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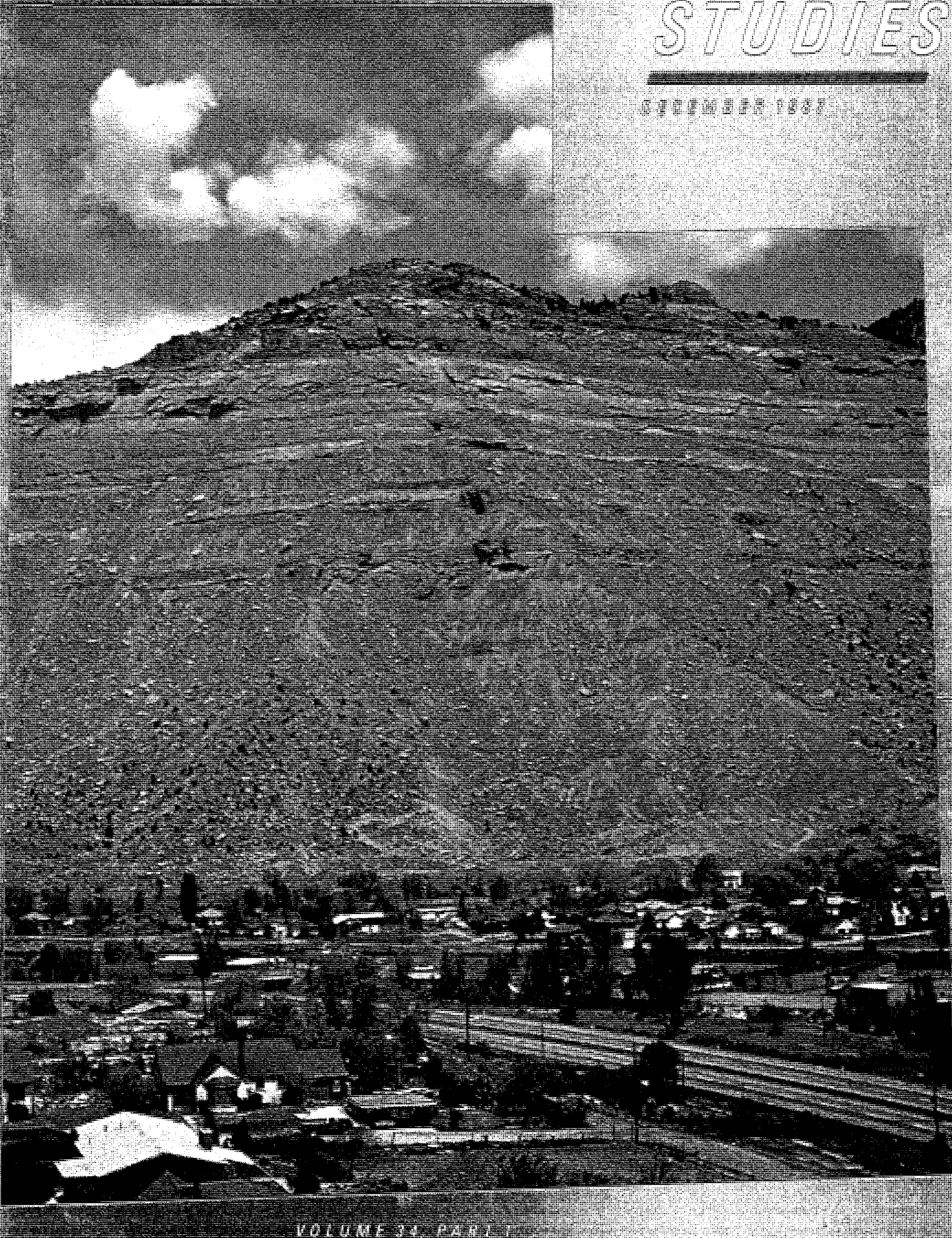

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Cover: Cretaceous coal-bearing rocks near Price, Utah

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Depositional History and Regional Correlation of the Carrico Lake Formation, Lander County, Nevada

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ABSTRACT

Upper Triassic rocks 434 m thick crop out in the Toiyabe Range, adjacent to Carrico Lake Valley, central Nevada. These rocks, herein designated the Carrico Lake Formation, consist of interbedded carbonates and conglomerates with very angular clasts.

The formation is divided into six lithofacies that are designated A through F in ascending order. Lithofacies A is a micritic limestone. Lithofacies B is an angular sandstone. Lithofacies C is composed of generally coarse biosparite. Lithofacies D consists of very angular quartzite-pebble conglomerate. Lithofacies E is red calcareous shale. Lithofacies F is a green-chert gritstone. These rocks represent at least three cycles of deposition, each beginning with shallow-marine ca rbonate and grading upward into clastic shoreline and fluvial sediments.

Correlation of the Carrico Lake Formation with other measured sections in the area indicates a nearshore paleogeographic setting.

INTRODUCTION

Several depositional environments are represented in Triassic rocks now exposed discontinuously in Great Basin ranges in central Nevada. The challenge is to determine former relationships and patterns of deposition. Upper Triassic rocks in the Toiyabe Range, Lander County, Nevada, heretofore undescribed, provide another datum point for interpreting the Triassic depositional history of Nevada. These rocks represent a shallow-marine, transitional zone between the correlative open-marine rocks of the Star Peak Group to the west and the subaerial platform rocks of the Chinle Formation to the east. Shallow subtidal and intertidal carbonate rocks are cyclically interbedded with angular conglomerates that were deposited in a prograding beach/fluvial system. Rocks of the Toiyabe Range, when placed in their regional setting, serve to link Upper Triassic rocks of the western United States and provide a more complete depositional history of the Triassic of central Nevada.

LOCATION

The area studied is located 70 km north of Austin, Nevada (fig. 1). Outcrops occur in the western foothills of the Toiyabe Range bordering Carrico Lake Valley, on the Hall Creek, Nevada, fifteen-minute quadrangle. Access is by county-maintained gravel roads and an unimproved jeep trail from Nevada 305.

METHODS AND NOMENCLATURE

Three stratigraphic sections were measured with Jacob's staff and Brunton compass. Thin sections were made of samples from all carbonate and shale units. Color nomenclature of lithologic units follows the color chart published by the Geological Society of America (1975). Terminology of carbonate rocks follows Folk (1959) and Dunham (1962). The classification system used is that which best seems to fit the specimen in question. Stylolite description follows Park and Schot's (1968) classification system. Clastic terminology is from Wentworth (1922).

PREVIOUS WORK

Triassic rocks in the Toiyabe Range were first discovered by J. H. Stewart in 1968 (see Stewart and McKee 1977) and were mapped by Silberling (personal communication 1983) (fig. 2). These are the easternmost exposures of marine Middle or Upper Triassic rocks known in Nevada. A trachyceratid ammonite, either *Trachyceras* or *Daxatina*, from these beds documents a latest Ladinian or

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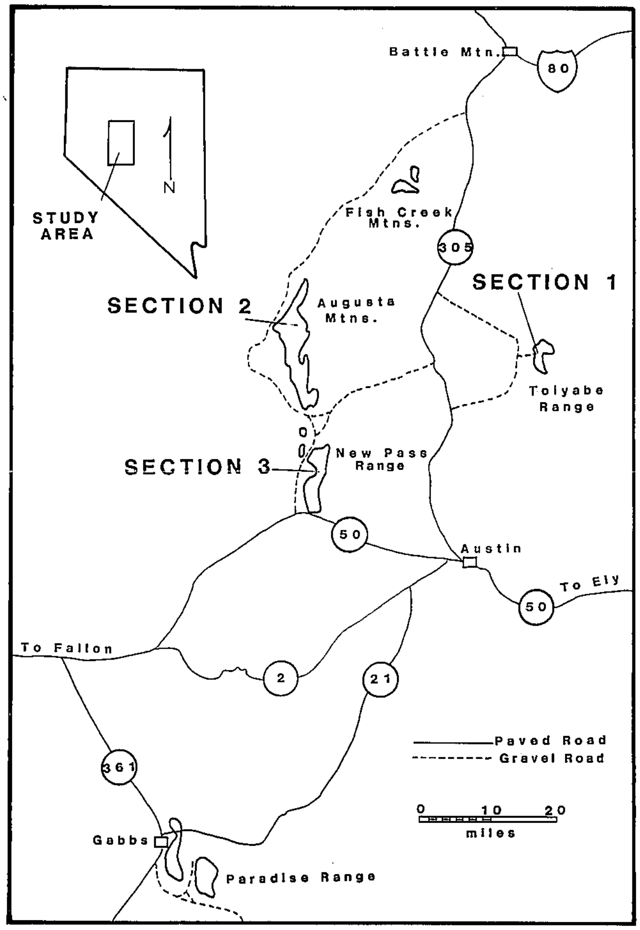


FIGURE 1.—*Index map of west central Nevada. Shaded areas indicate outcrop locations of Middle Triassic rocks. The Carrico Lake Formation was measured and described in the Toiyabe Range (section 1, fig. 4). Regionally correlative sections were measured in the Augusta Mountains (section 2, fig. 17), and the New Pass Range (section 3, fig. 18).*

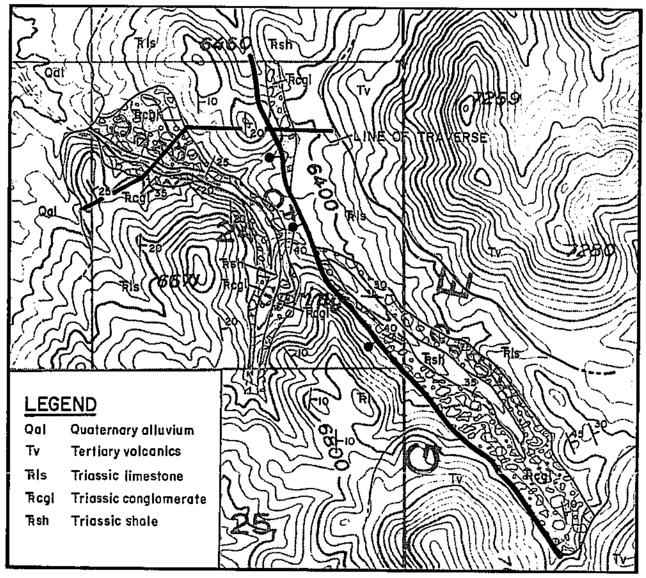


FIGURE 2.—*Geologic map of the Dead Ox Canyon area in the Toiyabe Range, adjacent to Carrico Lake Valley, west central Nevada (see fig. 1). The area was originally mapped by N. J. Silberling (unpublished) in the late sixties. The type section of the Carrico Lake Formation (fig. 4) was measured along the indicated line of traverse. It is located in section 24, T. 24 N, R. 45 E, Hall Creek, Nevada Quadrangle.*

earliest Karnian age (fig. 3) equivalent to the Smelser Pass Member of the Augusta Mountain Formation (Nichols and Silberling 1977). However, these isolated rocks in the Toiyabe Range are too different lithologically to be a part of the Augusta Mountain Formation. Neither are they like the age-equivalent rocks of the New Pass Range, described briefly in this paper.

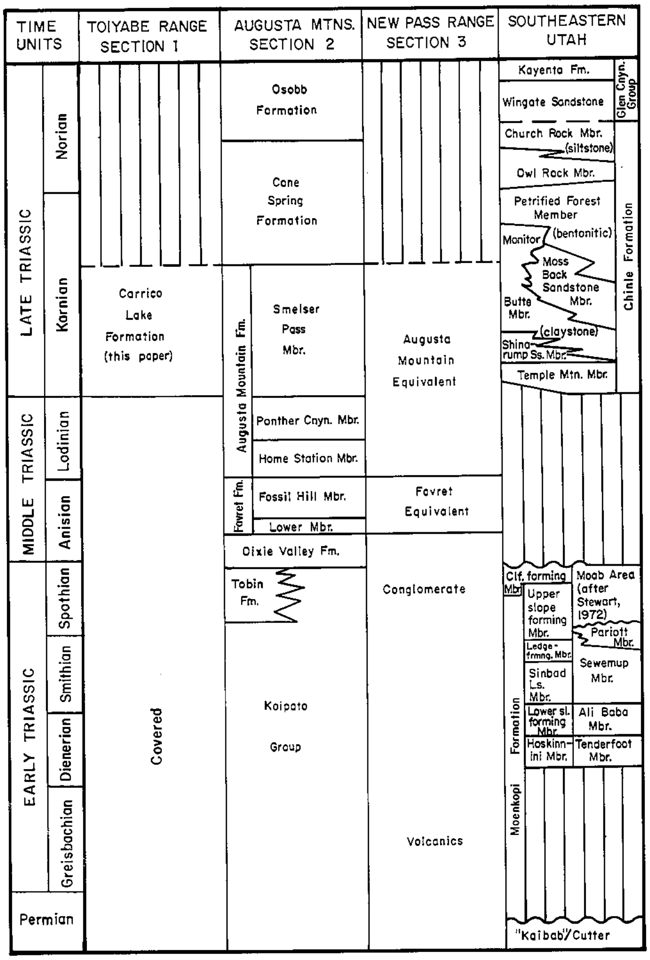
Middle Triassic rocks in central Nevada were first described by Muller and others (1951). Silberling and Roberts (1962) divided the rocks into the informal "Winnemucca" and "Augusta" sequences. The Winnemucca sequence consists mainly of terrigenous clastic rocks and was thought to represent an autochthonous facies. Rocks of the Augusta sequence are mostly carbonates initially thought to have been juxtaposed with the Winnemucca sequence along the inferred "Tobin thrust" branch of the Golconda thrust (Muller 1949).

Nichols and Silberling (1977) stated, "Detailed work by Burke (1979, 1973) in the southern Tobin Range, through which the trace of the Tobin thrust was supposed to extend, demonstrated that no such thrust fault exists and differences between the Winnemucca and Augusta sequences can be explained, for the most part, by rapid facies changes. Moreover, recent findings (Silberling 1970, 1973; MacMillan 1971, 1972; Nichols 1971; and Speed 1971a, 1971b) indicate that the Golconda thrust, which does juxtapose entirely different upper Paleozoic facies in the region, evidently predates deposition of these rocks. Movement on the Golconda thrust in north central Nevada most likely took place during the Sonoma orogeny, in latest Permian or Early Triassic time."

Silberling and Wallace (1967, 1969) formally named these rocks the Star Peak Group, which includes parts of both the Augusta and Winnemucca sequences. Basal conglomerates of the Winnemucca sequence were assigned to the Permian Koipato Group.

CARRICO LAKE FORMATION

Because rocks of the study section (section 1, fig. 4) have no named formational counterpart, they are here designated the Carrico Lake Formation, from the location of the type section in the western foothills of the Toiyabe Range, adjacent to Carrico Lake Valley, section 24, T. 24 N, R. 45 E, Lander County, Nevada.



1. From Hintze, L.F. (1973)

FIGURE 3.—*Correlation table showing how the three sections measured for this study correlate with temporally equivalent rocks in southeastern Utah. The Carrico Lake Formation, measured and described in the Toiyabe Range, is thought to be a nearshore deposit, separating cratonic rocks of the Chinle Formation in southeastern Utah from deeper marine rocks measured in the Augusta Mountains and the New Pass Range. See fig. 1 for the locations of section 1–3.*

Fossils from the Carrico Lake Formation in the Toiyabe Range were previously collected and identified by Mackenzie Gordon, Jr. (Stewart and McKee 1977, p. 30), and N. J. Silberling. Their collection, designated as 14800-15J, was taken from rocks located in section 1, T. 24 N, R. 45 E, Lander County, Nevada. It includes the following:

14800-15J

Ammonites:	a trachyceratid, probably *Trachyceras*
Pelecypods:	*Minetrigonia* sp.
	Pinna sp.
	pectenacids
Brachiopods:	*Reticulariina* aff. *R. roundyi* (Girty) and possibly one or two other kinds of spiriferoids
Sponges:	large cup-shaped form and small ovoid form
Gastropods:	several kinds
Bryozoa:	several individuals

The collection now resides with Dr. Silberling at the U.S.G.S. in Denver, Colorado.

About this collection Dr. Silberling wrote, "The trachyceratid ammonites date the collection as early Karnian (earliest Late Triassic) or possibly latest Ladinian (latest Middle Triassic). One of the well-represented kinds of spiriferoids is apparently the same species as that which occurs at the base of the Desatoyense Zone (lowermost Karnian) near the boundary between the lower and middle members of the Augusta Mountain Formation in the New Pass Range and in the limestone member of the Grantsville Formation near Ione, Nevada, which is of latest Ladinian or earliest Karnian age" (Stewart and McKee 1977, p. 30–31). A thin section of a typical limestone in the measured section (fig. 5) shows the broken and jumbled nature of the specimens. This renders further identification difficult.

An earliest Karnian (earliest Late Triassic) or possibly latest Ladinian (latest Middle Triassic) age is established for the Carrico Lake Formation by fossils in collection 14800-15J. This is within the age bracket of the Smelser Pass Member of the Middle and Upper Triassic Augusta Mountain Formation (Silberling and Roberts 1962) (fig. 3).

Rocks in the Carrico Lake Formation are readily divided into six lithofacies (A–F in ascending order) on the basis of combined outcrop and thin-section analysis. The defining parameters and lithologies are discussed for each lithofacies.

LITHOFACIES A

Rocks of lithofacies A are the limestone units of the section. These rocks appear in two separate horizons, from 0–36 m (units 1–3) and from 307–380 m (units 31–33). They are fault repeated at 424 m (unit 38, fig. 4), above which they are covered by Tertiary volcanics. Outcrops range from 60 cm ledges to 4 m cliffs and are generally mottled due to extensive burrowing. Color ranges from greenish gray to light olive gray.

Micritic limestone is the dominant lithology in basal units of this lithofacies and holds up medium ledges (60 cm) in units 1 and 3 (fig. 6) to 130 cm ledges in unit 2. Color ranges from greenish gray in unit 1 to light olive gray that weathers lighter in units 2 and 3. This darker color corresponds to an increasing strength in hydrocarbon odor. All units are extensively burrowed. Fossils are

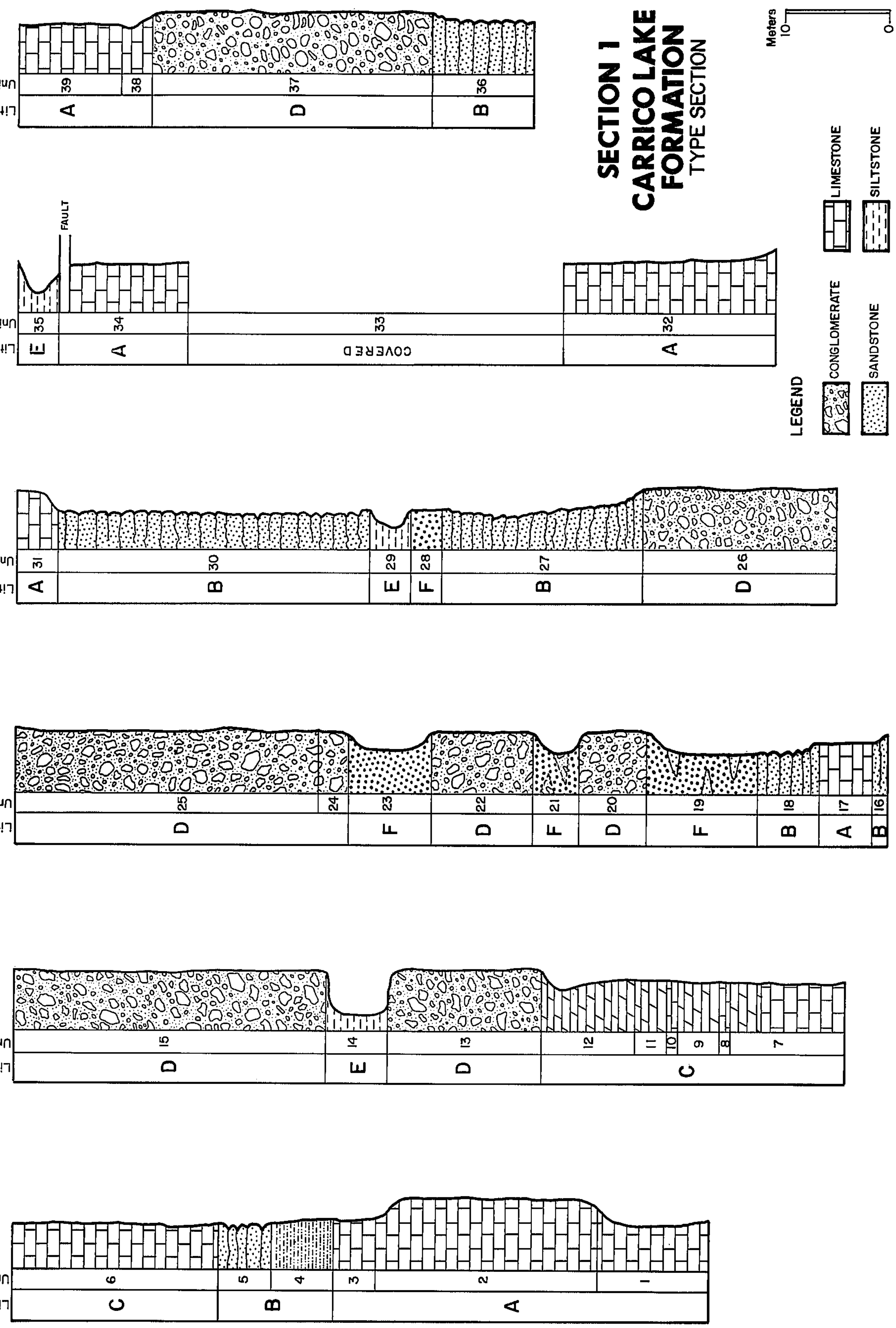


FIGURE 4.—*Measured section 1, type section of the Carrico Lake Formation, Toiyabe Range, section 24, T. 24 N, R. 45 E, Lander County, Nevada. See the appendix for unit descriptions.*

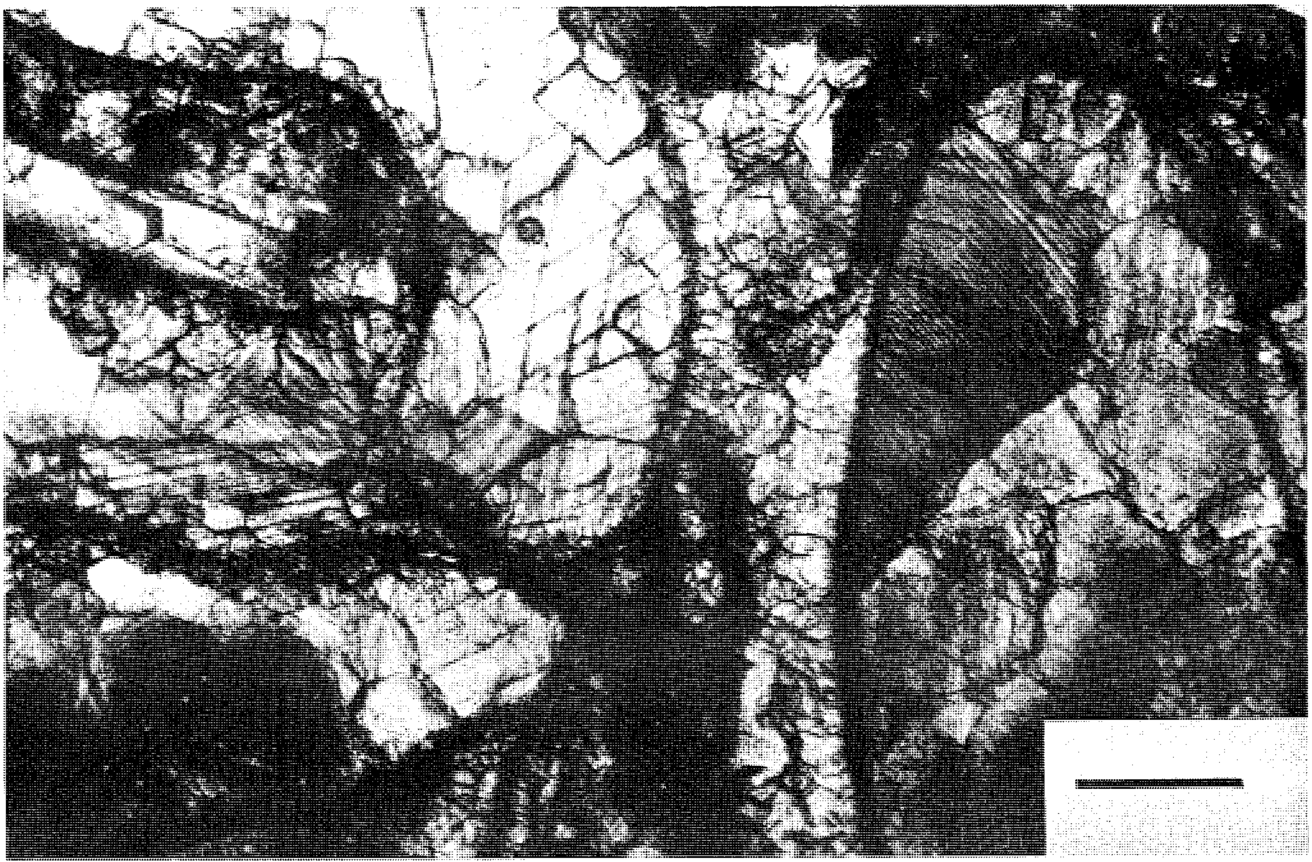


FIGURE 5.—*Photomicrograph: fossiliferous limestone of the Carrico Lake Formation showing well-developed micritic envelopes. The bivalve tests are replaced by neomorphic spar. The matrix has been nearly entirely recrystallized, leaving only a small amount of lime mud surrounding the pelloids in the upper right corner. This sample is from unit 31, section 1 (fig. 4). Bar is .5 mm in length.*

generally broken, but crinoids, thin-shelled bivalves, gastropods, sponge spicules, and corals are recognizable. All units are extensively burrowed. Fossils are generally broken, but crinoids, thin-shelled bivalves, gastropods, sponge spicules, and corals are recognizable. All shells are replaced by drusy calcspar. Unit 1 has vertical stylolites filled with rust-colored organic matter. In thin section, rocks in unit 1 are skeletal wackestone. Unit 3 is better described in thin section as a biopelsparite with pellets making up 60% of the rock. Unit 2 is more massively bedded than units 1 and 3 and also includes patches of rock containing greater amounts of organic matter with less clastic material. These patches are medium dark gray.

A 50 cm bed of angular chert pebble conglomerate separates units 2 and 3. The conglomerate consists of 5–10 mm clasts of light brown quartzite and light olive gray chert in a moderate brown calcareous matrix. The rock weathers into 5 cm parting units and is occasionally interbedded with a laminated coarse sandstone. Burrows in the limestone at the top of unit 2 are stained red due to an influx of ferruginous minerals associated with the conglomerate. Limestone of unit 3 immediately above the conglomerate contains stylolites filled with rust-colored organic matter and quartz-silt grains.

Rocks in unit 3 gradually become more coarse-crystalline upward and grade into lithofacies B (fig. 7). Colors lighten to a pale yellowish brown. The percentage of pellets increases upward through unit 3.

Rocks of units 17, 31–32 are slightly different than the other rocks of lithofacies A. They form 1.5 m ledges of fine crystalline limestone that is pale yellowish brown in color with dark yellowish orange staining. Patches of coarsely crystalline skeletal calcspar appear in the outcrop. Burrows are not present.

These rocks represent a cyclic recurrence of limestones like those in units 1–3. Those generally from slopes and outcrops are scarce. In thin section they are classified as a skeletal wackestone, with skeletal allochems forming 30% of the rocks, 30% recrystallized micritic cement, and less

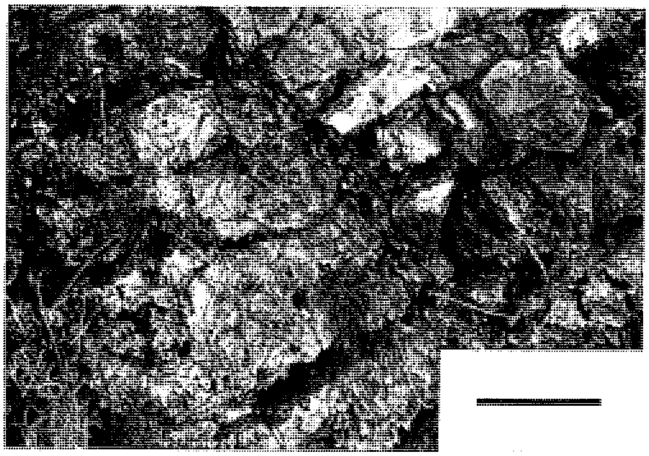


FIGURE 6.—*Limestone ledge in unit 3, section 1. This fractured, ledge-forming micrite comprises units 1 and 3. It is interbedded with the more massive limestone of unit 2. Mottling is due to extensive burrowing. Ledges average 60 cm in thickness. This outcrop is strikingly similar to unit 31, section 1, a photomicrograph of which is presented as fig. 5. Unit 3 and unit 31 are separated by 275 m of rock and represent two separate depositional cycles. The bar in the lower right corner measures 60 cm.*

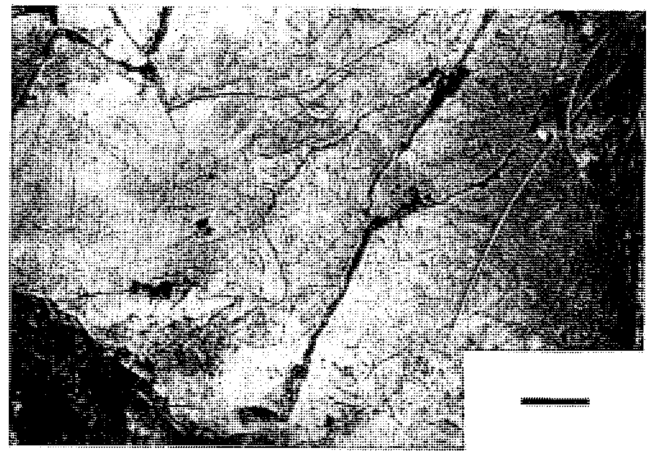


FIGURE 7.—*Coarse crystalline biosparite near the contact of units 3 and 4, section 1. This extensively recrystallized unit overlies limestone like that seen in fig. 6. Note the ubiquitous bivalve fragments. These are made up entirely of neomorphic spar. Bar in the lower right corner is 1 cm in length.*

than 10% pelloids. Skeletal allochems include bivalves and bryozoans with well-developed micritic envelopes surrounding the calcspar-replaced tests (fig. 5).

The rocks of unit 34 are generally sparry and form 4 m cliffs at approximately 380 m. They are light olive gray and extensively burrowed, with bivalve shells and crinoid fragments weathering out in relief. This unit has a hydrocarbon odor much like that of unit 1. Thick bivalve shells are occasionally seen. Two centimeter chert nodules occur locally. Unit 34 and unit 1 are strikingly similar.

Units 38 and 39 represent fault-repeated ledge-forming limestone of lithofacies A. They crop out at 424 m and are overlain by Tertiary dacite. They form 30–60 cm ledges, are light olive gray and extensively burrowed. Thin-section analysis shows these rocks to be a biopelmicrite, with pellets and lime mud making up 90% of the rock.

Allochems are replaced by drusy spar and include bivalves (97%) and a few (3%) echinoderm fragments. Interconnecting network stylolites are also present.

LITHOFACIES B

Sandstones of varying grain sizes are the distinguishing lithology of lithofacies B (fig. 8). The rocks are generally medium bedded, locally forming meter-high ledges, but elsewhere weathering into flaggy, 1–5 cm parting units that form slopes. Cement is calcareous and stained by limonite to a dark yellowish orange.

Units 4 and 5 are composed of coarse sandstone in a dolomitic limonite-stained matrix. Angular grit-size quartzite clasts are present locally, especially in unit 5 and 42 m. This unit lacks extensive limonite stains and is yellowish orange. Angular to subangular sand-size quartzite grains make up 85% of the rock while very angular 1–3 mm quartzite grains make up the rest. Local fractures are filled with calcspar.

Finer-grained sandstone makes up units 16, 18, 27, 30, and 36. These units weather into .5–2 cm parting units that form slopes. Color is generally dark yellowish orange and is much lighter on weathered surfaces. Grains are fine sand- to silt-size, and cement is dolomitic and limonite stained. Local beds show horizontal stratification, but cross-bedding was not observed. Units average 12 m thick but range up to 30 m for unit 27.

LITHOFACIES C

Coarsely crystalline biosparite dominates rocks of lithofacies C. The rocks form 40–60 cm ledges in a ledge-to-slope topography. Rocks range from pale greenish yellow to yellowish gray but weather darker. Dolomite that makes up the upper 18 m is fine crystalline and thinner bedded, changing from ledge to slope topography in the upper 10 m. Colors darken to brownish gray and finally to dark yellowish orange where the lithofacies grades into overlying clastic rocks.

Coarsely crystalline biosparite, in some places a coquina of bivalve shells, forms the lower 20 m of lithofacies C (fig. 9). Bivalve shells are generally 2 mm thick and are crushed. All cement and fossils have been recrystallized to neomorphic spar. Thin-section analysis reveals that 60% of the rock is made up of spar-replaced bivalve shells, 30% pellets, 5% sparry cement, and perhaps 5% quartz silt.

At 67 m, the biosparite grades into a medium-to-fine crystalline sparite. This unit contains fewer bivalves and is extensively burrowed. Periodic introduction of fine-grained sand and silt shows in local cross-bedding (fig. 10). Burrows increase upward in the section, with corresponding reduction in crystal size. At 83 m, coarsely crystalline biosparite reappears in a new cycle.

Four separate depositional cycles are recognized in lithofacies C (units 6–7, 8–9, 10–11, 12). In each cycle, coarsely crystalline biosparite grades upward into finely crystalline sparite and finally to dolomitic rocks. Bivalve pieces become increasingly rare upward, and burrowing intensifies, with a corresponding increase in dolomite.

LITHOFACIES D

Angular quartzite-pebble conglomerate is the dominant lithology of lithofacies D (fig. 11). These rocks form cliffs 5 m high in outcrops 20–30 m thick. Units are horizontally stratified, or more rarely cross-stratified. Unit 13, from 96–111 m, is an extremely angular conglomerate. Table 1 shows composition and cobble-size distribution of this unit. Upward in the section, green chert clasts are more predominant, and all clasts are well rounded.

Matrix in the conglomerate is mainly coarse sand and grit of the same general composition as the cobbles. Cement is calcareous and generally stained to a dark yellowish orange by limonite.

Pebbles in the angular rocks at 100 m are mostly 0.5 to 1 cm in diameter. The upper units (25, 26, 36) contain pebbles that average 1–2 cm and are also well rounded. Feldspar grains are also present in the lower units but are not present upward in the section.

The conglomerates are gradationally bounded by the sandy units of lithofacies B and the subaerial red shales of lithofacies E.

LITHOFACIES E

Red calcareous siltstone makes up all the units of lithofacies E. These units form slopes and occasionally are expressed as a pink soil. Bedding is thin and ranges from 1 to 2 cm. Very fine laminar structures occur, and cross-bed sets 0.5 cm high were observed. Rocks are uniformly pale reddish brown, and these units are useful as marker beds. Units are generally 4 to 6 m thick. Fossil plant roots may be present, although rare. There is no evidence of burrows or other fossils.

LITHOFACIES F

Green chert gritstone in a calcareous sand matrix characterizes lithofacies F. These 5–10 m units are generally interbedded with the coarser conglomerate of lithofacies D (fig. 12). Grains are coarse sand-to-grit size, and are generally very angular. Green chert is the dominant lithology of the clasts. Rocks are very friable on weathered surfaces. Outcrops are 50 cm high and form ledge-to-slope topography. Sandy wedges, interbedded with the gritstones, are rippled and finely laminated. In the upper units of this lithofacies there are lenses of conglomerate with subangular cobbles up to 12 cm in diameter, indicating a gradational boundary with the overlying conglomerate of lithofacies D. The matrix is very light gray. There is some evidence of cross-stratification. Beds of this calcareous gritstone, 1–3 m thick, crop out occasionally in the coarse conglomerates of lithofacies D.

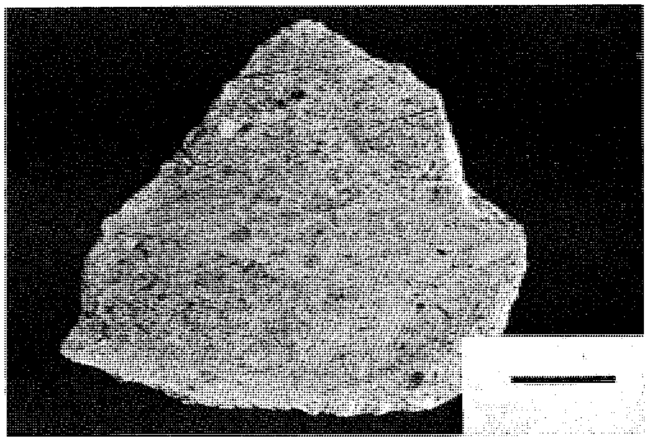


FIGURE 8.—*Sandstone of lithofacies B, unit 4, section 1, at 42 m. Note poor sorting and subangular to subrounded grains. Lithofacies B is a transitional unit between shallow marine carbonates and the angular terriginous conglomerates of lithofacies D. The bar in the lower right corner measures 1 cm.*

FACIES DESCRIPTION

The six lithofacies of the Carrico Lake Formation represent different environments of deposition. A discussion of the several variables involved in the interpretation of these environments follows. Carbonate and clastic rocks of the study section will be considered separately.

CARBONATES

Lithologic Variables

The most environmentally significant lithologic variables within the carbonate rocks are the grain constituents of the rocks and their enclosing matrix. The chief grains are skeletal fragments and pellets. Quartz silt is rare. The matrix of the lower rocks is dominately sparite, which is interpreted as being secondarily precipitated interstitial calcite. Rocks of units 31–33, however, have a predominantly micritic matrix.

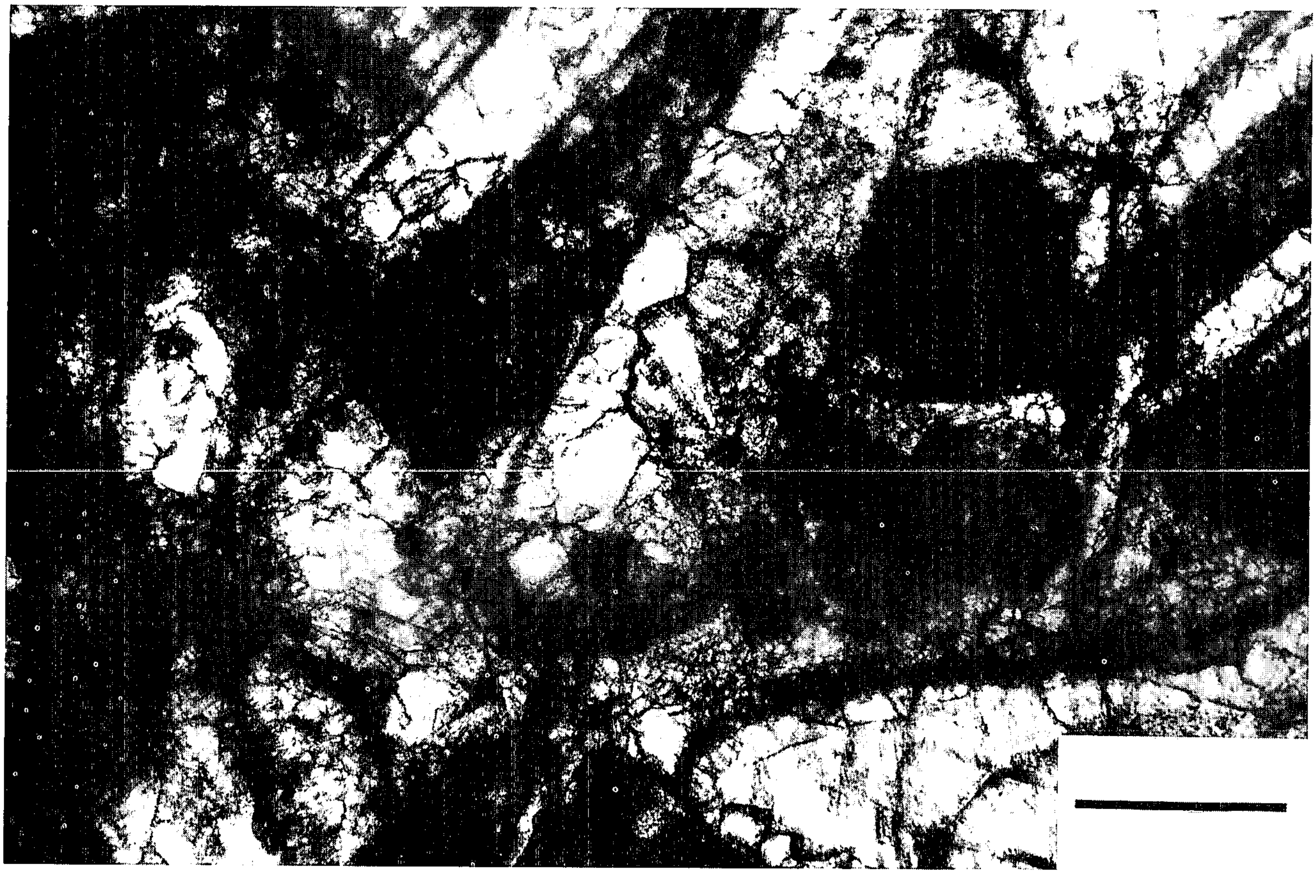


FIGURE 9.—*Photomicrograph: limestone fabric of lithofacies C at 47 m, unit 6, section 1. Note extensive recrystallization of fossil tests and cement to neomorphic spar. The bar in the lower right corner of the photo measures .64 mm.*

Skeletal Debris

The disarticulated and comminuted remains of bivalves, gastropods, and crinoids are found throughout the carbonate rock in the study section (fig. 13). The distribution of these skeletal grains seems mostly influenced by the original shape and architecture of the contributing organisms as well as by the amount of mechanical disintegration and chemical decomposition prior to burial according to the "Sorby" principle of Folk and Robles (1964). Generally, there is no simple relationship between skeletal grain composition or texture and facies distribution.

The abundance of skeletal debris, however, does vary regularly. In the more micritic rocks of units 31–33, skeletal allochems make up only 30% of the rocks, as opposed to 80% in some of the sparitic rocks (e.g., fig. 7). This may be due in part to the decrease in skeletal grain production caused by influx of terriginous clastic sediment into the area.

Pellets

The most common nonskeletal grains throughout the carbonate units are pellets. Pellets are defined as structureless micritic grains less than 0.2 mm in diameter (Folk 1962). They are assumed to be largely fecal in origin.

Neomorphic Spar

Neomorphic spar, presumable replacement of aragonitic mud, is the dominant material in units 1–3, 31–33, and 38, and lithofacies C. This texture, along with other characteristics of these rocks, suggest deposition in the zone of active current reworking.

Micrite

Micrite or microcrystalline calcite presumably represents an original carbonate mud and is the dominant matrix material in units 31–34, 38–39.

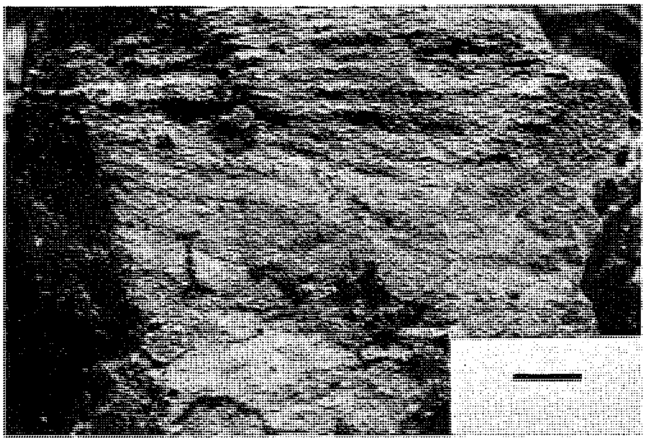


FIGURE 10.—*Localized cross-bedding in biosparite, caused by the periodic introduction of quartz silt into the shallow marine environment. Note the angular terriginous clasts seen in the lower right of the photo. The rock itself is a coarse crystalline biosparite, similar to that seen in fig. 7. The bar measures 1 cm.*

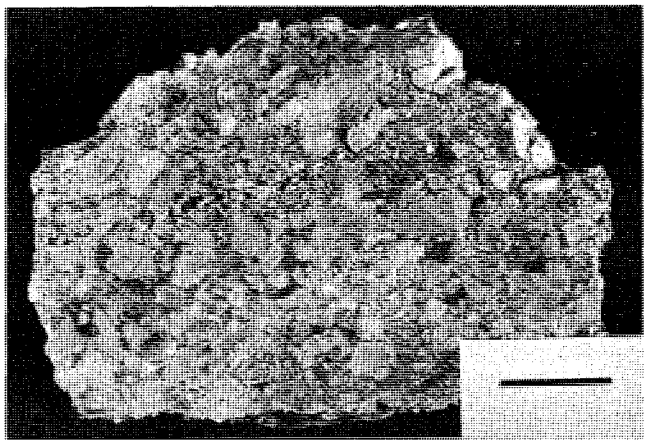


FIGURE 11.—*Angular conglomerate of lithofacies D. Note the extensive internal fracturing in the quartzite clasts. This internal fracturing may explain the extreme angularity of the clasts. The oligomictic nature of the rock may be due to the nature of the provenance rather than extreme transportation distance. The bar in the lower right corner measures 1 cm.*

Primary Structures

Burrows and very fine laminations are the principal primary structures found in the carbonate units. Laminations are a result of terriginous quartz-silt influx into the carbonate regime and occur only sporadically and in very coarsely crystalline limestone (e.g., unit 7). Burrows, however, are common throughout the carbonate rocks in the section and are especially abundant in micritic rocks of lithofacies A. Burrows in these rocks are best classified as pascichnia and dominichnia, as defined by Seilacher (1964).

Pascichnia are the winding trails or burrows of vagile mud eaters that reflect a grazing search for food by covering a given surface more or less efficiently and avoiding double coverage. Figure 14 shows burrows at 36 m and their characteristic patterns. The burrows are dominantly horizontal and contrast with the surrounding rocks because of dolomitization and subsequent differential weathering of the burrow tubes.

Paleontological Variables

Most fossil remains are so broken and comminuted that identification beyond the order level is impossible. Paleoecological deductions based on fossils are therefore difficult.

TERRIGENOUS CLASTIC ROCKS

Lithologic Variables

The several variables involved in interpretation of clastic facies are grain size, shape, sorting composition, and sedimentary structures.

Grain Size, Shape, and Sorting

Most of the pebbles in lithofacies D conglomerates are between one-half and one cm in diameter. These rocks may then be considered fairly well sorted conglomerates. The sand and grit of lithofacies B and E are also fairly well sorted. The clasts are extremely angular. The significance of this will be discussed in a later section.

Sedimentary Structures

Conglomeratic units exhibit crude stratification, with fining upward sequences up to 10 cm thick. Cross-bedding is also evident in some outcrops (fig. 15). Sands and grits of lithofacies B and F also show stratification and perhaps some oscillatory rippling.

Composition

Light brown, highly fractured quartzite is the dominant lithology for all clastic units in the section. It forms the pebbles and coarse sand matrix in the conglomeratic units. Quartzite fragments also occur in the gritstones and coarse sandstone of lithofacies B and F. Light olive chert is subordinate in the conglomerate units, but is more common in the gritstones of lithofacies F.

DEPOSITIONAL ENVIRONMENTS

CARBONATE ROCKS

Given lithologic, paleontologic, and primary structural information, inferences may be drawn as to the depositional environments of rocks of each lithofacies.

SIZE	NO.	%	COMPOSITION	%
3 cm	2	1	buff quartzite	93
2 cm	14	7	green chert	4
1 cm	57	28		
.5 cm	127	64	feldspar	2
grit size matrix		40	quartz sand	1

Table 1. Composition and cobble-size distribution of unit 13, section 1 (see fig. 1), at 100 m. Cobble-size grains make up 60% of the rock with 40% associated matrix. This is a very mature conglomerate, with 93% of the rock composed of buff quartzite.

Lithofacies A

Abundant marine fossils suggest an unrestricted marine environment for rocks of lithofacies A. In addition, abundant burrows suggest deposition in a shallow, subtidal environment. In the similar Helderberg Group (lower Devonian) of New York State (Laporte 1969), burrowing is absent in the supratidal beds of the Manlius Formation, but increases sharply in abundance in the intertidal and especially subtidal units. The coarser-textured sparry and cross-stratified beds contain few or no burrows.

Burrows in the study section are dominately horizontal along bedding planes, with only occasional vertical burrows through beds. As suggested by Rhoads (1967), in his study of modern-day burrowers, intertidal substrates are characterized by deeper, vertical burrows because of variable environmental conditions at or near the sediment surface. Continuously submerged subtidal environments, on the other hand, have more uniform and favorable conditions so that infaunal organisms burrow shallower and remain nearer the sediment surface.

Abundance of micrite in the lithofacies may also indicate deposition below wave zone. However, presence of broken and jumbled shells replaced by sparry calcite suggest that rocks of lithofacies A accumulated at least near the high-energy intertidal zone, hence their assignment to a shallow subtidal environment.

Lithofacies C

Rocks of lithofacies C (47–96 m) are similar to the coarse-textured, sparry rocks of the upper Coeymans Formation in New York as described by Laporte (1969). Rocks of the study section form a coquina of broken, jumbled bivalve fragments in some outcrops, and shells and matrix are nearly completely recrystallized to sparite. Some current stratification and a small percentage of quartz-silt grains are evident. This lithofacies represents the most shoreward of the carbonate units and is interpreted as an accumulation in a well-agitated environment well within the zone of regular wave and current reworking.

Thin-section analysis of closely spaced samples in units 1–3 of lithofacies A (32–36 m) suggest evidence of minor sea level fluctuation. Rocks at 33 m contain pellets and skeletal allochems in equal proportion. Half a meter upsection, 80% of the grains are pellets, and there is a noticeable increase in the quartz-silt fraction, suggesting that the water shoaled up. At 36 m, the quartz silt disappears, pellets and skeletal allochems again occur in equal proportions.

TERRIGENOUS CLASTIC ROCKS

Lithofacies B, D–F

Outcrop work indicates that lithofacies B, D–F, are genetically related, and should therefore be considered together when interpreting their respective environments of deposition.

The terrigenous clastic rocks of the study section represent several episodes of marine regression, beginning with the weak clastic influx represented by units 4 and 5. The planar-bedded sandstones of lithofacies B represent the sandy beach facies. They, along with the gritstones of lithofacies F, form the transition zone between the marine limestones of lithofacies A, and the conglomerates of lithofacies D. The gritstones of lithofacies F form a

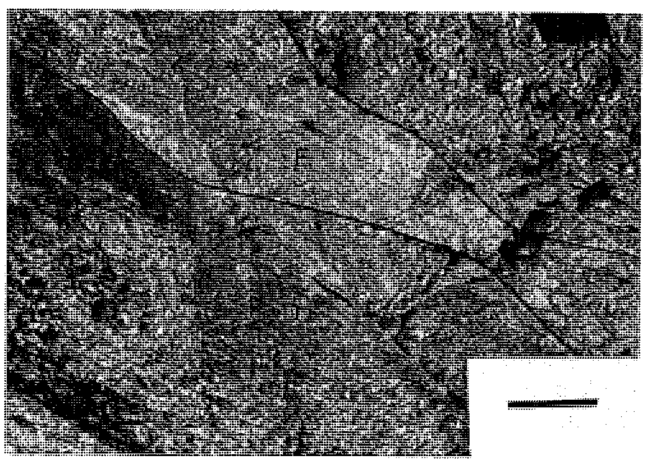


FIGURE 12.—*Interbedded gritstone and conglomerate of lithofacies F and D. Note the distinct difference in grain size and lithology between these two units. Lithofacies D is primarily poorly sorted, fractured, buff-colored quartzite, while lithofacies F has a calcareous matrix with a high percentage of green chert clasts. Bar in lower right corner measures 25 cm.*

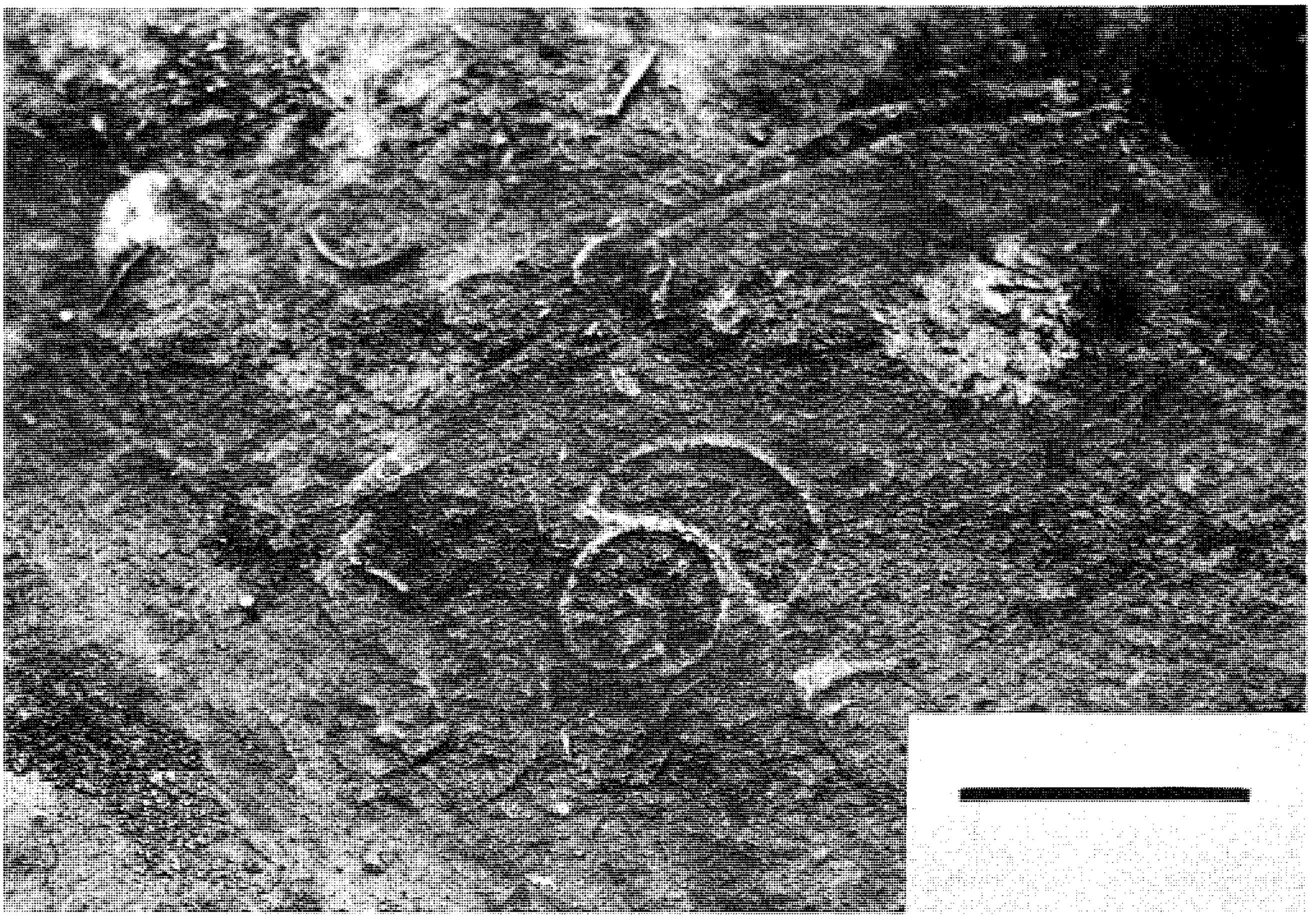


FIGURE 13.—*Disarticulated and comminuted skeletal fragments typical of the limestone in the study area. Tests are replaced by neomorphic spar, indicating that this unit (lithofacies C) was deposited in a relatively high energy shallow water environment. The bar in the lower right corner measures 1 cm.*

coarsening-upward sequence between the beach sands and the conglomerates. The presence of these sands and grits in the section signals the advance (e.g., units 18–19) or retreat (e.g., units 27–30) of the shorelines. The red shales of lithofacies E represent the subaerial interdistributary tidal flat facies.

The conglomerates of lithofacies D were deposited in a unique environment, rarely duplicated. The fact that they are matrix supported with fair-to-good orientation of clasts indicates they were transported as a low-viscosity debris flow, such as might be found in an overloaded fluvial system with a high stream gradient. The high degree of angularity displayed in the conglomerates of lithofacies D may be explained by noting that individual quartzite pebbles are internally fractured (fig. 11). Weathering debris from an extensively fractured provenance could yield extremely angular pebbles like those observed in unit 13. Effects of mechanical weathering during transportation could have shattered the rocks rather than rounding them off. A relatively short distance between provenance and depositional basin could further insure angularity of the transported fragments.

The extreme angularity of the cobbles also indicates that mechanical weathering was dominant. No evidence of chemical weathering is present.

DEPOSITIONAL MODEL FOR THE CARRICO LAKE FORMATION

The Carrico Lake Formation represents cyclic deposition of shallow-marine carbonate and terriginous deposits. Figure 16 illustrates proposed environments of deposition for each lithofacies.

Quiet marine conditions prevailed initially (units 1–3) in a shallow subtidal environment. Units 4 and 5 show a minor influx of fine-grained terriginous clastic sediments, harbingers of future clastic sedimentation. The water after this episode was certainly shallow, as evidenced by the intertidal rocks of units 6–12. Then began an influx of coarse-grained clastic sediments that overwhelmed and scoured into the marine carbonates (unit 13). Climatic

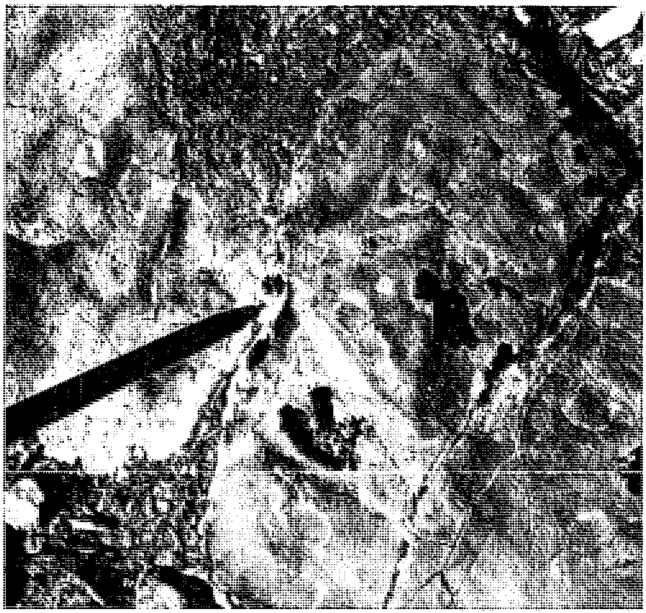


FIGURE 14.—*Differential weathering of burrows in unit 3, section 1, lithofacies A. The intense burrow mottling seen here is common throughout this lithofacies, which was deposited under more tranquil conditions than lithofacies C. Pen for scale.*

and/or tectonic changes on land caused rapid mechanical weathering of the fractured quartzite rocks. Fragments of these rocks were then transported a short distance in an overloaded fluvial system and dumped into the sea. Intercalation of the subaerial (unit 14) or subaqueous (unit 17) environments demonstrates the periodic influx of clastic sediments into shallower water, which may be related to local tectonic activity. Units 31–34 represent another period in which shallow, subtidal conditions were prevalent. These rocks (lithofacies A) do not differ appreciably from those of units 1–3 and are interpreted as a cyclical repetition of the same environmental conditions. Normal faulting between units 34 and 35 obscures evidence of what may be another depositional cycle.

The Carrico Lake Formation is overlain unconformably by Tertiary dacitic rocks.

LOCALLY CORRELATIVE STRATA

Two other sections of Middle Triassic rocks were measured to provide correlation with the Carrico Lake Formation and to provide an understanding of the local paleogeography. Section 2 (fig. 17) was measured in the Augusta Mountains (fig. 1). This section was measured entirely in the Star Peak Group, defined and described by Nichols and Silberling (1977). Section 3 (fig. 18), of equivalent rocks, was measured in the New Pass Range (fig. 1). These two sections will be discussed separately.

AUGUSTA MOUNTAIN SECTION

The Star Peak Group, described in section 2, is a genetically coherent carbonate platform complex that occurs in scattered exposures throughout northwestern Nevada. These strata range from Early to Middle Late Triassic in age, and where completely preserved, such as in the Augusta Mountains (fig. 1), may exceed 1000 m in thickness. A brief stratigraphic description of Star Peak units follows.

Koipato Group (Upper Permian)

The rocks of unit 1, section 2, are probably best assigned to the Permian Koipato Group. These are reddish brown, quartzite boulder metaconglomerates that form 5 m cliffs.

Tobin Formation (Upper Lower Triassic)

The Tobin Formation (Muller and others 1951), which forms the base of the Star Peak Group (units 2–3, section 2), consists principally of terrigenous fine-grained clastic rocks that are more or less calcareous and include some limestone and coarse terrigenous clastic rocks. In the Augusta Mountains, the Tobin Formation is 103 m thick and is mostly dark, unfossiliferous, commonly laminated, fissile, silty mudstone.

Dixie Valley Formation (Lower Middle Triassic)

The Dixie Valley Formation (units 4–5) is a conglomerate, dominated by green chert pebbles, that is interbedded with yellow, finely crystalline, ledge-forming dolomite. Calcite stringers occur throughout the dolomitic beds, which are 3–5 m thick at the base and thin to less than a meter toward the top of the formation. A total of 114 m of conglomerate is overlain by 12 m of very calcareous red shale.

Favret Formation (Middle Triassic)

The Favret Formation in the Augusta Mountains is divided into the upper Fossil Hill Member (unit 7) and a lower, unnamed member (unit 6). The lower member is a medium brownish gray, medium crystalline, cliff-forming limestone. A slight hydrocarbon odor is present throughout the unit. Thick, sparry bivalve shells are present near the base of the unit.

The upper Fossil Hill Member, named by Nichols and Silberling (1977), is a 361-m-thick sequence of fissile to flaggy, dark gray (N3) calcareous shale. Concretionary interbeds of fossiliferous lime mudstone occur throughout but are most abundant at the top of the unit. The member contains a rich fauna of cephalopods and pelagic *Daonella* bivalves. When broken, the chambers of ammonoids commonly yield liquid hydrocarbons (Nichols

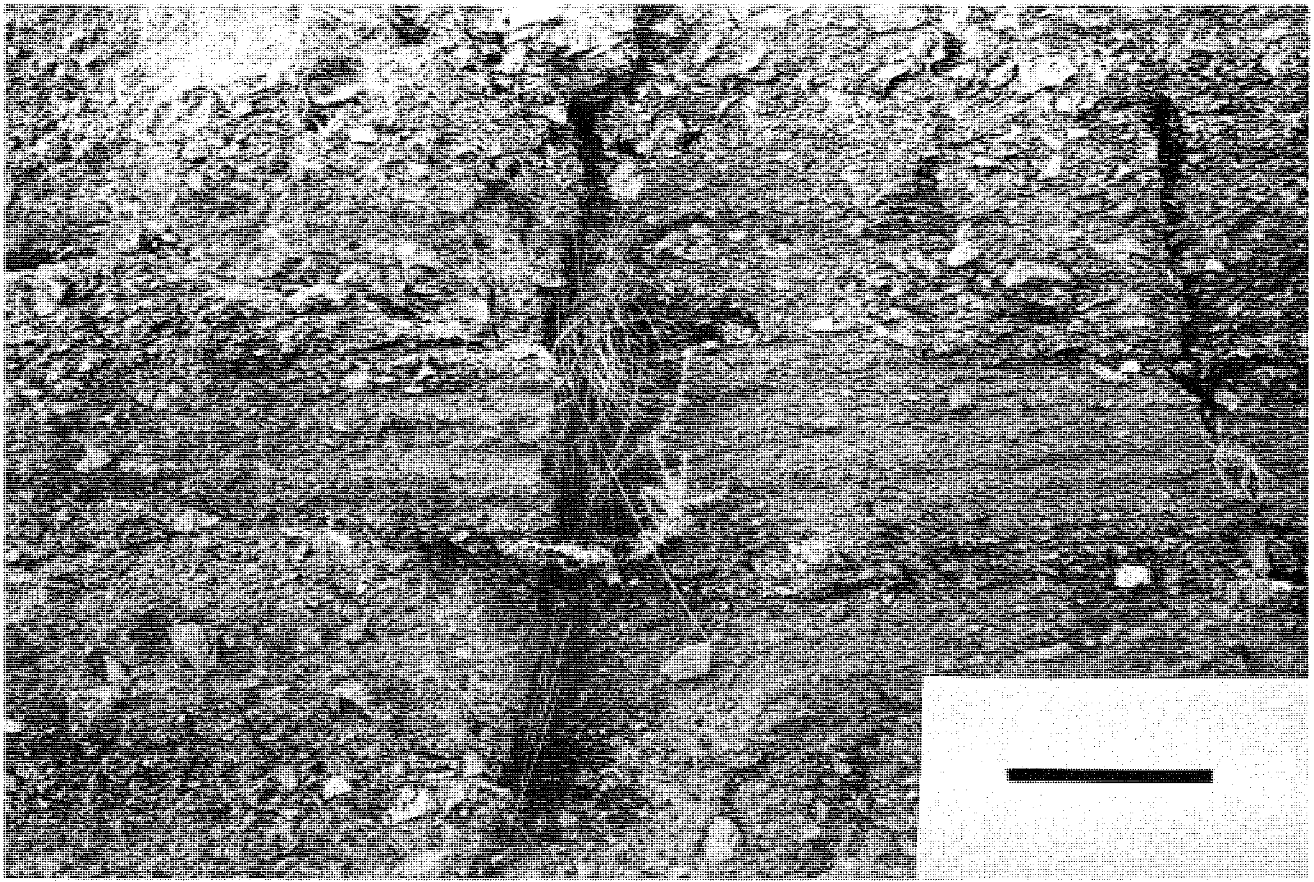


FIGURE 15.—*Rare cross-bedding in the angular conglomerates of lithofacies D. These rocks are proposed as debris-flow deposits and generally show no depositional structures. The bar in the lower right corner of the photo measures 15 cm.*

and Silberling 1977, p. 21). The more calcareous interbeds are composed of shells and fragments of thin-shelled bivalves, cephalopods, and ostracods that occur in a lime matrix with minor amounts of finely disseminated quartz silt. The micritic texture and the absence of high-energy allochems suggest deposition below wave base, in contrast with the high-energy conditions interpreted for the lower member.

Augusta Mountain Formation (Middle to Lower Upper Triassic)

This formation is generally medium brownish gray, coarsely crystalline limestone. A strong hydrocarbon odor pervades the rocks; however, fossils are rare. In the Augusta Mountains, the Augusta Mountain and overlying Cane Spring Formations were not differentiated. A total of 945 m of post-Favret limestone and dolomite were measured (unit 8).

The Augusta Mountain Formation is divided into three members: the lower Home Station Member, the middle Panther Canyon Member, and the upper Smelser Pass Member (Nichols and Silberling 1977, fig. 3, p. 23–24).

The Home Station Member consists of laterally variable dolomitic platform rocks. The unit also includes massive, cliff-forming saccharoidal secondary dolomite. The Panther Canyon Member is a sequence of supratidal dolomite overlain locally by clastic rocks.

The Smelser Pass Member is composed mainly of limestone, but near its top includes mafic volcanic and volcaniclastic rocks as much as 30 m thick. Age-diagnostic fossils are scarce in the Smelser Pass Member in the Augusta Mountains. Ammonites collected from the uppermost 3 m of the Smelser Pass Member at China Mountain (Nichols 1972) belong, in part, to the same species as the early Karnian fauna of the *Desatoyense* Zone described by Johnston (1941) from the New Pass Range. The Smelser Pass Member is therefore temporally equivalent to the Carrico Lake Formation previously described (see correlation table, fig. 3).

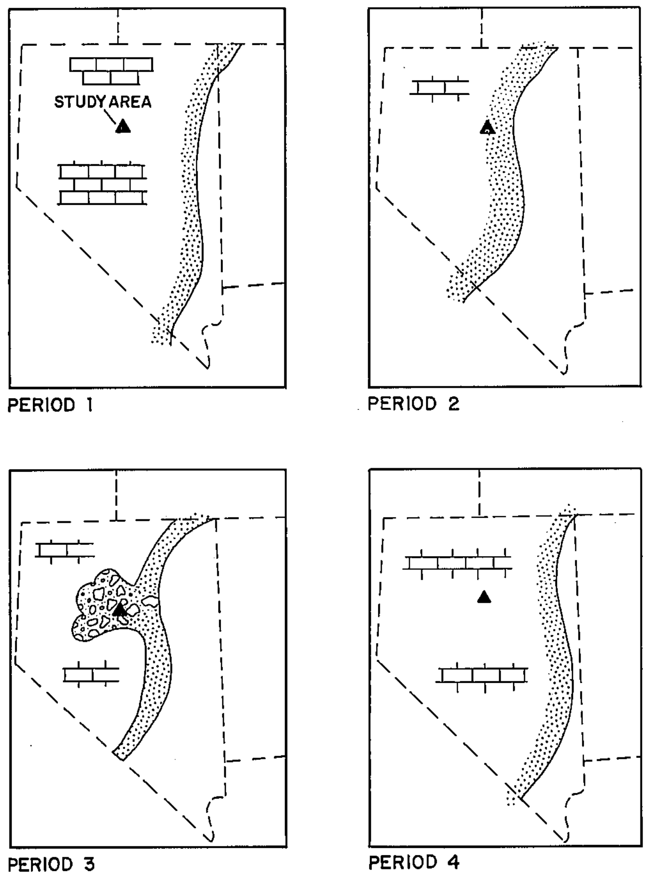


FIGURE 16.—*The depositional history of the Carrico Lake Formation, west central Nevada, can be separated into four episodes, designated oldest to youngest, periods 1–4. Quite marine conditions prevailed initially (period 1). Local climatic and/or tectonic changes initiated the influx of clastic sediments into the area (period 2), which reached its zenith with the deposition of very angular conglomerate, probably in seasonal pulses, as debris flows (period 3). This was most likely a local phenomenon as terriginous clastic sediments are not seen in any of the other correlative sequences studied. Period 4 is seen as a return to the prevailing quiet open-marine conditions seen in period 1.*

DEPOSITIONAL CHARACTERISTICS—STAR PEAK GROUP

Patterns of cyclic deposition, much like those observed in the Carrico Lake Formation, can be seen in the Augusta Mountain rocks. The medium brownish gray, ledge-forming limestone of unit 2 (section 2, fig. 17) appears again in unit 6, and again in the lower part as unit 8. Unit 2 rocks are conformably overlain by the thin-bedded black shales and blocky limestones of unit 3. These organic rich shales and limestones have a strong hydrocarbon odor when broken and are replete with skeletal debris. Ammonoids and *Daonellid* bivalves are ubiquitous. This lithofacies is represented in the upper portion of the Tobin Formation and reappears as the Fossil Hill Member of the Favret Formation (unit 7, fig. 17).

If the unit 1 (Koipato Group) conglomerates are included, two cycles of conglomerate followed by limestone, then shale, are seen—one from 0–99 m (units 1–3) and the other from 99–608 m (units 4–7). In each case, a period-dominated terriginous influx is followed by submergence and then stagnation.

NEW PASS RANGE SECTION

Calcareous Triassic strata that resemble and are correlative with the Star Peak Group crop out extensively in the New Pass Range, only 20 to 30 km south of the characteristic Star Peak exposures in the Augusta Mountains (fig. 1). These rocks could reasonably be included in the group, but only the Favret Formation has a close lithologic counterpart farther north. A brief stratigraphic description of the unit follows.

Favret-Equivalent Shale

In the New Pass Range, the Favret Formation (unit 3, section 3, fig. 18) unconformably overlies the metaconglomerate of the Koipato Group described as unit 1 of section 2 (fig. 17). This is the only formation that may be directly correlated to Star Peak rocks northward in the Augusta Mountains. The Favret Formation in the New Pass Range lacks the *Daonellid* bivalves and the strong hydrocarbon odor. At least a few meters of massive shelly limestone at the base of the Favret section in the New Pass Range correspond to the unnamed lower member described as unit 6 of section 2 (fig. 17). Nichols and Silberling (1977, p. 60) reported mid-Anisian ammonites from the lower member that are representative of the upper part of the *Acrochordiceras hyatti* beds in the zonation of Tozer (1971).

Limestone

About 500 m of mostly massive-bedded, ledge-forming, medium gray limestone overlies the Favret Formation (unit 4, fig. 18). The lower half of this limestone contains much interstratified calcareous siltstone, limestone with carbonate-supported quartz grains, and chert pebbles. The cleaner limestone beds above are rich in skeletal debris and have a correspondingly strong hydrocarbon smell. Organic buildups of colonial corals and large molluscan shells occur locally and are associated with crinoidal and algal grain-supported limestone. These open-marine bioclastic rocks have no lithic counterpart in Augusta Mountains, but they are probably correlative with the Panther Canyon Member of the Augusta Mountain Formation in the Augusta Mountains. Further de-

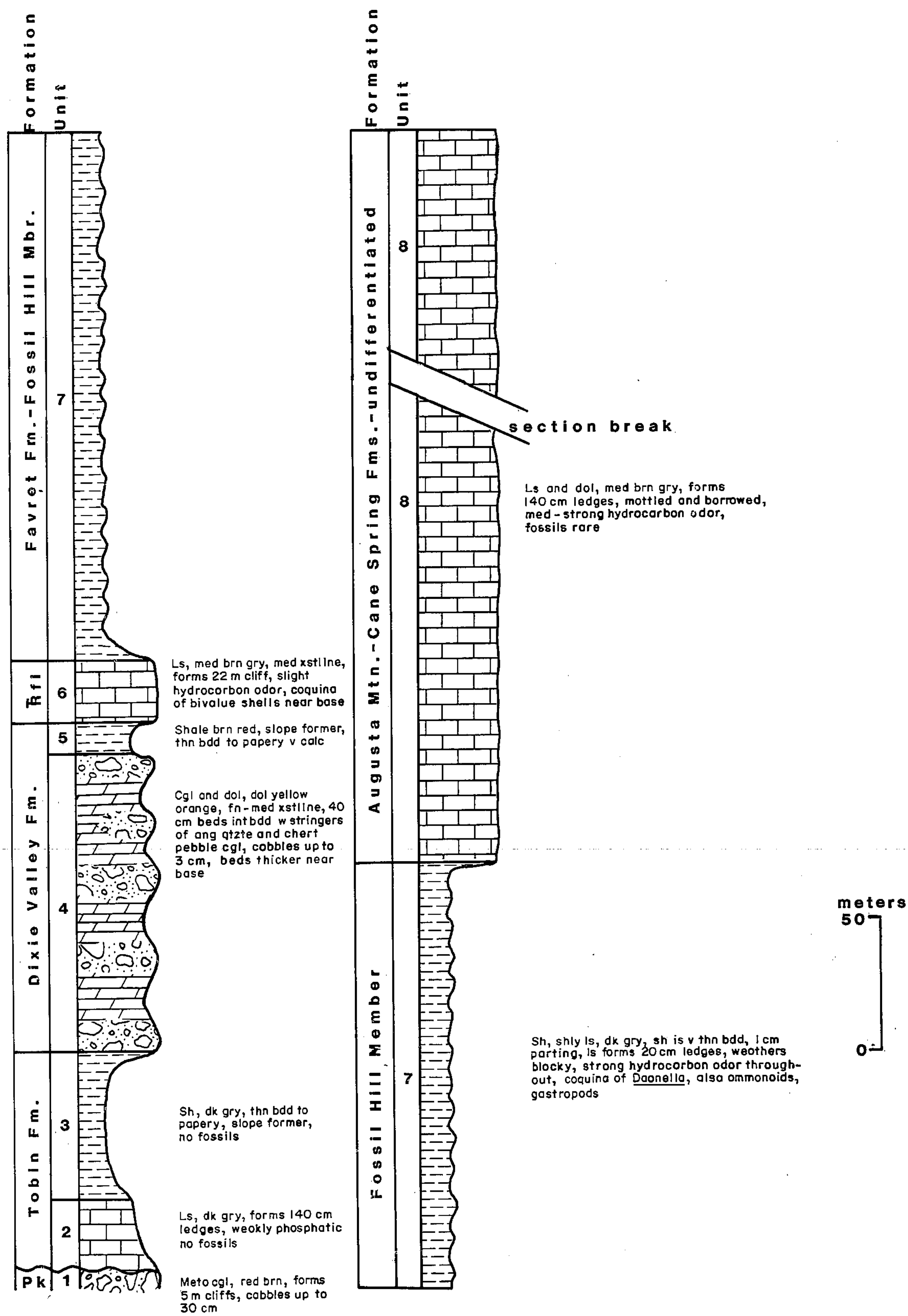


FIGURE 17.—*Measured section 2, Augusta Mountains (fig. 1), located in sections 1, 2, and 12, T. 25 N, R. 39 E, Cain Mountain Quadrangle, Nevada.*

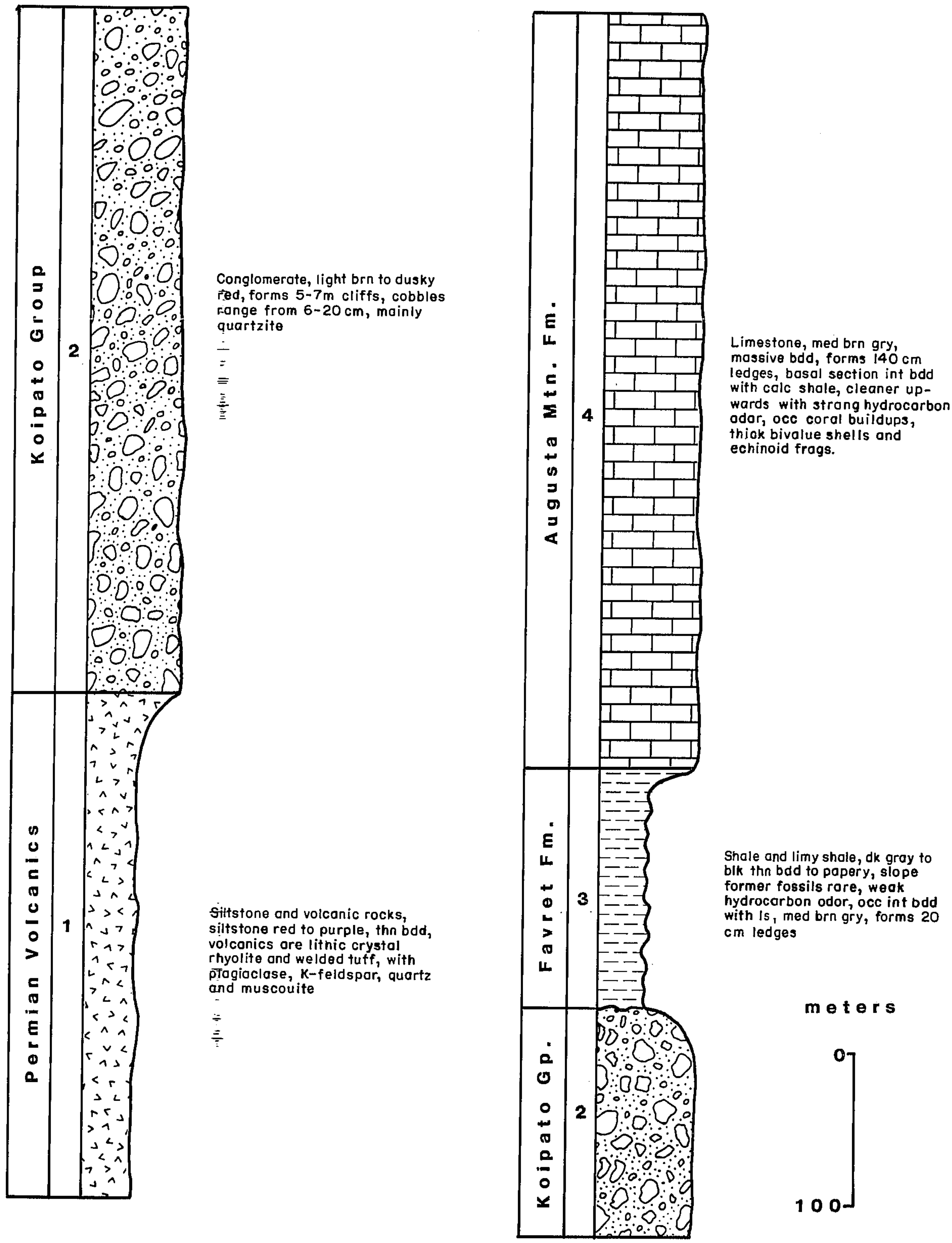


FIGURE 18.—*Measured section 3, New Pass Range (fig. 1), located in sections 17, 18, T. 21 N, R. 40 E, Edwards Creek Valley Quadrangle, Nevada.*

scription of these rocks in the New Pass Range is provided by MacMillan (1972).

REGIONAL DEPOSITIONAL SETTING

During medial Early Triassic time, a broad geosynclinal seaway occupied much of central Nevada. Marine limestones such as the Virgin Limestone Member of the Moenkopi Formation and the Thaynes Formation were deposited as a result. These formations grade eastward into tidal-flat mudstones and red shales. Open-marine calcareous strata may also have been deposited upon a fairly flat surface throughout much of western and southern Nevada, remnants of such strata being preserved in the Tobin Formation and equivalents. This marine system persisted, with brief interruptions due to coeval tectonic activity, until medial Late Triassic time when the terriginous clastic, pelitic, and sandy strata of the Auld Lang Syne Group were deposited. This may relate to a regional change in tectonic regime, such as the beginning of the Sierra Nevada magmatic arc. The Late Mesozoic Sevier orogeny and subsequent erosion destroyed the Middle Triassic carbonate rocks in western Utah and eastern Nevada, leaving the rocks of the Star Peak Group and equivalents as the only evidence of Middle Triassic deposition in the Western U.S. Regional correlation of early Late Triassic strata shows a regional facies relationship similar to that which existed in the Early Triassic (fig. 3). Continental deposits of the Chinle Formation in Utah are temporally equivalent to the open-marine limestone of the Smelser Pass Member of the Augusta Mountain and Cane Spring Formations of the Star Peak Group in central Nevada. The Carrico Lake Formation, temporally equivalent to the Smelser Pass Member of the Augusta Mountain Formation, is interpreted as a shallow subtidal-intertidal unit, deposited at or near the shoreline that separated the Star Peak open-marine basin to the west from the continental depositional systems to the east.

Figure 19 shows the relationship of the Carrico Lake Formation to other temporally equivalent rocks in the area.

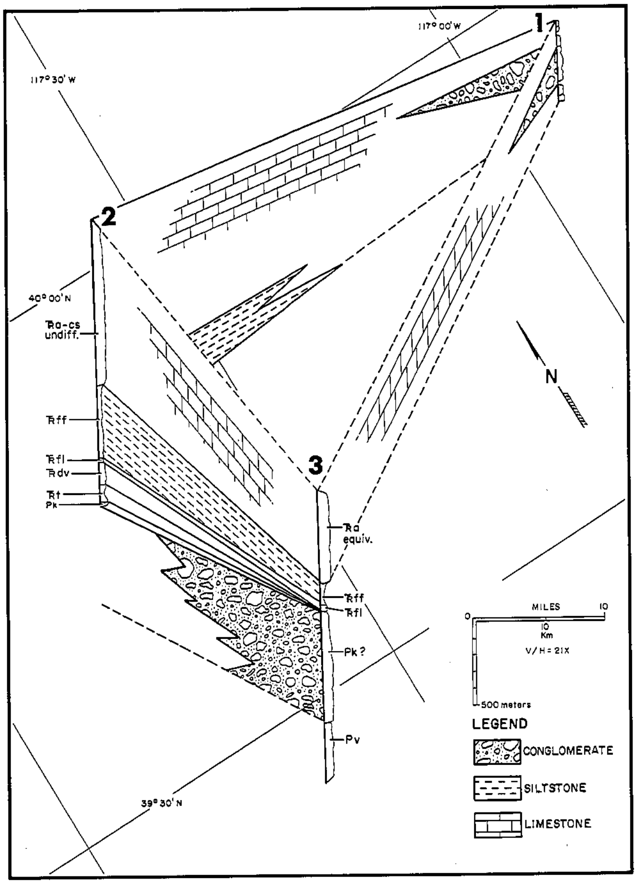


FIGURE 19.—*Regional cross section showing possible correlations between the three measured sections described in this paper (figs. 4, 17, 18). The Carrico Lake Formation (section 1 in the upper right corner) is stratigraphically and temporally equivalent to the undifferentiated August Mountain and Cain Spring Formations described in section 2 and the Augusta Mountain equivalent rocks measured in the New Pass Range (section 3). The angular conglomerates seen interbedded with shallow water carbonates in the Carrico Lake Formation pinch out to the west and southwest. The shallow water carbonates undergo a gradual change to deeper water facies to the west and southeast, further into the Upper Triassic marine basin.*

CONCLUSION

Rocks of the Carrico Lake Formation were deposited in a shallow-marine environment. Triassic rocks 300 km to the east (Chinle Formation) document emergence and subaerial sedimentation in that direction, and rocks 40 km to the west (Star Peak Group) indicate open-marine sedimentation. Local tectonic activity, related to the uplifts documented by Nichols and Silberling (1977), may account for the cyclic repetition of lithologic units, both in the open-marine Star Peak and shallow-marine Carrico Lake rocks.

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APPENDIX

MEASURED SECTIONS

Carrico Lake Valley Formation—Section 1

This section was measured in Dead Ox Canyon, in the Toiyabe Range, east of Carrico Lake Valley, section 24, T. 24 N, R. 45 E, Lander County, Nevada. The rocks are exposed in ledges and slopes on the hills, and in cliffs in the wash. This is the type section of the Carrico Lake Formation.

Unit	*Description*	*Unit Thickness (meters)*	*Cumulative Thickness*
39	Limestone, medium brownish gray, burrowed, fine crystalline, forms 60 cm ledges, few crinoid fragments, gastropods, thin-shelled bivalves.	10	434
38	Limestone, medium brownish gray, burrowed, fine crystalline, forms 30–45 cm ledges to slopes.	3	424
37	Conglomerate, angular, cobbles subrounded, up to 3 cm in diameter, some maroon hue.	27	421
36	Sandstone, flaggy, forms 1.5 m ledges, calcareous, weathers into 40 cm parting units, much like unit 16.	10	394
35	Shale, reddish brown, slightly calcareous, forms slopes.	4	384
34	Limestone, medium brownish gray, burrowed, bioclastic, fossil, hash recrystallized to calcspar, bivalves, crinoid stems, much like unit 1, some chert nodules, forms 4 m cliffs, strong hydrocarbon odor, thick bivalve shells seen occasionally.	12.5	380
33	COVERED	36	367.5
32	Limestone, medium brownish gray, slope former, extensively burrowed.	20.5	331.5
31	Limestone, bioclastic, medium brownish gray, some sparry veins, crinoid fragments, sponge spicules, thin bivalve shells, gastropod pieces, forms 30 cm ledges, locally burrowed.	4	311
30	Sandstone, weathers into thin-bedded parting units.	30	307
29	Shale, thin bedded, reddish brown, forms slopes, calcareous.	4	277
28	Gritstone, 40% green chert, 40% quartzite clasts, some feldspar.	3	273
27	Sandstone, flaggy, finer grained than unit 16, some laminar structures, no cross-bedding, limonite stained, forms slopes, highest ledges 20 cm.	19.5	270
26	Gritstone, 1 m ledges, dominated by green chert clasts, very angular.	18.5	250.5
25	Conglomerate, like unit 13, meter-high ledges, up to 2 m cliffs, some evidence of cross-bedding, 5-cm-high fining upward sequences that give the appearance of cross-bedding.	29	232
24	Conglomerate, clasts are 50% brown, 50% green chert, range up to 3 cm diameter, subangular, large green pebbles for the first time, matrix is white calcareous gritstone, some euhedral feldspar in grit.	3	203
23	Gritstone, subangular green chert clasts, white calcareous matrix.	8	200
22	Conglomerate, angular, identical to unit 13.	10	192
21	Gritstone, white calcareous matrix, lenses of coarse conglomerate with 2 cm cobbles, grit matrix is same composition as unit 13, very friable, some evidence of cross-bedding.	4.5	182
20	Conglomerate, angular quartzite pebbles, like unit 13, calcareous grit-size matrix, very angular.	6.6	188.5
19	Gritstone, green chert cobbles, arkosic, occasional sandy wedges, very angular clasts.	10.5	171
18	Sandstone, flaggy, limonite stained.	6	160.5
17	Limestone, fine crystalline, light brownish gray, fractures filled with rust-colored matter, patches of coarse crystalline calcspar, and bivalve hash.	5	154.5
16	Sandstone, calcareous, forms ledges, weathers into thin-bedded parting units, limonite stained, medium grained.	2.5	149.5
15	Conglomerate, quartzite pebbles, some green chert clasts, subangular, but much more rounded than unit 13, matrix is grit-size, contains black and green chert, calcareous cement, friable.	30	147
14	Shale, reddish brown, slope forming, very small laminae.	6	117
13	Conglomerate, quartzite pebbles, very angular, very well stratified, 95% buff-colored quartzite, rest grit-size green chert, feldspar, and quartz, cobbles range from 5 cm to grit-size, poorly sorted, cobble count in text (table 1).	15	111

12	Dolomite, limonite stained, no fractures, no visible fossils or burrows, grit-size chert clasts rare.	9	96
11	Dolomite, medium crystalline, fractures filled with calcspar, pyrolusite flowers, some sand, bivalves recrystallized into calcspar, medium brownish yellow.	3	98
10	Limestone, coarse crystalline, includes bivalve hash and flat pebble conglomerate, all tests recrystallized to calcspar.	1	84
9	Dolomite, fine crystalline, buff colored, burrowed.	4	83
8	Limestone, coarse crystalline, bivalve tests recrystallized to calcspar.	1	79
7	Limestone, medium crystalline, bivalves rare, extensively burrowed, some fine cross-bedding, grades upward into dolomite, medium brownish yellow, which then grades upward into unit 8.	11	78
6	Limestone, coarse crystalline, forms 20–40 cm ledges to slopes, some flat pebbles, occasionally laminations.	20	67
5	Sandstone, coarse-grained, calcareous cement, some cross-bedding, forms 50 cm ledges, includes a 10 cm bed of medium coarse-grained, very angular conglomerate with clasts up to 2 cm, very angular grit-size grains occasionally seen in the sandstone.	5	47
4	Siltstone, calcareous, limonite stained, fractured, fractures filled with coarse crystalline calcspar, may have root traces.	6	42
3	Limestone, ledge to slope former, 60 cm ledges, extensively burrowed, abundant thin bivalve shells, all shells are calcspar, overlain by a 50 cm bed of sandy gritstone, very angular clasts of green chert, quartz, euhedral feldspar.	4	36
2	Limestone, medium-coarse crystalline, locally crinoid hash, gastropods, bivalve shells, medium brownish gray, forms 130 cm ledges, extensively burrowed.	21.5	32
1	Limestone, medium brownish gray, forms 60 cm ledges, slight hydrocarbon odor, micritic, some thin bivalve fragments, crinoid stems, weathers lighter.	10.5	10.5

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