted cryptalgal lamina due to possible desiccation, section 2, unit 2, plain light, X15.*

ent growth rate is 0.2 mm/year as estimated from 4,000-year-old algal mats, but he warns against trying to estimate time represented by the thickness of these sediments. It will suffice to say here that the Shnabkaib algal-laminated gypsum represents moderate periods of time in a similar environment of deposition. Gill (1977) showed planar stromatolites up to 6 m thick in his cross sections through the Silurian sabkha cycles of the Michigan Basin. No recent algal mats this thick are known to the writer.

Limestone and Dolomite

Cadigan (1971, p. 24) states that carbonates in the Shnabkaib near Hurricane are almost exclusively limestone as opposed to dolomite. In this study, both dolomite and calcite were identified in mudstone (as seen in two XRD analyses) and as cement in some siltstones. Energy dispersive X-ray analysis revealed dolomite or high Mg calcite in mud, oolitic rocks, (which also had calcite), and laminated gypsum. No rhombohedral or zoned dolomite crystals were seen in thin section. Carbonate beds are believed to be calcitic or high magnesium calcite from the reaction to acid and staining which was done. The microcrystalline and dispersed/impure nature of the carbonates made it difficult to distinguish between calcium and magnesium carbonate. Gregory (1950) reported that dolomite is common in one of three sections. Formation of gypsum lowers the calcium concentration of water, thus raising the Mg/Ca ratio so the precipitation of dolomite or high Mg calcite can be expected. Less dolomite was identified than expected, perhaps in part because of calcification. Calcite was found replacing small gypsum crystals, but calcification is not seen as a fully satisfactory answer. Activity of algae may tend to enhance formation of $CaCO_3$ (Friedman and Sanders 1978, p. 175), and much of the carbonate could have been replaced by gypsum.

Limestone beds always occur in the lower half of the measured sections and are light gray or yellowish gray in color. No "bed" of dolomite was noted. In the westernmost section (8) carbonates comprise about 7% of the sediments. From section 8 there is a fairly regular decrease eastward until in section 6 no carbonate beds are found. Overall, carbonate beds make up less than 4% of the eight sections.

Beds of limestone are typically associated with both subjacent and superjacent siltstone and mudstone. Sediments below the limestone are often less resistant than those above. There may be more gypsum or carbonate cement in the upper beds. Several occurrences of thin gypsum beds closely associated with limestone were noted. Once an overlying siltstone bed was noted to have current ripple marks, and in one place in section 1 the limestone was immediately overlying mudcracked mudstone.

Limestones are invariably silty (up to 15% by weight) and usually contain peloids and/or ooids (fig. 9). The ooids range in size from 0.15 to 0.8 mm in diameter with 0.4 mm being typical whereas the peloids are usually less than 0.1 mm in size (these measurements are made from thin sections). Oolites have sometimes been squashed and/or broken from compaction while still soft, forming spastoliths (fig. 10). These rocks would be classified as wackestone or packstone (Dunham 1962, p. 117). Diagenetic recrystallization is very common, as can be seen in figure 11 and from epitaxial rims visible in previous figures. Gypsum has replaced some of the preexisting micritic matrix, and thin selenite/gypsum veins were occasionally seen cutting an ooid. Thin siltstone stringers and small rip-up clasts were also seen in the limestones.

Reber (1951, p. 44) did not mention any limestone in the Shnabkaib of the northern Beaver Dam Mountains some 60 km to the west, probably because of the scale at which he measured his sections while mapping that area. On a brief field study some 55 km to the north near Cedar City, no limestone beds were noted by this writer, but 130 km to the north in the southern Pavant Range crystalline limestone beds are reported as being common in the Shnabkaib (Crosby 1959, p. 28; Bob Davis personal communication).

ACCESSORY MINERALS

Pyrite is the only accessory mineral readily seen in the field worthy of mention other than selenite/gypsum. It occurs as small cubes up to 1 mm, and is found only in the light colored (gray) sediments (fig. 12). Frequently, pyrite has been replaced by limonite which has stained the surrounding sediments a dusky red color. The resulting color contrast (dusky red on gray) facilitates recognition of pyritic zones.

Pyrite occurs in mud partings within gypsum, in gyp-

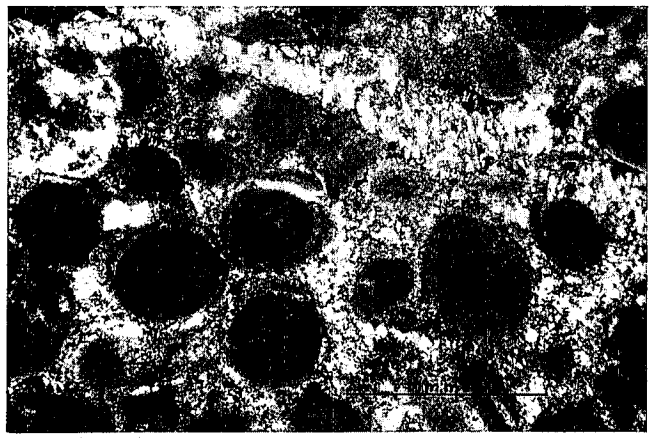


FIGURE 9.—*Photomicrograph of a moderate brown sample of peloidal oolitic wackestone. Note that matrix has been replaced by gypsum, secondary fractures filled with satin spar gypsum, and epitaxial rims, section 8, unit 1, crossed nicols, X15.*

siferous siltstones, in laminated gypsum, and at either the top or bottom of gypsum beds. It is stratigraphically controlled, being found on bedding planes, and is continuous for several meters. A general decrease in the amount and distribution of pyrite was noted from west to east, with no pyrite being observed in the easternmost section. In a roadcut along Interstate 15, a few kilometers south of St. George, pyrite is very common and forms cubes up to 5 mm in size. This roadcut is some 10 km east of section 8, where pyrite is also quite common but forms smaller cubes. The presence of pyrite in gray or greenish sediment is an indicator of reducing conditions at the time of formation, and hence the sediment was not subaerially exposed when deposited (Friedman and Sanders 1978, p. 525).

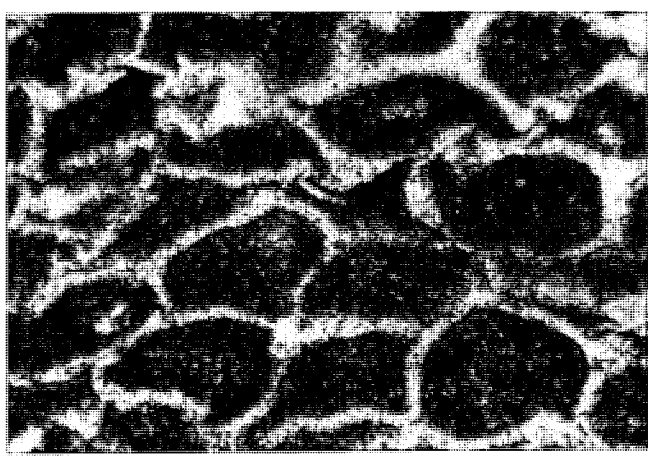


FIGURE 10.—*Photomicrograph of oolitic grainstone showing radial fibrous structure and replacement by gypsum (?). Deformed and crushed oolites are called spastoliths and may indicate rapid deposition of overlying rocks; section 4, unit 5, (field of view is 1.3 mm), X37.8.*

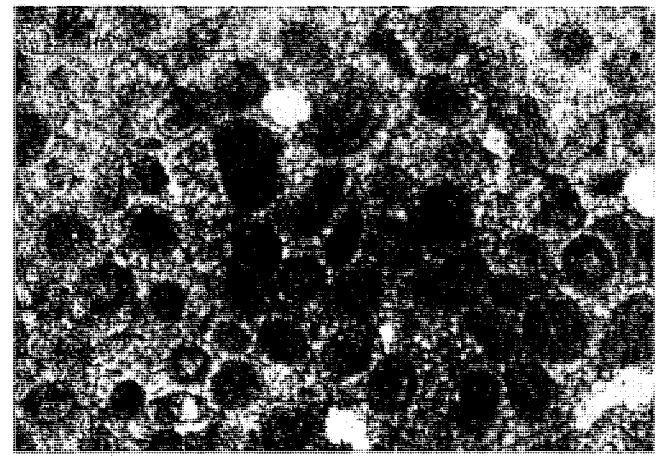


FIGURE 11.—*Photomicrograph of intra-oolitic peloidal wackestone, mostly recrystallized calcite, section 5, unit 10, plain light, X15.*

SEDIMENTARY STRUCTURES

In the section on lithology, several sedimentary structures were mentioned. Ripple marks and bedding were used as distinguishing characteristics in the siltstones. In addition, mudcracks, contorted bedding, scour marks, and small-scale ball-and-pillow structures were observed.

RIPPLE MARKS AND BEDDING

Commonly, individual beds are laminated or thinly bedded; rarely are beds more than a few centimeters thick. The main exceptions are the massive gypsum and layers of mudstone. The growth and diagenesis of gypsum would have destroyed any primary structure that may have occurred in the gypsum beds at the time of deposition.

Siltstones normally have even parallel beds which are continuous for several meters, though wavy lenticular

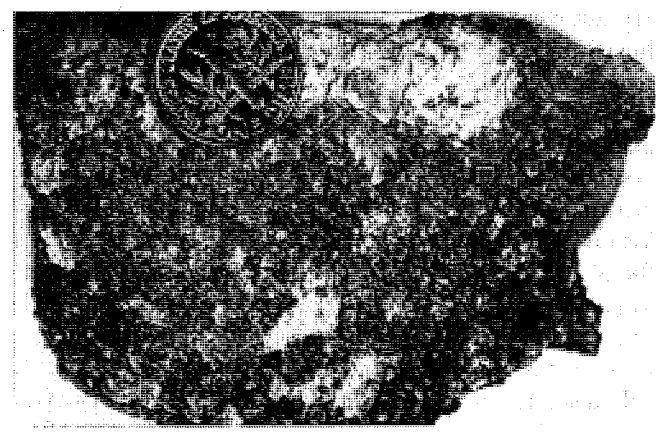


FIGURE 12.—*A layer of small pyrite cubes on a muddy gypsiferous siltstone.*

beds are found (fig. 13). Laminations are typically less than 3 mm thick and vary from even parallel to discontinuous, wavy, and nonparallel. In the shaly or muddy siltstones both flaser and lenticular bedding are common (fig. 4). As seen in figure 8, the laminae of the algal-laminated gypsum are very thin. Also of note are occasional interbedded and small-scale fining-upward sequences composed of coarse to fine silt.

Ripple-marked or cross-laminated sediments are fairly common and were found in one-fifth of the units measured. The ripple marks were less common than observed in some red bed members of the Moenkopi Formation in several localities. Because of the nonresistant nature of the Shnabkaib, few ripple-marked surfaces were found; cross-laminations, however, were more common. As a result, a meaningful statistical approach to transport direction, ripple-size, and morphology was essentially impossible. But what was seen compares very favorably with a sampling of 300 ripple marks in the Moenkopi by McKee (1954, p. 58) as seen in table 1.

Ripple marks and cross-lamination occur three times more frequently in the light-colored sediments than in the red or brown sediments, probably as a result of the generally more resistant nature of the light-colored rocks and as a function of primary deposition. The typical ripple mark in the Shnabkaib is a small asymmetrical parallel ripple which is thinly laminated and usually occurs in a thin to medium bed of siltstone. Variations include bifurcation of crests, some symmetrical/bimodal ripples, and some which show a climbing character. Interference ripples were also seen in two localities, one near section 3 and another just south of St. George. Of 13 transport directions recorded from ripple marks in the measured sections, the average direction was N 12° W. At only one locality was a ripple-marked surface of a few square meters exposed—in a streambed north of section 3. It consists of several layers of straight-crested, parallel ripples with the transport direction consistent on any one layer but ranging from N 45° E to N 30° E in the different layers. Interference ripples were also present in these light gray siltstones. Near the base of section 2 was found the only large-scale cross-bedding (about 30 cm long). It was in association with lensing siltstone beds. This cross-bedding and lensing appear to be due to local current channeling.

Reineck and Singh (1975, p. 23) reported that a ripple index (ratio of ripple length to amplitude) greater than 15

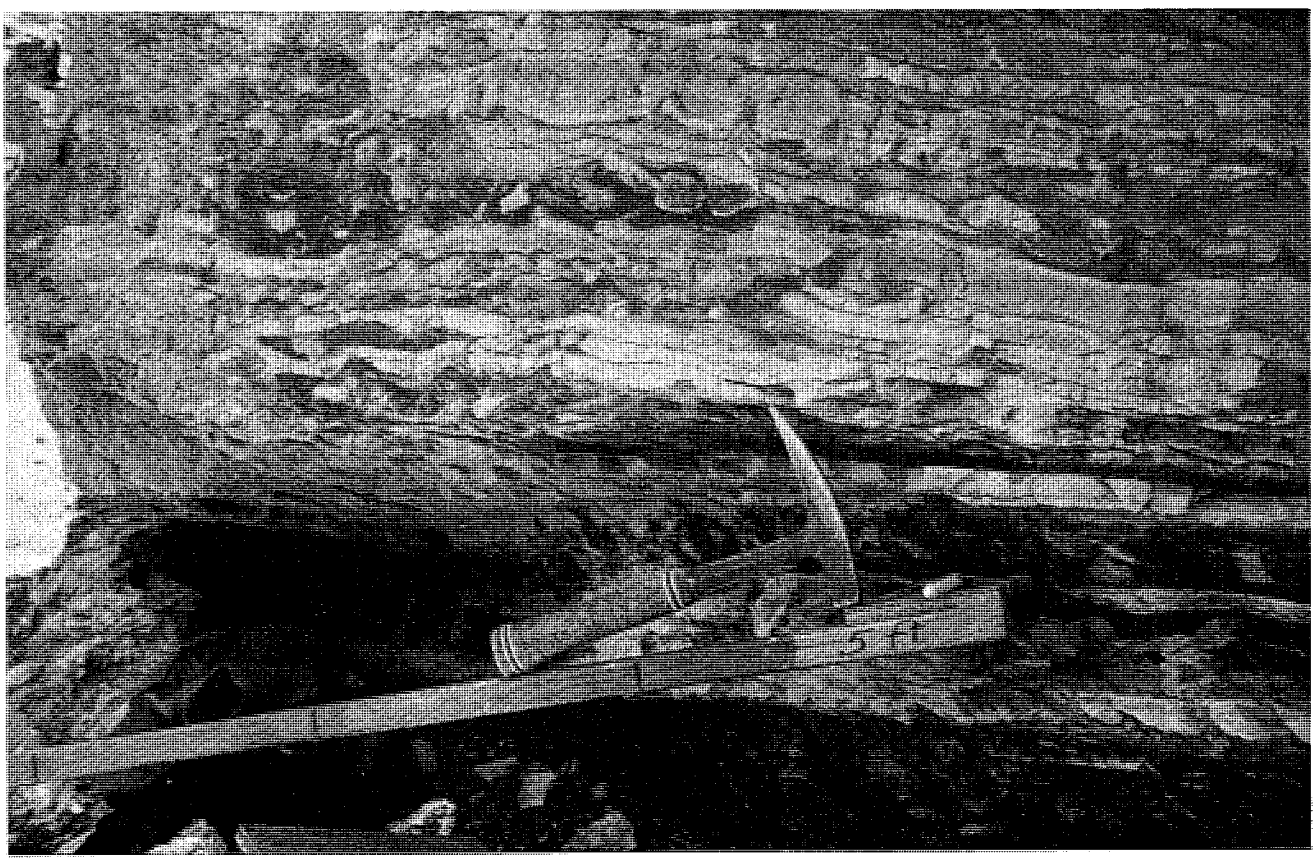


FIGURE 13.—*Wavy lenticular bedding, mottled bedding, and possible ball and pillow structure in silt and mudstone; roadcut, section 2, unit 14.*

Table 1. Comparison of Ripple Mark Morphology with McKee (1954)

		Range	Average	Mode
Ripple length	This study (13 readings)	18–35 mm	23 mm	25 mm
	McKee (300 readings)	13–76 mm*	25–38 mm**	25–38 mm
Ripple amplitude	This study	2–4 mm	3.2 mm	2 mm
	McKee	0.8–9.5 mm	3.2 mm	3.2 mm
Ripple index	This study	5–17	9	9
	McKee	5–15	9	8

*96% of McKee's readings fell within this range; he also reported 1% less than ½" (12.7 mm) long and 3% greater than 3" (76.2 mm) in length.
**McKee reported his lengths within ranges, thus no exact length is possible for comparison.

is formed only by wind or water currents and not waves. Various geologists report that an index of less than 15 is typical of formation by currents or waves and not wind (Reineck and Singh 1975, p. 46; and McKee 1954, p. 58). Indices of 8–15 are typically formed by currents whereas indices of 6–8 are most typical of waves (Reineck and Singh 1975, p. 45). Reineck and Singh (1975, p. 28) also reported that wave ripples have more regular crests which may bifurcate whereas current ripples are more irregular and bifurcation is absent. McKee (1954, p. 57) interpreted the most common ripple mark in his study, an asymmetrical parallel ripple mark with a ripple index of 9 and a length of 25 mm, as being formed by shallow-water currents. Interference ripples indicate both shallow currents and waves. The foregoing and association with other indicators of shallow water lead to the conclusion that ripple marks in the Shnabkaib were formed in shallow water by both currents and waves.

DESICCATION CRACKS

Desiccation cracks were seen in at least one area of each section except section 6. They could have been much more common than observed since good exposures are needed to see them, and it is difficult to find mudcracks preserved in the brittle mudstone which is typically covered by talus. Desiccation cracks seen were about evenly divided between the light-and red-colored sediments and were found in structureless or horizontally stratified siltstones and mudstones. In one instance, they were found directly on top of a bed of muddy gypsiferous stromatolite. The cracks typically are 1–2 cm across at the top, 1–5 cm deep, and 7–12 cm apart. These mudcracks are seen in plan view, in cross section, and as mud curls. Possible evidence of previous mud curls was seen in one unit with a mud pebble conglomerate. In section 2 some unusually large mudcracks are 5 cm ± wide, 12 cm ± deep, and some 15 cm apart (fig. 14).

SOFT-SEDIMENT DEFORMATION

Contorted bedding is common in the Shnabkaib and was frequently caused by growth of gypsum within the sediment (fig. 15). The gypsum nodules coalesce to form enterolithic structures. Much of the contortion is due to the hydration of anhydrite to gypsum and the in situ growth of anhydrite or gypsum crystals. Most of the convolute bedding is found in the light-colored sediments and is associated with gypsum. Tepee structures 3 cm ± high are fairly common in some gypsiferous laminated sediments.

In section 7, unit 5, a layer of yellowish gray calcareous mudballs 2 to 3 cm in size were found. A few wavy submillimeter black (organic?) streaks were seen in them. The mud balls were likely formed when a layer of mud or clay was broken up and became rounded due to the rolling action of small waves. Formation of such mud balls has been noted by the writer on the shores of Utah Lake, Utah. In section 2, unit 13, what appears to be cm-scale ball-and-pillow structure was noted (fig. 13). In a roadcut near St. George small-scale scour marks were found.

PALEONTOLOGY

Other than fossil algae remnants, little evidence of life has been found in the Shnabkaib. Probably because of high salinity and to diagenesis, the environment was apparently not conducive to a diverse fauna or to fossil preservation.

Gregory (1950, p. 63) listed fossils found in the Moenkopi in the Zion National Park region, and Stewart and others (1972, p. 67) reasoned by process of elimination that the *"Meekoceras" micromphalus* listed by Gregory was found in the Shnabkaib. If so, it was probably washed into the area and did not live there since the environment was not one believed capable of supporting ammonoid life. McKee (1954, p. 75) reported that Gregory collected a few poorly preserved and unidentified brachiopods, pe-

lecypods, and gastropods 20 to 50 m above the base of the Shnabkaib near section 3 of this paper. Though no fossils were found in section 3, I did find gastropod and pelecypod fragments in three other sections. The only other fossils found mentioned in the literature for this member are *Pentacrinus whitei* columnals in the Pavant Range 130 km to the north by Crosby (1959, p. 28) and Feast (1979, p. 30).

In this study, fossil remnants were found in one bed in sections 5, 7, and 8. These medium thick beds with fossils are invariably light-colored, silty, and muddy limestones with some short (up to 11 cm long) horizontal trails. In section 1 vertical burrows were found with no associated fossil fragments. These burrows are 2–3 cm deep and slightly curved at the base forming a *j*-like pattern. They occur in a yellowish gray muddy gypsiferous siltstone that also contains some algal filaments. All fossils are poorly preserved, lack internal structures, and are recrystallized or replaced. Gastropod fragments (1 cm in size) were found in section 5, small (1 cm) pelecypods (*Monotis* ?) and steinkerns (?) were found in sections 5, 7, and 8 (fig. 16).

Flat-lying algal mats, which were discussed briefly with laminated gypsum, were apparently very extensive at the time of deposition. The writer has yet to read of investigators mentioning algae in the Shnabkaib. A review of the literature on both ancient and modern algal mats showed that flat-lying algal mats (as opposed to blister, colloform, etc.) have the highest potential for preservation in the geologic record and are mainly composed of blue-green algae (Butler 1969, p. 73; Gunatilaka 1975, p. 292; Park 1977, p. 48; and Wilson 1975, p. 360).

The abundance of peloids seen in thin section is evidence of much more abundant burrowing or grazing life than otherwise thought from the few burrows and trails observed. Poor preservation of trails and burrows can be explained by crumbly mudstone and destructive nature of gypsum and algae both on and within the sediment. Gunatilaka (1975, p. 290), in his study of algal mats, observed that, though cerithid gastropods were abundant on the mats, their trails were destroyed by sedimentation and algal growth.

FIGURE 14.—*Large mudcracks (?) extending from gypsiferous siltstone into mudstone, road level, section 2, unit 11.*

PALEOENVIRONMENT

Near the town of Virgin, Utah, rocks of the Shnabkaib Member of the Moenkopi Formation represent sedimentation along the fluctuating coastline of a very shallow hypersaline sea. Sedimentation took place during a minor eastward transgression of the sea in an arid climate across a broad floodplain. The shallow water and low relief of the coast caused a low-energy seaway.

PALEOCLIMATE

During deposition, the climate was likely uniformly warm and arid. Evidence for such a climate is derived from lithology, postulated latitude, and comparison with modern analogues of this environment. Red beds and evaporites are usually indicators of warm, arid climes.

FIGURE 15.—*Deformed bedding caused by the growth of a large translucent gypsum nodule, section 3, unit 3.*

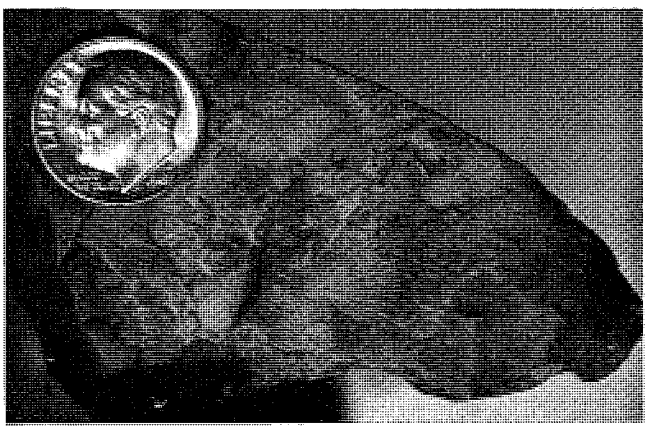


FIGURE 16.—*Very silty limestone with best fossil found and some steinkerns (?); none of the original shell is preserved; section 8, unit 9.*

Abundant gypsum is a clear indicator of net evaporation, and net evaporation is a function of both low precipitation and restricted circulation. Abundant algae and carbonate deposition are also enhanced by warm climates. Friedman and Sanders (1978, p. 180) state that nodular anhydrite is the signature of a sea-marginal sabkha in an arid climate.

Using paleogeographic and paleoclimatic maps of Dott and Batten (1971, p. 292, 345) it is estimated that southwest Utah was within 5° latitude of the equator and arid during deposition of the Shnabkaib. At such a latitude seasonal variations in temperature would have been minimal and warm weather the norm.

For comparison purposes it is postulated that the Abu Dhabi area of the Trucial Coast in the Persian Gulf is a modern analogue of the depositional environment of the Shnabkaib. It has been reported by Kinsman (1969, p. 838–39) that the average seawater temperature at the Trucial Coast is 29°C (84°F) and varies from 15°–40°C (59°–104°F). He also reports that for the formation and preservation of supratidal anhydrite a mean annual temperature greater than 22°C with seasonal fluctuations over 35°C is essential. Park (1977, p. 491) in his study of the same area reported that rainfall was less than 100 mm/yr and the air temperature varied from 15°–55°C (59°–131°F).

Another comparable arid evaporite coast is that found at the Ojo de Liebre Lagoons in Baja California. This series of lagoons lies 28° north latitude and average 20 mm of rain a year. Sediments there have a high percentage of clastics, halite, and gypsum but very little dolomite (Phleger 1969, p. 824).

SALINITY

Abundant gypsum is clear evidence of hypersaline conditions whereas the rare fossiliferous carbonates indicate more normal-marine salinities. Indirect evidence for hypersalinity is the lack of fossils throughout most of the rock record and the presence of thick algal mats. Friedman and Sanders (1978, p. 337) report that the cerithid gastropods which feed on the algae are less tolerant of high salinities than the algae. It is believed that in some modern areas algal mats are thin largely because of the voracious gastropods.

Scruton (1953, p. 2503) listed salinity ranges for precipitation of different minerals at typical densities as follows:

$CaCO_3$ precipitates from 72–199 ppm
$CaSO_4$ precipitates from 199–332 ppm
$CaSO_4$ & NaCl precipitate from 353–457 ppm

Park (1977, p. 487) reports salinities varying from 50–75 ppm in the algal mats at the Trucial Coast (normal seawater is 35 ppm). Gunatilaka (1975, p. 295) states that algae can tolerate salinities of 60 ppm without trouble, but little more. Maximum salinities of 330 ppm have been found in sea-marginal pools associated with bedded gypsum at the Red Sea (Friedman 1978, p. 180). On the basis of these modern examples, it seems reasonable to expect that the salinities in the Shnabkaib sea and evaporating ponds would have ranged from about 40 to 350 ppm. Since no evidence was found for NaCl deposition, it is unlikely that salinities would have exceeded 350 ppm often or in large areas.

WATER ENERGY

Evidence indicates that at least the part of the Shnabkaib seaway studied was an area of low water energy. Structureless mudstone indicates deposition in standing bodies of water. Much of the fine sediment could have been blown in by the wind. Thin laterally continuous beds of fairly uniform thickness are often indicators of low-energy conditions as well as a gradual slope. A gradual slope would have dissipated wave energy over a large area and currents would have been nonexistent or very weak in the shallow waters. Other indicators of low energy include the very fine grained rocks, but such rocks can also be due to a distant and/or fine-grained source. There is evidence of areas of moderate energy with the clean oolitic carbonates which indicates enough energy to roll the particles back and forth and winnow away the fine sediment, but such a rock is rare here. More often the oolitic rocks are mixed with peloids and are only moderately well sorted. Lenticular and flaser bedding indicate alternate periods of currents and calm waters. These currents were likely tidal in origin. Cross-stratification from anything other than small ripples was observed only once and is found at the base of section 2. This occurrence of current cross-bedding could be from a small drainage channel off the tidal flats.

LITHOLOGIC ASSOCIATIONS

Lithologic associations indicate that the rocks of the Shnabkaib represent a shallow eastward transgression and subsequent withdrawal of the sea across an area of very low relief. The low slope caused wide variations in the strandline with minor changes in relative sea level or topography. Lack of rapid changes in the rock record is an indicator of distant or gentle broad tectonic activity at the time (a good review of the tectonics at that time is found in Cadigan 1971, p. 41–42). It is thought that numerous small fluctuations of the strandline are more likely due to migration, formation, and destruction of barrier bars or shoals than to tectonics.

Direction of Transgression

When compared to the enclosing middle red and upper red members, the Shnabkaib is clearly transgressive, but

just barely. In this area of Utah, the Moenkopi has three transgressive members: Timpoweap, Virgin Limestone, and the Shnabkaib; they are separated by three informal red-bed members. In each case, the transgression was from the west or northwest (Stewart and others 1972, p. 76; and McKee 1954, p. 78–79). The direction of transgression is also illustrated in figure 17 and in a comparison of sections 6 and 8, the most eastern and most western sections, respectively (table 2). Evidence of transgression and of shallow-water deposition discounts the possibility of a barred basin as a cause for deposition of evaporites in this area. Broad distribution of this member helps dismiss the possibility of gypsum deposition at the distal arm of a restricted sea (see isopach map of Stewart and others 1972).

Basin Slope

Intermixing of lithologies, scarcity of sharp lithologic boundaries, and the many color changes between gray and brown can be evidence for a slope of very low relief. Lateral continuity of beds also can indicate a gentle slope. A slight topographic variation such as a buildup of algae or an oolite ridge or barrier bar could cause ponding or a wide variation in the strandline. Wind-driven water could also affect the strandline and deposition substantially. Stewart and others (1972, p. 77) suggest that the depositional slope of the Moenkopi Formation may have been on the order of 1 foot per mile. At the Trucial Coast, the slope of the algae belt ranges from 1:1000 to 1:3000; also it is reported that algal mats do not develop if the slope is steeper than 1:1000 (Butler 1969, p. 73; Reading 1979, p. 182–86). Such a low slope could cause the intertidal zone to be several km wide with a tidal range of a few meters.

WATER DEPTH

As well as indicating energy, ooids can also indicate shallow water. It is reported that ooids form in water less than 6 m in depth (Greensmith 1978, p. 145). At Abu Dhabi ooids are found along barrier bars, in tidal deltas, and forming levees along tidal channels which are exposed at low tide. At a depth of 2 m an abrupt change from pure oolite sands to mixed ooid-pellet sand takes place (Reading 1979, p. 179).

Blue-green algae can occur throughout the photic zone, which in normal seas may be as deep as 50 m. Schreiber (1981, p. 18) reasoned that, since hypersaline waters are often poorly oxygenated, there may be high organic residue in suspension, restricting light penetration to 10–20 cm or less. Evidence of poor oxygenation and high organics in the Shnabkaib may be the layers of pyrite. Pyrite is an indication of a reducing environment, which could be developed if decaying organic matter (algae) used up the available oxygen (Dunbar and Rodgers 1957, p. 212). At the Trucial Coast blue-green algae do not occur below 10 m water depth nor above the high-water mark (HWM), where it is destroyed by desiccation (Park 1977, p. 487).

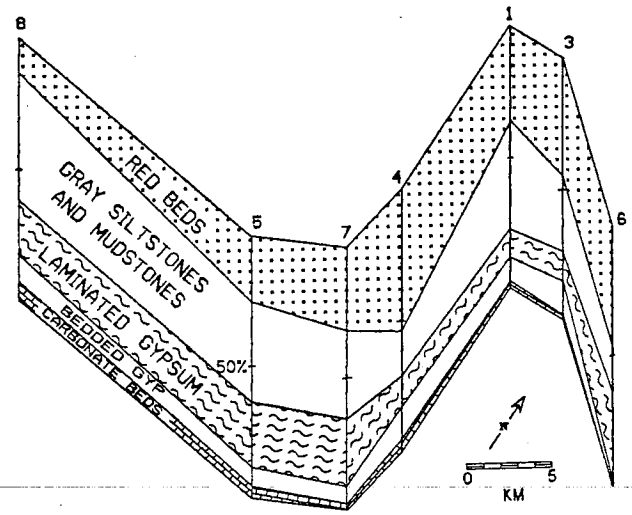


FIGURE 17.—*Fence diagram depicting percentages of various lithologies. Section 2 is omitted since it is incomplete. Carbonate beds decrease and red beds increase from west to east, showing direction of transgression.*

Table 2. Comparison of Sections 6 and 8

	Section 6 (easternmost)	Section 8 (westernmost)
1. thickness of section	69 m (least of the 8 sections)	123 m
2. amount of limestone	absent	most (of 8 sections)
3. fossils	absent	most (of 8 sections)
4. bedded gypsum	least	more
5. % red color	46% (green common also)	13% (least)
6. ripple marks	more common	rare
7. pyrite	absent	most common, largest crystals
8. gypsum nodules	common	absent

Algal mats are typical of the quiet water of the upper intertidal zone, though they do occur in other parts of the intertidal zone and up to lower supratidal, (Butler 1969, p. 73–74; Gunatilaka 1975, p. 292; Park 1977, p. 488; and Reading 1979, p. 181ff). The very shallow water postulated for the Shnabkaib did not allow the algae to build up as mounds or pillars, but only as flat mats.

Though gypsum per se does not indicate a particular water depth, it is more commonly found in very shallow waters. But as mentioned before, abundant gypsum nodules are formed in the capillary zone above the HWM. Other indicators of shallow water that are found are small rip-up clasts, mud-pebble conglomerate, climbing ripples, oscillation ripples, and mudcracks.

SEDIMENTARY MODEL

For the purposes of this paper environments represented in the Shnabkaib in the area studied will be divided into three basic subenvironments; namely, supratidal, intertidal, and subtidal (fig. 18). Much in these environments corresponds to standard carbonate facies #8 and #9 of Wilson (1975, p. 350–60). He calls facies #8 "restricted circulation on marine platform" and facies #9 "platform evaporite facies." Many recent papers have been written on evaporites, perhaps because of the petroleum potential in this environment (Kirkland and Evans 1981, Schreiber 1981). Authors on ancient evaporites frequently use Abu Dhabi as a modern example of a sea-marginal evaporitic environment.

On a broad shelf of such low relief as is postulated for this rock body, it is very difficult (and perhaps pointless at times) to differentiate between these environments. In particular, because of wind and slight tidal variations, the size of the intertidal zone would vary substantially in breadth. This would make a transition zone between the intertidal and supratidal zones and make the two indistinguishable from each other. Other difficulties with this member are the fine grain size and diagenesis. Fine grain/crystal size makes difficult mineral identification and interpretation of environment. Diagenesis can change the placement, mineralogy, and fabric of gypsum and result in the changing of nearby sedimentary structures. Di-

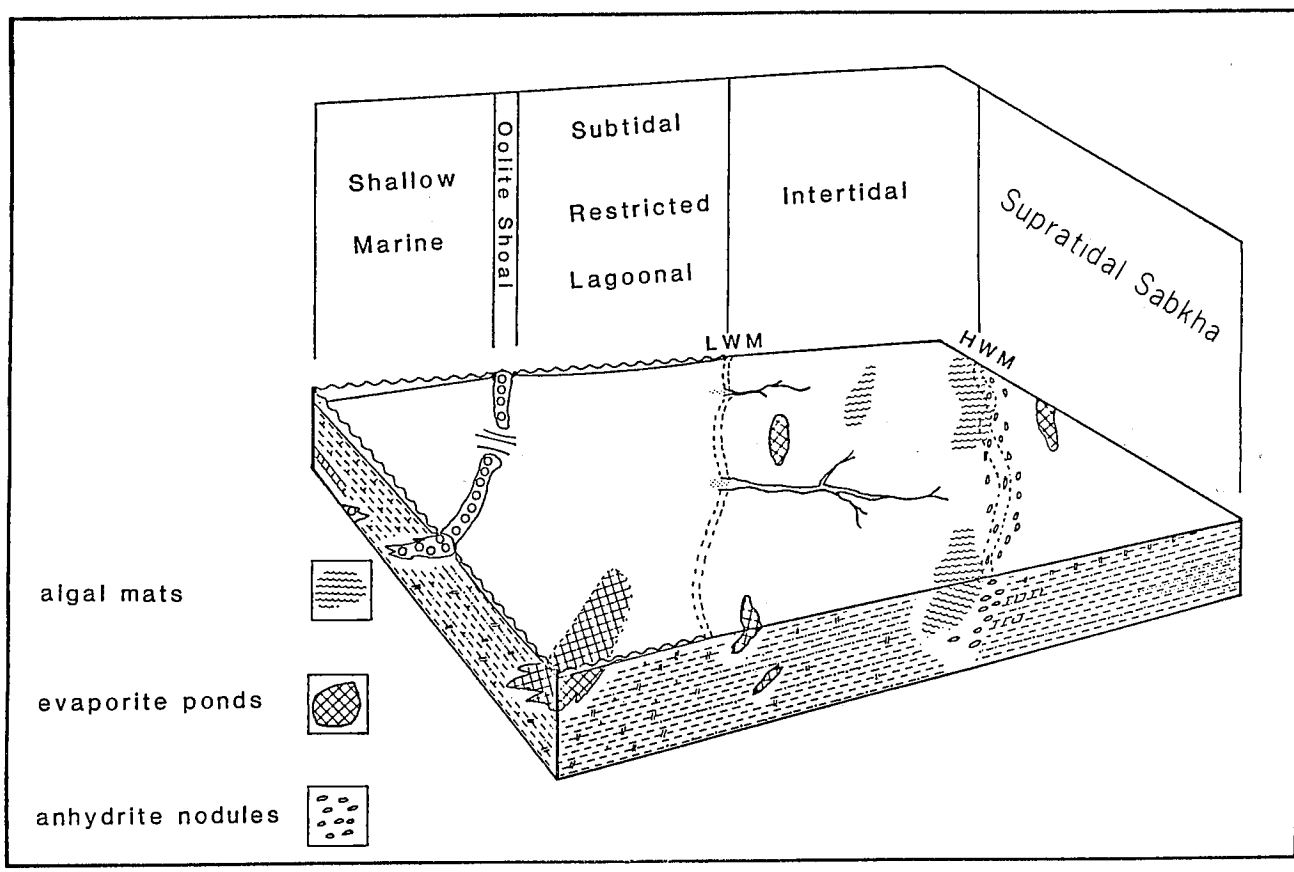


FIGURE 18.—*Depositional model for the Shnabkaib member, showing wide intertidal areas with algal mats, gypsum nodules at high-water mark, and evaporitic ponds forming mainly in the restricted lagoonal area.*

agenesis can also cause replacement of carbonates with each other or with gypsum, or it can cause changes in sediment color. Nevertheless the distinction will be attempted.

SUPRATIDAL ENVIRONMENT

Rocks deposited in a supratidal environment are those above the HWM but within the reach of storm or wind-driven water. Though perhaps not meeting this definition, any rocks from a coastal floodplain will be included in this section.

The presence of gypsum nodules seems to be one of the most readily identifiable lithologies/structures that is restricted to the supratidal coastal sabkha area, as was pointed out in the discussion on gypsum nodules. Nodules form above the HWM and within the water table or capillary zone. Nodules occur in both gray and brown horizontally laminated silts or muddy siltstones and often caused distortions in the sediments. Often the nodules were found near the gray/brown contact. Since the nodules grew within the sediment while the sediment was still soft, it is believed that the enclosing rocks were also formed in the supratidal or uppermost intertidal zone.

Another major indicator of supratidal deposition is the oxidized brownish sediments. But as pointed out by McKee (1954, p. 78) and Poborski (1954, p. 982–83), the color of primary reddish sediments deposited under tidal waters could have been preserved if the salinity had been sufficiently high to prevent the activity of sulphate-reducing bacteria. Though some red beds may be from tidal-flat areas, most are believed to have been deposited on a floodplain, especially when associated with cusp ripple marks, lithoclasts, and a scarcity of fossils. Association with intertidal deposits and similarities with the middle and upper red members help identify the red beds as terrestrial deposits. Other characteristics of supratidal deposits that are noted are gypsum, mudcracks, dolomitic sediments, and a lack of fossils. Some of the laminated gypsum is probably from this zone since discontinuous laminated sediments are characteristic of the supratidal environment (Lucia 1972, p. 170ff). But since most of the laminated gypsum is in the light-colored rocks, it is believed that most were formed in the intertidal zone.

INTERTIDAL ENVIRONMENT

Intertidal sediments are those which are deposited between normal high and low tides. This may be referred to as a tidal flat. As pointed out in the discussion on water depth, large flat-lying algal mats are most distinctive of the upper intertidal zone. As sediments are blown out or wash over the sticky algal mats, they are trapped. Mud, dolomite, gypsum, and pellets can be expected to be interlaminated with the algae. In the sections measured, dolomite or high Mg calcite was identified with energy-dispersive X-ray analysis, but it did not seem to be common. Biota other than algae is rare in a hypersaline intertidal zone. However, some vertical burrowing organisms may occur (Heckel 1972, p. 244), but burrows are rare in the sections measured.

Gray or greenish siltstones, silty mudstones, gypsum, and pelletal lime muds are typical of an intertidal zone (Baldwin 1973, Reading 1979 and others) and are common in the Shnabkaib. This is especially true when combined with small parallel ripples, symmetrical ripples, flaser or lenticular bedding, and mudcracks. Also common to this environment and to the Shnabkaib are gray pyritic or limonitic silts and shales. Occasional lenticular cross-bedded siltstone and sandstone beds may indicate former channels that drained the tidal flats.

SUBTIDAL ENVIRONMENT

The subtidal environment is defined here as the areas in shallow water and below low tide, including lagoonal sediments. Shallow-marine rocks are represented by fossiliferous silty carbonates, oolitic carbonates, gray laminated shales (or mudstone), silty micrite, and pyritic silts and shales. Horizontal or U-shaped burrows and trails were occasionally seen and are more typical of shallow marine than of hypersaline intertidal or supratidal areas (Heckel 1972, p. 244, and others).

Sediments of restricted lagoons include gray laminated or structureless mudstones, siltstones, peloidal muds, and bedded gypsum (Lucia 1973, p. 162–64). The thickest gypsum beds are found in the westernmost sections where more water (and thus more salt) was available to evaporate to form thick gypsum beds. A great deal of water needed to evaporate to form such gypsum beds. Poborski (1954, p. 986) suggested that some of the bedded gypsum could be eroded from the underlying gypsiferous alpha member of the Permian Kaibab Limestone, but this writer does not know of any nearby place where the Kaibab Limestone was being substantially eroded during deposition of the Shnabkaib. Restricted lagoons could have been found in the intertidal zone, where they may have been periodically cut off completely from the sea. But the lagoons must have had periodic (at least) water recharge to have formed gypsum beds several meters thick.

SUMMARY

Rocks of the Shnabkaib Member near the town of Virgin, Utah, represent a shallow, fluctuating transgression from the west across a broad, gentle floodplain. Shallow water, a warm arid climate, and restricted circulation due to low relief and possibly, in part, to barrier bars combined to cause hypersaline waters and the formation of

coastal sabkhas. The end of Shnabkaib deposition occurred with the withdrawal of the sea to the west.

Subtidal and lagoonal sediments are represented by gray, burrowed, and fossiliferous silty ooid-peloidal limestones; structureless or laminated silty mudstones or shales; and pyritic siltstones. Gypsum beds formed from the evaporation of restricted lagoonal waters and hypersaline ponds. Extensive intertidal sedimentation is represented by thick accumulations of flat-lying muddy, cryptalgal laminated gypsum; light gray or greenish gray, laminated, muddy siltstones; peloidal micrites; and pyritic, argillaceous siltstones. Parallel and symmetrical ripple marks, flaser or lenticular bedding, small-scale graded bedding, and mudcracks help identify intertidal deposition. Layers of gypsum nodules and associated contorted bedding help to identify the supratidal environment. Also important in identifying the supratidal/sabkha and floodplain environment are moderate brown, horizontally laminated siltstone and silty mudstone or shale. These lithologies are more diagnostic when combined with other features typical of a supratidal environment such as disrupted bedding, mudcracks, cusp ripple marks, and a lack of fossils.

The appendix for this paper, manuscript pages 1–20, is on file at the Department of Geology, Brigham Young University, where a copy may be obtained.

REFERENCES CITED

Baldwin, E. J., 1973, The Moenkopi Formation of north-central Arizona—an interpretation of ancient environments based upon sedimentary structures and stratification types: Journal of Sedimentary Petrology, v. 43, no. 1, p. 92–106.

Bassler, H., Reeside, J. B., Jr., 1921, Oil prospects in Washington County, Utah: U.S. Geological Survey Bulletin no. 726-C, p. 90–92.

Bissell, H. J., 1970, Petrology and petrography of Lower Triassic marine carbonates of southern Nevada: International Sedimentary Petrology Series, v. 14, Leiden, Netherlands, 27p.

Butler, G. P., 1969, Modern evaporite deposition and geochemistry of coexisting brines, the sabkha, Trucial Coast, Arabian Gulf: Journal of Sedimentary Petrology, v. 39, no. 1, p. 70–89.

Cadigan, R. A., 1971, Petrology of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region: U.S. Geological Survey Professional Paper 692, 70p.

Crosby, G. W., 1959, Geology of the South Pavant Range, Millard and Sevier Counties, Utah: Brigham Young University Geology Studies, v. 6, no. 3, 59p.

Dott, R. H., and Batten, R. L., 1971, Evolution of the Earth, 2nd ed: McGraw-Hill, New York, 489p.

Dunbar, C. O., and Rodgers, J., 1957, Principles of stratigraphy: John Wiley and Sons, New York, 356p.

Dunham, R. J., 1962, Classification of carbonate rocks according to depositional texture: In Ham, W. E. (ed.), Classification of carbonate rocks, a symposium: American Association of Petroleum Geologists Memoir 1, p. 108–21.

Feast, C. E., 1979, The structural history of two klippen on the west flank of the Pavant Mountains, west central Utah: Master's thesis, University of Florida, Gainesville, 60p.

Friedman, G. M., 1978, Depositional environments of evaporite deposits: In Marine evaporites: Society of Economic Paleontologists and Mineralogists, short course no. 4, Oklahoma City.

Friedman, G. M., and Sanders, J. E., 1978, Principles of sedimentology: John Wiley and Sons, New York, 576p.

Gill, D., 1977, Salina A-1 sabkha cycles and the Late Silurian paleogeography of the Michigan Basin: Journal of Sedimentary Petrology, v. 47, no. 3, p. 979–1017.

Greensmith, J. T., 1978, Petrology of the sedimentary rocks, 6th ed: Unwin Brothers Ltd., London, 241p.

Gregory, H. E., 1950, Geology and geography of the Zion Park region, Utah and Arizona: U.S. Geological Survey Professional Paper 220, 200p.

Gunatilaka, A., 1975, Some aspects of the biology and sedimentology of laminated algal mats from Mannor Lagoon, north-west Ceylon: Sedimentary Geology, v. 14, p. 275–300.

Heckel, P. H., 1972, Recognition of ancient shallow marine environments: In Rigby, J. K., and Hamblin, W. K. (eds.), Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralogists, Special Publication 16, p. 226–87.

Huntington, E., and Goldthwait, J. W., 1904, The Hurricane fault in the Toquerville district, Utah: Harvard University Museum of Comparative Zoology Bulletin, v. 42, no. 5, p. 199–259.

Ingram, R. L., 1954, Terminology for the thickness of stratification and parting units in sedimentary rocks: Geological Society America Bulletin, v. 65, p. 937–38.

Kendall, C. G. St. C., and Skipwith, P. A. d'E., 1969, Holocene shallow-water carbonate and evaporite sediments of Khoral Bazam, Abu Dhabi, southwest Persian Gulf: American Association of Petroleum Geologists Bulletin, v. 53, no. 4, p. 841–69.

Kinsman, D. J. J., 1969, Modes of formation, sedimentary associations, and diagnostic features of shallow-water and supratidal evaporites: American Association of Petroleum Geologists Bulletin, v. 53, no. 4, p. 830–40.

Kirkland, D. W., and Evans, R., 1981, Source-rock potential of evaporitic environment: American Association of Petroleum Geologists Bulletin, v. 65, no. 2, p. 181–90.

Lucia, F. J., 1972, Recognition of evaporite-carbonate shoreline sedimentation: In Rigby, J. K., and Hamblin, W. K. (eds.), Recognition of ancient sedimentary environments: Society of Economic Paleontologists and Mineralogists Special Publication 16, p. 160–92.

McKee, E. D., 1954, Stratigraphy and history of the Moenkopi Formation: Geological Society of America Memoir 61, 133p.

Park, R. K., 1977, The preservation potential of some recent stromatolites: Sedimentology, v. 24, p. 485–506.

Phleger, F. B., 1969, A modern evaporite deposit in Mexico: American Association of Petroleum Geologists Bulletin, v. 53, no. 4, p. 824–29.

Poborski, S. J., 1954, Virgin Formation (Triassic) of the St. George, Utah, area: Geological Society of America Bulletin, v. 65, p. 971–1006.

Reading, H. G. (ed.), 1979, Arid shorelines and evaporites: In Sedimentary environment and facies: New York, Elsevier, p. 178–206.

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., Jr., and Bassler, H., 1922, Stratigraphic sections in southwestern Utah and northeastern Arizona: U.S. Geological Survey Professional Paper 129-D, p. 53–77.

Reineck, H. E., and Singh, I. B., 1975, Depositional sedimentary environments, with reference to terrigenous clastics: Springer-Verlag, New York, 412p.

Schreiber, B. C., 1981, Marine evaporites: Facies development and relation to hydrocarbons and mineral genesis, v. 2: Fall Education Conference, American Association of Petroleum Geologists, Calgary, Canada, 44p.

Scruton, P. C., 1953, Deposition of evaporites: American Association of Petroleum Geologists Bulletin, v. 37, no. 11, p. 2498–2512.

Stewart, J. H., Poole, F. G., and Wilson, R. F., 1972, Stratigraphy and origin of the Triassic Moenkopi Formation and related strata in the Colorado Plateau region, with a section of sedimentary petrology by R. A. Cadigan: U.S. Geological Survey Professional Paper 691, 195p.

Ward, L. F., 1901, Geology of the Little Colorado Valley: American Journal of Science, 4th series, v. 12, p. 401–13.

Wilson, J. L., 1975, Carbonate facies in geologic history: Springer-Verlag, New York, 470p.