CALIFORNIA STATE UNIVERSITY NORTHRIDGE

STRATIGRAPHY OF EARLY TO MIDDLE(?) TRIASSIC MARINE TO CONTINENTAL ROCKS, SOUTHERN INYO MOUNTAINS, CALIFORNIA

A thesis submitted in partial satisfaction of the requirements for the degree of Master of Science in Geology

by

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To Juli
whose love and support
made this possible

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ABSTRACT

STRATIGRAPHY OF EARLY TO MIDDLE(?) TRIASSIC MARINE TO CONTINENTAL ROCKS, SOUTHERN INYO MOUNTAINS, CALIFORNIA

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Mark Stephen Oborne

Master of Science in Geology

Early Triassic marine to continental strata exposed along the west flank of the southern Inyo Mountains contain a record of transition from a tectonically quiescent marine environment to a tectonically active, terrestrial, Andean-type, volcanic-plutonic arc environment.

Study of these transitional rocks reveals the following stratigraphic units (from lower to upper): generally structureless blue-gray limestone (Bls); a heterogeneous sequence of limestone and fine-grained sandstone and siltstone (Hm); yellow-orange, limonite-bearing, very fine silty marble (Ym); grayish-red and grayish-green sandstone, and siltstone, claystone, and minor conglomerate (Rm); red-brown, tabular-bedded sandstone and conglomerate (Rc); grayish-green, fine- to coarse-grained, generally poorly sorted, predominantly structureless sandstone and minor sandy conglomerate (Gc); pale-olive, calcitic claystone and minor tabular-bedded, pebble and granule conglomerate

(Osh); yellowish-gray calcareous chert (Wc); grayish-red, well-sorted, fine-grained sandstone (Rss); light-brownish-gray, sandy pebble conglomerate and boulder conglomerate (Vcg); grayish-red and pale-red, well sorted, silty, fine-grained sandstone and conglomerate (Rgss); and volcanic flow rock or sill rock (Volc).

The heterogeneous marine rocks (Hm) together with the thick-bedded limestone (Bls) are interpreted to be shallow marine deposits formed in a quiet-water, tidally influenced coastal area that was subject to the passage of storm waves and mild wave currents. The contact between these marine rocks and the overlying continental deposits is conformable in the south and unconformable in the north.

The limonite-bearing marble (Ym) is interpreted to be a supratidal sabkha deposit. These deposits interfinger with midfan to fan-base clastic rocks of the Rm and Rc lithosomes which compose an alluvial fan assemblage named the Cerro Gordo fan. Rm is interpreted to be sheetflood deposits formed mostly at the fan-base. Conglomeratic rocks of the Rc lithosome are interpreted to be braided-stream and debris-flood deposits, generally more proximal than Rm, formed mostly on the midfan. These deposits do not contain volcanic clasts and therefore probably predate volcanic eruption in the area.

Lithosomes above Rc and Rm alluvial fan deposits contain volcanic debris and therefore are interpreted to post-date volcanic eruption. These deposits are units Gc, Osh, Rss, Wc, and Vcg, and represent continued deposition on the Cerro Gordo fan following volcanic eruption. Gc deposits are volcanic rich and are interpreted to represent debris flood and waning-stage flow deposits formed in a reducing environment. The Osh lithosome is interpreted as fine-grained overbank deposits silting up an abandoned Gc channel. Rss deposits are interpreted as midfan to fan-base interdistributary deposits formed in very shallow, braided channels as low longitudinal bars, channel fill, and as sheetflood deposits. The Vcg unit probably was deposited in a confined channel which filled with boulder conglomerate during a storm event and then with braided-stream deposits during lower stage flow.

Wc calcareous chert occurs at several stratigraphic horizons. A tenable interpretation of the depositional environment is that Wc deposits represent very altered, reworked tuffaceous deposits or ignimbrite flow deposits.

The parallel-laminated, fine-grained sandstone and less abundant conglomerate of the Rgss unit formed as rapidly aggrading distributary and interdistributary sediments on an alluvial fan. This fan existed adjacent to and north of the Cerro Gordo fan described above, and is named the Swansea fan. The Swansea fan deposits contain less volcanic debris and more calcareous debris than post-eruption deposits on the Cerro Gordo fan.

Volcanic eruption was preceded in the north exposures by a period of uplift and erosion. The resulting unconformity, most apparent in the Union Wash area, underlies the Swansea alluvial fan. Intercalation between marine and nonmarine strata in the Union Wash area indicates incursions of the sea, possibly related to deflation accompanying extrusion of lava from magma chambers under the area.

The large boulder size of some of the volcanic and calcareous clasts indicates the close proximity and rugged nature of the source terrane. Siliceous clasts in the study area commonly are well rounded and either represent reworked sediments or indicate a more distal source terrane than that which provided the volcanic and calcareous clasts. Limited data indicate a N. 60° E. paleocurrent direction and a source terrane that existed to the southwest in the area of the nascent Sierran volcanic arc.

INTRODUCTION

Scope and Purpose

Two lithologic assemblages of early Mesozoic age are recognized in eastern California. The older of these, of Early Triassic age, is a series of interbedded carbonate, fine-grained clastic rocks, and conglomerate. This marine sequence has recently been interpreted by Burchfiel and others (1980) as an overlap assemblage which was deposited across diverse terrains juxtaposed and deformed during a late Paleozoic or earliest Mesozoic orogeny in southeastern California. Depositionally overlying this overlap assemblage is a sequence of coarse-grained clastic rocks which grade upward into volcaniclastic rocks and finally volcanic flow rocks that represent the extrusive portion of the nascent Sierran volcanic-plutonic arc.

The contact between these two sequences represents a significant tectonic and stratigraphic transition. The sedimentologic record of this transition, as exposed in the southern Inyo Mountains of eastern California, is the topic of this thesis.

Strata of Triassic to Jurassic(?) age exposed along the west flank of the southern Inyo Mountains (Fig. 1) consist of a lower sequence of marine shale, limestone, and minor conglomerate and an upper sequence of continental conglomerate and volcaniclastic and volcanic flow rocks. I have examined the stratigraphy along the transition between these two sequences in order to define more clearly the changes in depositional environments, to identify provenance, and to interpret

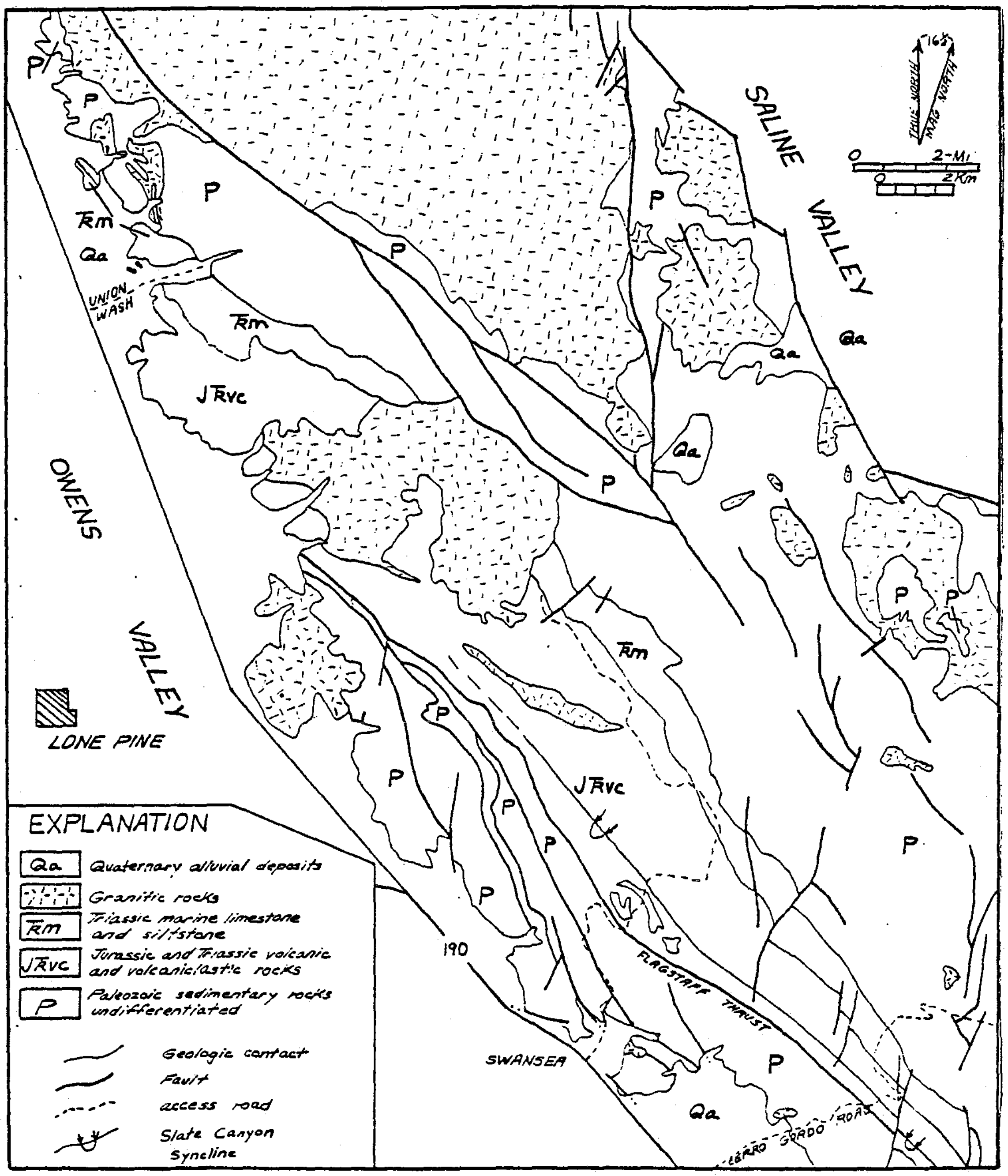


Figure I. Generalized geologic map of the southern Inyo Mountains. Adapted from Ross (1967).

the paleogeography.

About 45 days were spent in the field during the spring and summer of 1981. Field work was concentrated in three subareas selected on the basis of their accessibility and their relative positions along the trace of the transitional sequence. The subareas are from northwest to southeast:

1. south of Union Wash, near the northern end of the exposures;
2. north of Swansea, where the transitional sequence is exposed along a four-wheel drive road; and
3. along Cerro Gordo Road, near the southern limit of exposures of strata of Triassic age.

Location and Geography

The Inyo Mountains consist of an elongate, northwest-trending, fault-bounded range that lies on the western edge of the Basin and Range province in southeastern California (Fig. 1). Rocks of Triassic age of the overlap assemblage and overlying rocks of Triassic-Jurassic(?) age representing the arc assemblage are exposed as a northwest-trending, linear belt along the west flank of the southern Inyo Mountains. Exposures of lower Mesozoic rocks extend from an area just southeast of the town of Keeler, where they disappear beneath a late Cenozoic basalt field, northward for 41.6 km (26 mi) past the town of Swansea to the vicinity of Union Wash.

Rough graded dirt roads provide access to the Mesozoic rocks in several localities. Access to the exposures is good in the Union Wash area and along Cerro Gordo road, and can be accomplished with a two-wheel drive vehicle. A four-wheel drive vehicle or trail bike is recommended for the rough road that trends eastward from Swansea.

Previous Work

Geologic study of the southern Inyo Mountains, especially in the area of the mine workings at Cerro Gordo, began in the late 1800's and early 1900's. The first geologic work significant to this study was conducted by Knopf (1914). This early work and a later, more comprehensive work by Knopf (1918) and Kirk (1918) presented the first geologic reconnaissance and stratigraphic study of the area. Kirk's 1918 (p. 47-48) study presents the first informal division of the marine rocks into three members. Smith (1914, 1932) presented the first paleontologic studies of the ammonoids within the Triassic strata in the Union Wash area. Merriam (1963) presented an excellent summary of these earliest studies to which the reader is referred.

Merriam (1963) studied the geology and stratigraphy of Triassic strata at the Cerro Gordo and Union Wash areas. His mapping revealed that the Triassic section rests unconformably upon the late Paleozoic Owens Valley and Keeler Canyon Formations. A more recent study by Stone and Stevens (1980) revealed that, throughout the area between Darwin Canyon and the Inyo Mountains east of Lone Pine, variations in the age and depositional environment of rocks juxtaposed across this unconformity occurred during late Paleozoic time. Their studies indicate that several events of high-angle faulting may have occurred during late Paleozoic time resulting in creation of uplifted blocks and intervening basins. Late Paleozoic miogeoclinal strata deposited prior to these faulting events consist of a sequence of deep-water turbidites, which grade upward into shallow marine rocks. Erosion subsequent to faulting and tilting removed as much as 2,000 m of late Paleozoic strata and much of the shallow-water deposits was removed. The breakup of the miogeocline into uplifted blocks determined the localized and lenticular nature of pre-Triassic rocks above the unconformity (Stone and Stevens, 1980).

Following Knopf (1914), Merriam (1963) divided early Mesozoic rocks in the Inyo Mountains into a lower marine sequence consisting of three members and a conformably overlying volcanic and terrestrial sequence divided into two members (Fig. 2). The upper member of the marine sequence and the lower member of the terrestrial and volcanic sequence include that interval of the lower Mesozoic strata examined in this study. The contact between the lower marine sequence (overlap assemblage) and the overlying Triassic to Jurassic(?) volcanic sequence (arc assemblage) was reported by Merriam (1963) to be conformable. However, he noted that dips in the volcanic sequence are generally less steep than those in the upper part of the marine sequence, which suggests the possibility of angular discordance.

Triassic marine strata vary in total thickness between 540 m (1,800 ft) and 748 m (2,493 ft) (Merriam, 1963; Elayer, 1974). The uppermost informal member of the marine section as defined by Merriam (1963) is the reefy limestone unit. This unit is 225 m (750 ft) thick at Cerro Gordo and lies stratigraphically below the lowest conglomerate of the "land-laid" Triassic volcanic sequence. The base of the limestone unit is defined by Merriam (1963) as the horizon at which the gray limestone begins to predominate over shale. The most notable lithologic feature of this unit is the presence of several broadly lens shaped exposures of highly resistant, hogback-forming, medium- to dark-gray or bluish-gray marble. These marble exposures as observed by

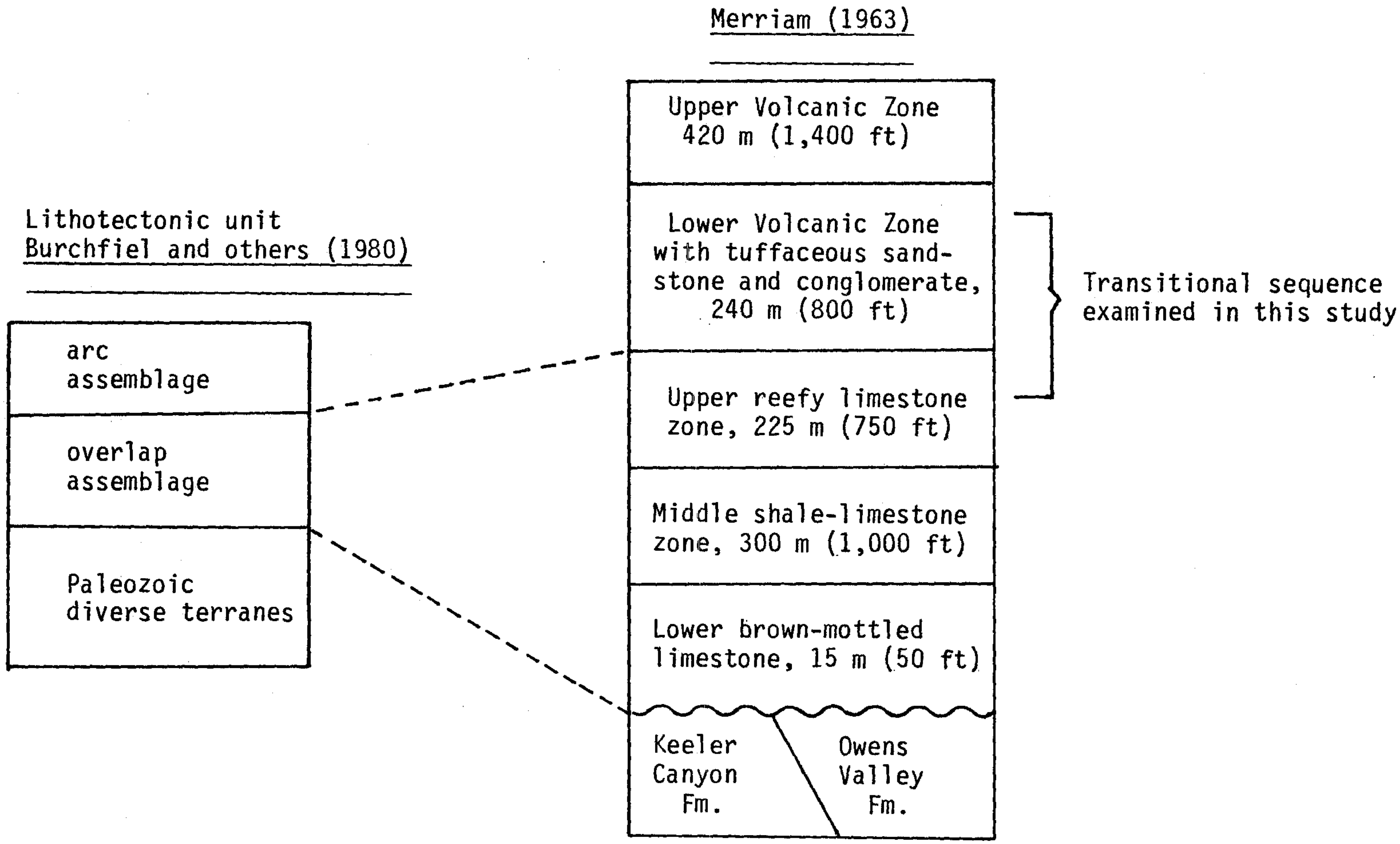


Figure 2. Relation of Triassic rocks of the Inyo Mountains, as informally divided by Merriam (1963) for exposures at Cerro Gordo area, to lithotectonic units discussed by Burchfiel and others (1980). Transitional sequence of this study shown with bracket. Contact between Keeler Canyon and Owens Valley Formations in some places faulted, other places unconformable (G. C. Dunne, pers. comm.).

Merriam range from 15 m (50 ft) to approximately 60 m (200 ft) in thickness and are informally referred to as the "Blue Gate lime". Merriam further described the limestone of this upper member as varying in structure from fairly well bedded to very thick bedded and massive with intervals of pink and orange shale present in the lower part. Pink shale in the lower portion contains marine fossils. However, the reddish color of these rocks led Merriam to suggest that these shale beds may represent brief emergence and weathering. When traced northward, the exposures of thick-bedded limestone disappear almost entirely from the section near Union Wash. Although there are very few clear indications of organic activity in these limestone exposures, Merriam (1963, p. 30) reported traces of possible calcareous algae.

The marine Triassic rocks in the Inyo Mountains are referred to as the Union Wash Formation by Mount in an article titled "Stratigraphy and Paleontology of the Marine Triassic, Inyo Mountains, Inyo County, California" that appeared in an informal publication titled "Bulletin of the Southern California Paleontologic Society" (vol. 3, no. 7, July 1971, p. 1-4 and 9). Mount proposed that exposures of the marine Triassic rocks in the Union Wash area be the type locality. Mount maintains that although the basal part of the Triassic section at Union Wash may be complicated by folding and minor faulting (Kirk, 1918), this section is the best type area for the formation because of easy accessibility, because of the presence of ammonoids, and because this section has been referred to more in the literature than any other.

The name Union Wash Formation seems appropriate for a section with a type locality in the area of Union Wash, but there is considerable variation in the stratigraphic relations of these rocks to the south of Union Wash. It may be that the Triassic section at Union Wash is not the most representative of these rocks. Therefore, it seems that formal designation of a name for these rocks should await clearer definition of the total stratigraphy and notification in a nationally circulated scientific journal.

The Triassic to Jurassic(?) volcanic and volcaniclastic sequence overlying the reefy limestone member consists of andesitic flows, tuffs, and breccias, with intercalated sandstone, shale, and conglomerate. These rocks which fill the core of a large syncline, are reported to be at least 1,920 m (6,000 ft) thick near Union Wash (Merriam, 1963), and are progressively cut out southward by the Flagstaff thrust fault in the area of Cerro Gordo Road, where thicknesses of 600 m (2,200 ft) and 540 m (1,800 ft) have been reported by Merriam (1963) and Elayer (1974, p. 59), respectively.

Merriam divided the volcanic sequence into two stratigraphic units (Fig. 2). The upper unit is the thickest, being a reported 420 m (1,400 ft) at Cerro Gordo; it consists predominantly of andesitic flows and volcanic flow breccia. Red and green shale, slate, sandstone, and conglomerate interbedded with the volcanic rocks pass laterally into water-laid pyroclastic rocks, and are believed to be of continental origin (Merriam, 1963, p. 31).

The lower unit of the Triassic to Jurassic(?) volcanic section, as described by Merriam (1963) consists of dense tuffaceous rocks, shale, sandstone, and conglomerate. Dunne and others (1978, p. 191) interpreted this lower volcaniclastic and conglomerate unit as alluvial fan deposits "as indicated by their great lateral persistence, bimodal distribution of clast and matrix grain sizes, local imbrication of clasts, and local channeling".

Age

The age of Triassic strata in the Inyo Mountains is based in part on ammonites recovered from the Triassic marine rocks at Union Wash. The earliest published work on these ammonite zones was conducted by Smith (1914, 1932) who assigned ammonoids from the Union Wash section to the Meekoceras and Parapopanocerous Zones, thus establishing an Early to Middle Triassic age. More recently, ammonites from the Parapopanocerous Zone are considered to be entirely of Early Triassic age (Siberling and Tozer, 1968).

The upper strata of the marine rocks were inferred to be late Early Triassic age by Dunne and others (1978), because they conformably overlie and are lithologically similar to the underlying Early Triassic strata. This inference is consistent with arguments presented by Elayer (1974), who inferred an age of younger late Early Triassic for the upper portion of the marine section. It follows that the transition from overlap to arc assemblage, which is represented by rocks that overlie these upper marine Triassic rocks, is late Early Triassic age or younger, possibly Middle(?) Triassic, because the sedimentation rate may have fluctuated considerably during deposition of the marine rocks, and was probably much faster during deposition of the arc sequence.

Collinson and Hasenmueller (1978) have identified new conodont zones of the Triassic in Nevada, Utah, and southeastern California. Their findings indicate a Smithian to upper Spathian Stage (upper

Lower Triassic) for the marine portion of the Union Wash section. Calvin Stevens and students are actively studying the biostratigraphy of the Triassic marine rocks in eastern California, and early results from their work indicate all strata below the Blue Gate lime are Early Triassic in age (Calvin Stevens, pers. comm., 1982).

The volcanic and volcaniclastic rocks of the southern Inyo Mountains are intruded by a pluton in the New York Butte quadrangle which has a K/Ar biotite apparent age of 137 m.y. (Ross, 1969). This age limit, together with age constraints imposed by the stratigraphic position above the late Early Triassic marine rocks, brackets the age of the volcanic and volcaniclastic sequence as Middle(?) Triassic to Late Jurassic. Dunne and others (1978) suggested that, if the pluton in the New York Butte quadrangle can be correlated with the Early Jurassic Hunter Mountain batholith, then the age of the volcanic section is further restricted to Middle(?) Triassic to Early Jurassic. Recent petrographic and chemical data, however, indicate that this pluton is not correlative with the Hunter Mountain batholith, and thus the age does not necessarily fall within the age span of the Hunter Mountain batholith.

Structure

Triassic rocks in the Inyo Mountains, although well exposed, are strongly deformed by northwest-trending axial-plane cleavage associated with large folds. The most notable of these folds is the Slate Canyon syncline (Fig. 1). This fold plunges northwest 20° to 45° in the central and northern portions of the range (George Dunne, pers. comm., 1982) and is slightly east vergent, with a trough surface trace which trends northwest within the Triassic-Jurassic arc assemblage (Elayer, 1974; Dunne and others, 1978). The transitional sequence from marine to volcanic rocks is preserved on the upright east limb of this large syncline; the west limb is dissected by numerous reverse and normal faults, and the western continuation of the transitional sequence is not recognized on this limb. The principal reverse fault that cuts out the marine section on the west limb has been termed the Flagstaff thrust fault by Kelley (1973), and Kelley and Stevens (1975), and is the lowermost major fault of their Swansea thrust system. Together with the large folds and pervasive axial-plane cleavage, this fault records east- to northeast-directed contractile strain during Mesozoic time (Kelley and Stevens, 1975; Dunne and others, 1978). Latest movements on these faults occurred after early Late Jurassic time because dikes of the Independence dike swarm are cut in several places (George Dunne, pers. comm., 1982). Pervasive yet variable ductile strain associated with these large structures is expressed within the transitional sequence by flattening and stretching of clasts and primary sedimentary structures. The contacts between major lithosome bodies commonly are sheared and silicified, making the interpretation of the stratigraphic nature of unit boundaries difficult.

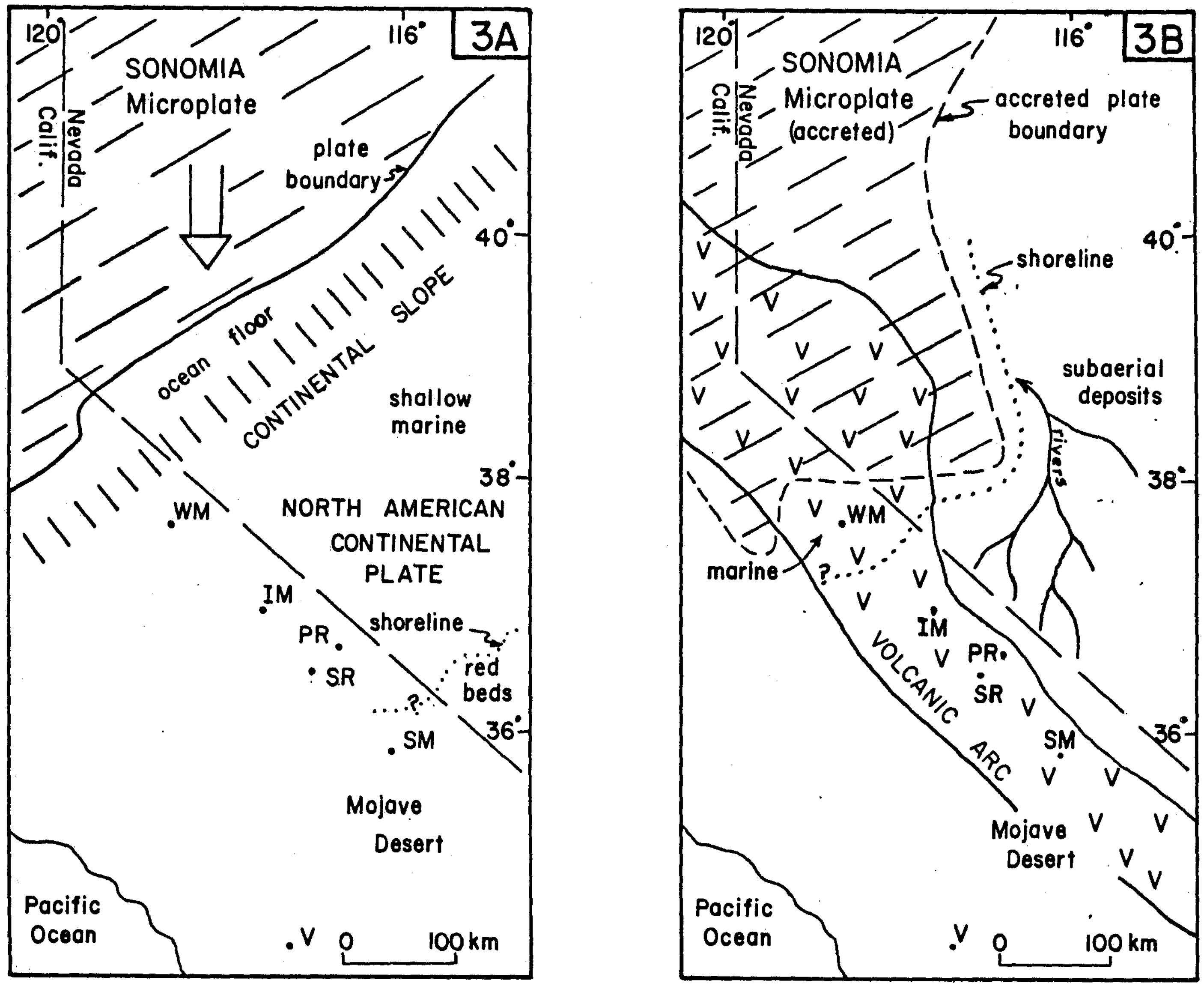
Northwest- and northeast-trending, small-scale, strike-separation faults offset the transitional rocks in places and may represent a Late Cretaceous conjugate set (Elayer, 1975; Dunne and others, 1978).

GEOLOGIC SETTING

Early Triassic strata of the southern Inyo Mountains, together with other Early Triassic marine sequences exposed across Nevada, Utah, and eastern California (Fig. 3A), are interpreted as the final phase of widespread, quiet-water marine deposition within the Cordilleran miogeocline (Collinson and Hasenmueller, 1978). In the northern Mojave Desert and Death Valley regions of California, these marine strata unconformably overlap deformed Paleozoic rocks that may represent a southwestern extension of the Sonoman orogenic belt (Burchfiel and others, 1980; Miller, 1981). Two unconformities of late Paleozoic age have been recognized in the Inyo Mountains. The younger of these is recognized in Darwin Canyon and the southern Inyo Mountains where early Early Triassic marine rocks unconformably overlie deformed upper Paleozoic rocks as young as late Permian age (Stone and Stevens, 1980; Stevens, pers. comm., 1982). This younger unconformity is similar to the widely recognized late Paleozoic-Triassic unconformity that has been equated with the Sonoman orogeny. However, recent studies by Paul Stone (pers. comm., 1982) indicate that this young unconformity is not strongly angular and, in some places, the contact is almost a paraconformity. This indicates that this young unconformity is not the same as the widely recognized late Paleozoic-Triassic unconformity.

The second unconformity recognized in the area of the southern Inyo Mountains is of high angularity, and in this respect resembles the late Paleozoic-Triassic unconformity. However, this second unconformity is Early Permain in age (Paul Stone, pers. comm., 1982). It seems then, that the widely recognized unconformity generally equated with

Figure 3. Broad paleogeographic trends during late Paleozoic to Early Triassic time, showing Sonomia, continental slope, and post-collision Andean-type volcanic arc. Adapted after Speed (1978, 1979). Figure 3A shows a shallow marine sea across Nevada corresponding to the miogeocline of Collinson and Hasenmueller (1978). Large arrow indicates direction of relative velocity of impinging plates, continent fixed. The southwestern extension of the shoreline into the Mojave Desert region is not clear, however, marine province shown in Figure 3A (Burchfiel and Davis, 1981). Figure 3B illustrates a time following the collision of Sonomia with the continent and formation of the Andean-type arc. The shoreline shown in eastern California is inferred from Fiske and Tobish (1978) who indicate that repeated marine transgressions and regressions characterize the volcanic arc sequence of the Ritter Range pendant. Alluvial fans of the marine to continental transitional sequence preceed the eastward migration of the arc. Fluvial systems transport sediments from the volcanic arc in eastern California and perhaps also Arizona (Stewart and others, 1972) to fluvial-deltaic conduits at the eastern margin of the subsident region occupied by the collided Sonomia plate and adjacent shelf terrane. Abbreviations are as follows: WM, White Mountains; IM, Inyo Mountains; PR, Panamint Range; SR, Slate Range; SM, Soda Mountains; V, Victorville.


3A
120°
116°
SONOMIA Microplate
Nevada
Calif.
plate boundary
ocean floor
CONTINENTAL SLOPE
40°
shallow marine
38°
WM
NORTH AMERICAN CONTINENTAL PLATE
IM
PR
SR
shoreline
red beds
?
36°
SM
Mojave Desert
Pacific Ocean
V
0 100 km
3B
120°
116°
SONOMIA Microplate (accreted)
Nevada
Calif.
accreted plate boundary
40°
shoreline
subaerial deposits
rivers
38°
WM
marine
?
IM
PR
SR
VOLCANIC ARC
SM
36°
Mojave Desert
Pacific Ocean
V
0 100 km

the Sonoman orogeny is either of Early Permian age in the southern Inyo Mountains, or is not present.

The exact timing of collision and initiation of the Sonoman orogeny relative to deposition of the marine Triassic overlap assemblage in the Inyo Mountains is not as yet clear. Miller (1981) reports that a pluton with a minimum age of 233 $\pm$ 13 m.y. intrudes deformed strata in the Mojave region. Miller further indicates that this deformation may be a more southern expression of the Sonoman orogeny. This indicates that "Sonoman" deformation occurred earlier to the south than in the type area in Nevada. Because of the differences in the reported age of "Sonoman" deformation, it is not clear at this time what the relative position of the Sonomia microplate was at the time of deposition of the marine Triassic rocks of the overlap assemblage. Figure 3A shows the island arc (Sonomia) to be near collision with the North American plate in Triassic time (Speed, 1979) but, this is at this time a generalization. Figure 3B illustrates a time following collision between Sonomia and the North American plate. Reorientation of plate convergence resulted in formation of a new subduction zone and creation of the Andean-type, Sierran, volcanic-plutonic arc (Speed, 1979). This arc terrane cuts across older, long-standing, tectonic trends. The arc cross cuts continental rocks of the North American plate (Kistler, 1978; Speed, 1979). Extrusive volcanic rocks of this arc overlie Triassic marine rocks of the overlap assemblage at widely scattered exposures in southeastern California.

The change from miogeoclinal-type deposition of the overlap assemblage to arc-type deposition in southeastern California has been recognized to be transitional in nature based upon the presence of volcanic detritus within the marine rocks of the upper portion of the overlap assemblage (Grose, 1959). A coarse conglomeratic unit, widely recognized near the base of the arc assemblage (Johnson, 1957; Grose, 1959; Merriam, 1963; Miller, 1978), contains abundant limestone clasts and is reported also to contain volcanic clasts in the Panamint Range (Johnson, 1957), Soda Mountains (Grose, 1959), and in the Victorville area of the Mojave Desert (Miller, 1978). In addition, intrusive clasts are recognized in the conglomeratic units in the Victorville area, where Miller (1978) has interpreted these units as alluvial fan deposits interfingering with shallow marine or lacustrine deposits. Plutonic clasts also are reported by Smith and other (1968) in rocks provisionally assigned to the Triassic in the Slate Range, but the base of the metavolcanic sequence is not exposed there, and the age and stratigraphic position of the conglomerate is uncertain.

East of the Mojave Desert, in southern Nevada, the Moenkopi Formation of Early Triassic age is overlain by the Chinle Formation and its basal member, the Shinarump conglomerate. These strata are correlated by Grose with the Soda Mountain Formation in eastern California. The Shinarump contains limestone and volcanic clasts that were interpreted by Stewart and others (1972a) as being derived from the postulated Mogollon highland south of the Colorado Plateau region. Tuff and bentonitic clay are reported in the upper portion of the Moenkopi Formation (Hewett, 1956). Recent studies indicate that these tuffaceous sediments are probably Jurassic or younger in age (Doug Walker, Massachusetts Institute of Technology, pers. comm., 1982). Volcanic clasts are identified by Walker in the Moenkopi Formation in northeastern Mojave Desert, and imbrication structures from these beds indicate a local transport direction from the southwest.

North of the Inyo Mountains, in the eastern Sierra Nevada, strata of the arc assemblage are exposed as a discontinuous belt across the Saddlebag Lake, Ritter Range, Mount Morrison, and Pine Creek pendants. Lithologies that could readily be correlated with the overlap sequence are not reported from these pendants, where the arc assemblage directly overlies deformed Paleozoic rocks (Schweikert, 1978). The nature of the contact between Paleozoic and early Mesozoic rocks in the eastern Sierra has been the subject of debate. Morgan and Rankin (1972) suggested that the contact is a fault, whereas Brook and others (1974) argued that the contact is an angular unconformity. This unconformity may be of Permian and Triassic age because the youngest rocks underlying the unconformity are Pennsylvanian and Permian(?), and the oldest rocks overlying the unconformity are latest Permian or earliest Triassic (Nokleburg and Kistler, 1980). The onset of volcanism and deposition of the arc assemblage rocks in the eastern Sierra Nevada began about 240 m.y.b.p., as indicated by a Rb-Sr whole-rock isochron of 240 m.y. from metavolcanic rocks of the Koip sequence above the unconformity (Kistler, 1966; Brook, 1973, 1977; Nokleburg and Kistler, 1980).

Basal conglomerate of the metavolcanic rocks in the Saddlebag Lake pendant was reported by Brook (1973) to consist mostly of clasts of chert with rare pelitic and quartzofeldspathic hornfelses and marbles. These clast compositions are similar to those described by Kistler (1966) for exposures of the basal conglomerate of his Koip sequence in the Ritter Range pendant.

Conglomerate with volcanic, carbonate, and coarser quartzite clasts is present in the lower volcaniclastic and sedimentary sequence of the arc assemblage in the White Mountains (Crowder and Ross, 1972). The base of the arc assemblage in the White Mountains is not exposed, however, and correlation with other exposures of the arc assemblage is uncertain. Rocks of the arc assemblage in the White Mountains were reported to be Permián(?) to Jurassic(?) in age (Crowder and Ross, 1972).

Rocks of the Andean-type volcanic arc exposed in the White, Inyo, and Panamint Ranges are interpreted by Speed (1978a) to be a southeasterly subaerial prolongation of the predominantly marine volcanic terrane of early Mesozoic age present in southwestern Nevada. These arc rocks in Nevada are thought to overlie unconformably the late Paleozoic arc, termed Sonomia (Speed, 1979), which is thought to have accreted to North America in Triassic time (Fig. 3B).

In summary, the available literature concerning Early Triassic rocks in eastern California indicates that a shallow sea transgressed across the area shortly after a phase of emergence, perhaps accompanied by deformation. Shallow marine deposition was terminated by uplift and the influx of volcanogenic detritus and coarse sedimentary clastic debris at about late Early to Middle Triassic time in the Inyo and Panamint Ranges. In southern Nevada and Arizona regional fluvial transport was northerly to northwesterly across a progressively widening region of subaerial exposure from volcanic sources in southeastern California and perhaps also in Arizona (Stewart, 1969; Stewart and others, 1972; Speed, 1978). The clastic deposits in southeastern California were covered by volcanic flow rocks extruded contemporaneously with emplacement of the first plutons of the Sierra Nevada batholith in Triassic time.

STRATIGRAPHY AND DEPOSITIONAL ENVIRONMENTS

Introduction

Field Procedures

Seven stratigraphic sections were measured along the trace of the transitional sequence using tape and Brunton compass (Compton, 1962, p. 239-240). Measured sections were chosen on the basis of quality of exposure, completeness of section, and lateral disposition. Three additional sections were described, and the thicknesses of these were calculated orthographically from contacts mapped on enlarged aerial photographs. At each section locality and at various points along the trace of the transition, conglomerate slab samples were collected and the largest clast sizes were noted. Samples of lithosomes were collected at all measured section localities. Lithosomes were described in detail in the field and primary structures were sketched. Nomenclature for sedimentary structures is from Reineck and Singh (1975).

Lithosomes and stratigraphic units were mapped on enlarged U. S. eological Survey aerial photographs (approximate scale 1:9,350). tructural features were mapped where helpful in establishing correct cies associations.

Plate II presents somewhat generalized columns of the measured tions "hung" on the base of the first large volcanic flow. From se data and geologic mapping, a generalized lateral facies diagram constructed (Plate III).

In the following discussion lithosome units (Table I) are divided three groupings: shallow marine, transitional, and nonmarine.

TABLE 1. SUMMARY OF LITHOLOGY OF UNITS OF THE TRANSITIONAL SEQUENCE

Bls - grayish-blue marble and limestone, structureless to thick bedded, local lenses of fine-grained sandstone, rare ripple bedding.

Hm - parallel-laminated, light-gray, silty micrite and yellowish-brown, very fine-sandy siltstone; dark-gray, silty, finely crystalline, echinoderm biosparite; greenish-gray, calcitic siltstone and lesser silty clay-shale, parallel-laminated, with rare wavy bedding; interbedded medium- to dark-gray limestone and pale-red, calcitic mudstone and siltstone with tabular, laterally continuous bed form, abundant parallel laminations, and ammonites.

Ym - yellow-orange, limonite-bearing, very fine silty microsparite and marble; light-green, silty very fine sandstone; minor pebbly and granular very coarse sandstone.

Rm - grayish-red and grayish-green, calcitic sandstone, siltstone, claystone, and minor conglomerate.

Rc - red-brown, tabular-bedded sandstone and conglomerate. Conglomerate is clast to matrix supported with scattered imbrication structure, average conglomerate is coarsely sandy and granular to pebbly, and bimodal. Sandstone is well sorted to poorly sorted and commonly parallel laminated.

Gc - grayish-green, fine- to coarse-grained, generally poorly sorted sandstone and minor sandy conglomerate. Predominantly structureless, locally tabular bedded with fining-upward textures.

Osh - pale-olive, calcitic claystone and minor tabular-bedded pebble and granule conglomerate.

Wc - yellowish-gray, calcareous chert with remnant ghost shapes of feldspar phenocrysts(?), structureless to rarely tabular bedded.

Rss - grayish-red, well-sorted, fine-grained sandstone, contains tabular beds of pebble and cobble conglomerate, contains low-angle cross-bedding.

Vcg - light-brownish-gray, sandy pebble conglomerate and fine to coarse sandstone with lensoidal to tabular bed form and fining-upward textures; poorly sorted, sandy, volcanic-boulder conglomerate.

Rgss - grayish-red and pale-red, well-sorted, silty, fine-grained sandstone with less abundant sandy pebble conglomerate.

Volc - reddish-brown volcanic rock, altered, replaced, and disrupted by cleavage.

Lithosomes are described from south to north starting with the stratigraphically lower marine rocks and proceeding up section. A notation designation, shown on Plate I, is used for reference to measured sections. Measured sections in the Cerro Gordo area have the notation prefix CG, sections in the Swansea Wash road area have the prefix SW, and those from the Union Wash area have the prefix UW. The notation MS indicates a measured section, whereas the notation EMS (sections shown on Plates II and III) indicates that the section thickness was calculated orthographically from the aerial photographs. The lower portion of the most southerly section in the Swansea Wash area (SW-3MS) was measured in the field, and the upper portion was orthographically calculated from aerial photographs. Plate I illustrates just those sections measured in the field. Plates II and III illustrate both measured and calculated sections.

Laboratory Procedures

Laboratory work included identification of rock types and textures through petrographic analysis. Seventy thin sections were examined, 40 of which were prepared by the author and 30 prepared professionally. Rocks were named in accordance with the classification system of Folk (1974). Sorting and textural maturity were estimated (Folk, 1974, p. 147-148, 156, 167) and constituent percentages were estimated using visual percentage charts. Rock color in the field and laboratory was determined by comparison with a color chart (Goddard, 1970). Roundness was estimated in thin section and slab study by comparison with the Powers (1953) roundness chart.

Nineteen slab samples were described with use of a binocular microscope. A mylar overlay was mounted over each slab and individual pebbles were traced, numbered, and noted as to size range (Wentworth size grades, 1922), roundness, and composition. In general 100 pebbles were counted per sample. In some samples such as CG-2A and UW-4 (Table 12) it was difficult to distinguish individual pebbles because the conglomerate and coarse sandstone have undergone ductile strain. Conglomerate samples exhibit varying strain, and the effect on individual clasts varies with clast composition. Competent siliceous clasts are in most samples not too deformed, whereas relatively less competent clasts, usually calcareous types and volcanic types, are flattened and thus tend to be more angular. These deformed clasts were noted as to roundness according to the best estimation of primary roundness.

Alizarine red staining solution (Friedman, 1959) was used on slab samples to aid in composition identification. With this stain, calcite is stained dark red and dolomite is not stained except on excess exposure. A sample of Vcg conglomerate was etched overnight in 50% HCl solution to help differentiate between calcareous and volcanic rock fragments.

Orientation of thin sections and slab cuts commonly was governed by the cleavage orientation. Many rocks, especially fine-grained rocks such as Rm, are severely disrupted by cleavage. Intersection of cleavage traces has produced a structural fabric such that the rock breaks out in thin chips. At some places a packet of these chips was collected and taped together. The packet was then impregnated with epoxy to hold the sample together such that a thin section could be prepared.

Paleocurrent data were restored to horizontal by rotation on a

Wulff stereonet in accordance with the procedures outlined by Ragan (1975, p. 100-101).

Shallow Marine Lithosomes

Blue-Gray Limestone (Bls)

This lithosome is equivalent to the "Blue Gate lime" beds as described by Merriam (1963) for exposures in the Cerro Gordo area. These limestone and marble units generally are structureless to thick-bedded, grayish blue (5PB5/7; color designation from Goddard, 1970) in color, and form conspicuous hogback outcrops. Individual exposures are locally tabular with good continuity of thickness, but on a regional scale are broadly lens shaped.

The upper and lower contacts of Bls are sharp and planar. The Bls lithosome interfingers with the heterogeneous marine unit (Hm) and lies adjacent to the yellow limestone unit (Yls) at SW-3MS. Exposures range in thickness from 11 m at the Swansea area to 14 m along Cerro Gordo Road (Plate II).

This unit is exposed at several levels within the upper informal member of the Triassic marine rocks, particularly in the Cerro Gordo area. This repetition may be a primary stratigraphic feature, or it may result from tight folding or faulting of a single horizon.

The marble is fine to coarsely crystalline and contains traces of cleavage expressed as en echelon streaks of dark residue associated with areas of grain diminution. No ghost fossil shapes were observed, and at the SW-2MS locality parallel laminations are revealed in thin section to be alternating medium and finely crystalline calcite. In outcrop, abundant stylolites were observed, attesting to large-scale dissolution. Calcite veins occur irregularly and in sigmoidally shaped fractures.

Rare, faint expressions of bedding within the Bls lithosome were observed at several localities. At most of these localities beds are 0.5 to 1.0 m thick and are defined by vague separation planes or differences in color. Bedding seems to thin upward in the Bls lithosome at SW-3MS from crudely defined beds 40 to 60 cm thick to thin, platy, tabular beds approximately 6 cm thick.

Fossils are rare in the Bls unit. A poorly preserved fossil resembling an orthocone nautiloid was collected from the lithosome at the SW-1MS locality near the Burgess Mine. In addition, at this same locality, 1 to 3 mm long angular fragments resembling sponge spicules were observed. Biogenic evidence includes the preservation at one isolated locality in the Cerro Gordo area of possible stromatolitic structures, recognized as domal-shaped, delicately laminated, light- and dark-grayish-blue carbonate. No trace of algal filaments was observed, however, in any of the five thin sections from this lithosome. It is also possible that these domal laminations are folds.

Thinner sets of tabular-bedded limestone in the upper portion of the Triassic marine strata at Union Wash, just north of the intrusive rocks which obliterate the Triassic section near New York Butte (Plate III), may be the lateral equivalent of the Bls lithosome recognized to the south. Geologic reconnaissance of the Triassic strata near the northern margin of the intrusive rocks reveals that the thin limestone beds characteristic of the Union Wash section become thicker southward, and begin to resemble the thick limestone units of the Bls unit.

Fine-grained, well-sorted, calcitic quartzarenite(?) occurs in horizons up to 1 cm thick in the upper portion of the lowest Bls unit at SW-3MS locality. The fine-sandy laminae are parallel laminated and symmetrically ripple laminated with pointed crests and rounded troughs resembling oscillation ripples and chevron ripples.

Rare, fine-grained, well-sorted calcitic quartzarenite(?) and intercalated silty limestone lenses up to about 2 m thick are present within the Bls units (see SW-3MS, Plate II). These lenses are sandier than normal, are approximately 5 m in length, and interfinger with the enclosing grayish-blue marble. Parallel-laminated silty limestone occurs within these more clastic lenses, and where observed, bed thickness decreases upward from 20 cm to approximately 2 cm. Asymmetrical lenses of fine sandstone occur in the upper portion of the lenses. Marble overlying a lens at SW-3MS is mottled light and dark-grayish blue and contains what may be burrow structures.

Heterogeneous Marine Rocks (Hm)

This unit consists of a group of lithologically diverse lithosomes generally associated stratigraphically with Bls and considered to be of marine origin. The following descriptions of lithosomes begin in the southern exposures and progress northward.

A silty micrite and well-sorted very fine sandy siltstone lithosome overlies Bls at the Cerro Gordo area and underlies Bls in the Swansea Wash study localities. Thickness of this lithosome is variable due to its interfingered nature with Yls and with Bls. This lithosome is 50 m thick at CG-1MS where the upper contact is drawn at the bottom of the less resistant siltstone and mudstone of Rm. In most cases, as at SW-1MS and SW-3MS, the lower portion of this lithosome was not observed, and a maximum or average thickness cannot be determined. As with all fine-grained rocks in the study area, this lithosome is strongly deformed by cleavage.

In general, fine-sandy silt decreases in percentage northward from CG-1MS where it composes 75% of the lithosome, to SW-2MS, where laminated silty micrite composes 90%. Both lithologies contain remnant parallel laminations. However, structural disruption in most cases prevents tracing these laminae for more than a few centimeters. At CG-1MS silty micrite occurs as tabular, internally laminated beds with a thickness range of 5 to 30 cm, and an average thickness which decreases upward from 25 cm to 4 cm. Silty micrite weathers from grayish orange (10YR7/4) to medium light gray (N6), and it is medium dark gray (N4) on a fresh surface. Some silt laminae observed in thin section pinch out into micrite.

Very fine sandy siltstone is calcitic and submature, weathers to moderate yellowish brown (10YR5/4), and is between dark yellowish orange (10YR6/6) and moderate yellowish brown (10YR5/4) on a fresh surface.

Traces of limonite are present in most of these rocks. Authigenic minerals include probable pyrite, now altered to magnetite(?) and hematite.

Silty, finely crystalline, biosparite occurs as tabular, laterally continuous beds interbedded with the silty micrite and sandy siltstone at the base of sections SW-2MS and SW-3MS. The biosparite weathers to medium dark gray (N4) and is dark gray (N3) on a fresh surface. Bed thickness is usually less than 3 m, and the fossil debris is concentrated at the top of the bed. Internal stratification within these beds is interpreted to be parallel and tabular with thicknesses of 20 to 30 cm decreasing to about 10 cm as the percentage of fossil debris increases.

Composition of these fossiliferous limestones, and of a sample from the blue-gray limestone at Union Wash, is summarized in Table 2. Shells compose a significant percentage of the allochems in the bio-sparite found at the Swansea Wash area. These fossils are unidentifiable in hand sample, and the microstructure is largely recrystallized, preventing identification in thin section. Echinoderm fragments were recognized by their characteristic unit extinction and plate shapes. One fragment with stereome structure was identified by Richard Squires (pers. comm., 1981). Echinoderm fragments are slightly abraded and very poorly sorted.

Calcitic very fine sandstone, siltstone, and lesser amounts of silty claystone occur in a thick sequence below Bls at SW-1MS. The very fine sandstone weathers from dark greenish gray (5G4/1) to greenish gray (5G6/1) in color and is medium gray (N5) to dark greenish gray (5G4/1) on a fresh surface. Fine sandstone composes about 90% of this sequence and occurs as thin laminae and as beds ranging in thickness from 1 mm to 15 cm. These beds are structureless to more rarely parallel laminated and have sharp separation planes. The base of the thicker beds is in places very mildly undulatory or wavy.

Silty claystone and siltstone compose 10% of this sequence and in places contain recognizable preserved laminae of alternating light-gray and gray-green color. The siltstone overall is light gray (N7) on weathered and fresh surfaces. The claystone is interlaminated with the siltstone with thickness varying from 1 to 12 mm, and in one sam-

TABLE 2. COMPOSITION OF FOSSILIFEROUS LIMESTONE

	SW-2,3	SW-3.2	UW-3,3
percent terrigenous framework	10	40	2
percent allochems	15	10	2
percent micrite	75	50	96
terrigenous framework size (mm)	.05	.025-.05	clay?-.05
fossil size (mm)	.25-5.0	.25 15.0	1.0-5.0
allochem types:			
echinoderm	70*	90	--
ammonite	--	--	100**
indeterminant shell	30	10	--
pellets	Trace	--	--

* Trace encrusting bryozoa
** Shell type inferred from identification from hand sample

ple ripple laminae, seemingly symmetrical, are present. Horizontal laminations in one sample of the siltstone are truncated by a rippled erosion surface overlain by silty claystone.

The silty claystone observed in thin section is not calcitic and shows mass extinction when viewed under the polarizing microscope. The alignment of the clay may be a primary feature, but similar textures are observed within siliceous clasts and matrix of some of the clastic rocks, and it is probably a secondary structural fabric.

Heterogeneous marine strata at Union Wash consist of 60 to 70% medium- to dark-gray limestone and 30 to 40% pale-red calcitic mudstone and siltstone. The limestone is medium gray (N6) on weathered surfaces and dark gray (N7) on fresh surfaces. It commonly contains poorly preserved ammonites which are coarsely recrystallized to black calcite and flattened into the plane of cleavage. In some beds ammonite fossils are abundant and compose as much as 10 to 20% of the limestone. Limestone is very well bedded at Union Wash with extremely good lateral persistence. Bed thickness ranges from 3 cm to a little over 2 m. The limestone is in places parallel laminated and has slightly silty horizons. At one locality at UW-3MS laminations of a single, fine-sand-grain thickness were observed. Parallel-laminated silty limestone with laminations from 1 to 2 mm thick are interbedded with the more predominant gray limestone and pale-red siltstone at Union Wash. Silty limestone beds also rarely contain shell fragments that may be broken ammonites.

Pale-red, calcitic, immature quartzarenite(?) mudstone and siltstone interbedded with the limestone described above is often parallel laminated and ammonite bearing. Laminations range from 1 to 7 mm in thickness. This lithology increases in percentage up section at UW-3MS, and this upper portion is in part erosionally removed northward at UW-4MS (Plate I).

Parallel-laminated, well-sorted calcitic coarse siltstone, in places very flaggy, overlies the limestone and pale-red siltstone at Union Wash. This siltstone weathers to light brown, in places with a slight pale-red tint, and is gray brown on a fresh surface. Ammonites are present in the lower portion of this brown siltstone at UW-3MS.

This light-brown siltstone is commonly parallel laminated, and at one locality at UW-3MS these laminations are wavy and bifurcating and resemble tidal bedding. In scattered places interbeds of very-light-brown, slightly silty micrite, apparently about 5 mm in thickness, have been boudinaged into spheroids and arranged into concentric trains and curving patterns.

Environment of Deposition

The presence of ammonoids, echinoderm fragments, and other possible marine fossils, even though they may have been transported after death, indicates an overall marine environment for the Bls and Hm lithosomes. The specific subenvironment of deposition of the Bls unit, however, is not clear. Oscillation wave ripple marks and chevron wave ripple marks (Reineck and Singh, 1975, p. 25) in the upper Bls unit, together with the possible stromatolitic structure, indicate a shallow-water environment. Merriam (1963, p. 30) noted traces of possible calcareous algae within the Bls unit, and he suggested that these deposits may have originated as reefs.

The abundance of micrite (if primary) and very fine silt and clay grain sizes throughout the Hm rocks, together with lack of oolitic textures, indicate weak, non-winnowing currents. Laminations suggest a slightly changing velocity of transporting medium, intermittency of deposition, or slight changes in sediment provenance (Heckel, 1972). Laminations also suggest an environment unfavorable to burrowing benthic organisms.

The textures, structures, and fossils noted above indicate a quiet water, shallow-marine, depositional environment. The coarser biosparite beds at the SW-2MS and SW-3MS localities may have formed by the passage of storm waves (Brenner and Davies, 1973, p. 1690-1692).

The presence of pyrite may indicate a slightly reducing environment and an excess of organic matter (Pettijohn, 1975, p. 412 and 423). Alternatively, the pyrite may have been brought into the system by hydrothermal fluids.

Possible tidal bedding within the Hm lithosome at Union Wash suggests a tidal flat environment for a portion of the marine strata. A low tidal range for these rocks is suggested by three characteristics that Walker and Harms (1975) used as criteria for such an environment in their study of the Catskill Formation in central Pennsylvania. They are:

1. the absence of channels, which would form from runoff of a moderate tidal influence,
2. the close vertical association of marine and nonmarine environments,
3. the absence of winnowed sands.

Yellow marble (Ym)

Lithology

The Ym lithosome is present only at the southerly CG-2 and SW-3 measured section localities (Plate II). In the Cerro Gordo area, it occupies a stratigraphic position above the Bls limestone, below and interbedded with Rm, and below Rc. At the southern Swansea Wash area, Ym is stratigraphically above and interbedded with Bls. The unit is of variable thickness, being 47 m thick at Cerro Gordo and 23 to 30 m thick in the Swansea area. The lower contact of this unit is somewhat arbitrary at Cerro Gordo where Ym and Hm are interbedded. The lower contact is drawn at the base of the lowest yellow-orange, limonite-rich bed. The upper contact at Cerro Gordo, and to a lesser degree at Swansea, is also somewhat arbitrary because beds of Ym are found stratigraphically high within the Rm unit. For convenience the upper contact of Ym is drawn where lithofacies of Rm come to predominate over those of Ym. The lower contact at Swansea (SW-3MS) is sharp and planar where Ym overlies Bls.

The Ym lithosome consists of (in decreasing percentage) yellow-range, very fine-grained, silty microsparite to marble; light-green, ilty, very fine-grained sandstone; and pebbly and granular, very arse-grained sandstone. The yellow-orange, limonitic marble beds e present at both Cerro Gordo and Swansea areas, as are the light-en sandstone beds, but the pebbly and granular, very coarse-grained dstone was observed only at the CG-2MS locality. These lithologies randomly interbedded throughout the unit and no set stratigraphic tion within the Ym unit for any lithology was recognized. Further, clicity of lithofacies repetition is apparent.

Weathered color of the silty microsparite to marble ranges from pale yellow orange (10YR8/6) to dark yellowish orange (10YR6/6). Fresh colors are predominantly dark yellowish orange (10YR6/6). These marbles are commonly tabular bedded and parallel laminated. In thin section, this stratification, shown by color and weathering resistance, is seen to consist of silty streaks and laminae up to 2.5 mm thick within the yellow-orange marble. The micrite and sparite comprise up to 80% of the rock and are densely disseminated with limonite. Authigenic magnetite(?), grown as spherulites, in places gives the rock a spotted appearance. At Cerro Gordo, stratification was observed to range from 1 mm to 3.5 cm in thickness and average .5 cm. At SW-3MS stratification within the yellow-orange limestone ranges from 1 to 100 cm and averages 2 cm in thickness. The thicker of these beds stand out with much more relief than the adjacent thinner bedded, yellow-orange limestone. These thicker beds are finely parallel laminated and more rarely wavy laminated. They contain rare lenses and discontinuous irregular laminae of grayish fine calcitic siltstone that are commonly asymmetrical, and vary in length from 3 to 14 cm.

In the Swansea area the siltstone and mudstone laminae compose as much as 10% of the Ym unit. Orangish, very fine sandy siltstone laminae with ripple cross-bedding were observed at SW-3MS. The main body of the ripples are composed of foreset laminae. In one exposure a set of foreset laminae truncates an older set. The erosion surface between the two ripple sets is mildly undulatory and may be a rippled surface that is not genetically related to the underlying ripple foreset laminae. The ripples may thus be form discordant (Reinech and

Singh, 1975, p. 25). The ripples seem to be asymmetrical wave ripples with steeper lee sides than stoss sides (Reinech and Singh, 1975, p. 25).

Angular calcitic mudstone clasts, set in a matrix of yellow-orange marble, occur at both the Cerro Gordo and Swansea sections. The clasts occur in beds that are a maximum of 1.3 m thick, and the percentage of clasts decreases upward within the beds. The clasts show no preferred orientation, as might be expected if this texture were the result of structural transposition of once continuous laminae within the marble matrix, and they are interpreted to be rip-up clasts. The rip-ups vary in color from dark green at Swansea to light orangish brown at Cerro Gordo. The clasts commonly contain remnant parallel lamination. The maximum observed clast size is 30 cm at CG-2MS.

Yellow-orange marble beds at Cerro Gordo contain rare isolated, rounded limestone cobbles and pebbles. The cobbles are up to 26 cm in maximum diameter.

A fabric was observed in a slab cut of a sample retrieved from the lower Ym lithosome at SW-3MS. This sample consists of micrite-cemented, limonite-bearing, slightly silty mudstone and megaquartz-ınd chert-bearing marble. The marble occurs as folded thin laminae .0 to 6.0 mm in thickness which pinch and swell and have a "cottage heese" fabric resembling calcitized anhydrite fabric (Till, 1978, g. 8-28, p. 196). Scattered silt grains occur within the mudstone minae between marble laminae. Clear definition of this fabric and ; relationship to structural fabric awaits additional field work and pling.

Light-greenish-gray (5G8/1), fine-grained sandstone is interbedded with the yellow-orange marble. The sandstone is cemented with calcite and at the Swansea area composes as much as 40% of the Ym unit. The rocks are very structurally disrupted and no sedimentary structures are preserved. The green sandstone composes less than 5% of Ym at Cerro Gordo and increases in percentage up section and is interbedded also with the overlying Rm lithosome.

Structurally disrupted, green pebbly and granular, very coarse sandstone to pebbly granule conglomerate beds are interbedded with the yellow orange limestone at Cerro Gordo (see CG-2MS). These green conglomerate beds are poorly sorted. The beds are generally 2 m thick and range from 2 to 5 m in thickness. They are matrix supported, bimodal, and micrite and limonite cemented (Table 3). The conglomerate is a chert-bearing calclithite, and in places it contains submature siltstone clasts. No sedimentary structures are preserved within these beds, and the nature of top and bottom contacts is not clear. In some places cobbles of this green conglomerate occur in the immediately overlying yellow-orange limestone beds. The conglomerate beds are tabular in limited exposure, but do not have good lateral continuity, and are traceable for only a few tens of meters.

Environment of deposition

These rocks are interpreted as deposits of a supratidal and/or sabkha environment. The abundant, disseminated limonite may be a replacement of iron-sulphide formed during evaporation of brine waters within low ponded areas (Friedman, 1966). The presence of possible calcitized anhydrite fabrics is supportive of this interpretation.

TABLE 3. PERCENT COMPOSITION YM CONGLOMERATE

sample	% terrigenous framework	% cement	Framework	quartz	weathered feldspar	orthoclase	plagioclase	mica	chert * (Rock Fragments)	micrite (Rock Fragments)	silty micrite (Rock Fragments)	siltstone (Rock Fragments)	volcanic (Rock Fragments)	opaque	others
CG-2,1	80	20		5	2	--	Tr	--	10	25	45	13	--	--	Tr
CG 2,5	55	45		4	--	--	--	--	16	--	40	40	--	--	Tr

* Includes silty and sandy chert

The parallel lamination within the yellow-orange limestone beds, particularly recognizable at SW-3MS, may be stromatolitic structure, but due to calcification and siliceous replacement, algal filaments, if once present, were apparently not preserved.

A supratidal or sabkha environment is further indicated by the stratigraphic position of these deposits between rocks interpreted as shallow marine (Bls, Hm) and rocks interpreted as nonmarine (Rm, Rc).

The green sandstone probably is fluvial in nature, and was deposited in low, wet areas, or in a stream bed, where aeration was insufficient to maintain oxidizing conditions. This interpretation is based principally upon the close association of these rocks with adjacent fluvial deposits (Rc), and upon the interpretation that the associated yellow marble formed in a low topographic area, almost at sea level.

The yellow-orange marble beds with rip-up clasts may have formed during storm events when the marine waters advanced inland briefly and flood or ebb currents worked the sabkha environment. Conversely, flood waters originating landward may have ripped these beds, but the fluvial debris associated with this event, if not represented by the green sandstone and conglomerate, is not present. The green conglomerate may represent fluvial influxes into non-aerated low, wet areas, as described for the green sandstone. It might also represent a low supratidal channel. However, longitudinal cross bedding and other structures characteristic of tidal channels either were not formed or were not preserved.

These deposits are similar in many ways to those described by Schenk (1975) for exposures of the intertidalites of the Middle Carboniferous Windsor Group, Maritime Provinces, Canada. He reports a sabkha environment at the toe of alluvial fans.

Nonmarine Lithosomes

Red mudstone (Rm)

Lithology

The red mudstone lithosome, consisting of calcitic sandstone, siltstone, claystone, and less abundant conglomerate, is most abundant in the Cerro Gordo area, where the lithosome is variable in thickness and usually occurs below the Rc conglomerate. Fine sandstone and siltstone locally present below the red conglomerate (Rc) lithosome at SW-3MS and below the gray and red sandstone lithosome (Grss) at SW-1MS are also placed within this unit.

Calcitic fine sandstone is more common toward the top of the unit where it is interbedded with medium sandstone and less abundant claystone. Calcitic siltstone and claystone is more common in the Cerro Gordo area.

Relief and exposure of the Rm unit are poor, and cleavage disruption is intense. Rm is thickest in the Cerro Gordo area where it reaches a maximum of 95 m. The unit pinches and swells along strike but in general thins northward of the Cerro Gordo exposures to SW-3MS where approximately 8 m are exposed.

The lower contact of the Rm lithosome is placed where Rm lithofacies predominate over Ym lithofacies as at CG-2MS, or Hm lithofacies ıs at CG-1MS. The top of the unit is defined as the base of the first ıajor conglomerate of the clastic, nonmarine Rc lithosome. The conact between the Rm and Rc unit is sharp in places, and pebble conglomerate of Rc lies directly upon Rm siltstone. The contact is notably erosional at SW-3MS where Rc conglomerate overlies Rm fine sandstone. However, in general, the contact seems conformable, and in places Rm sandstone is interbedded with Rc conglomerate.

The Rm lithosome predominantly weathers grayish red (5R4/2) and is very dark red (5R2/6) on fresh surfaces. Grayish-green (5R2/6) weathered and grayish-green (10GY5/2) fresh-colored siltstone and sandstone comprise approximately 10% of the unit at CG-1MS. These greenish lithologies decrease in percentage northward to SW-3MS where green sandstone is interbedded with the Ym unit but is not present in Rm.

The Rm unit consists predominantly of very fine, well-sorted, calcitic submature coarse siltstone and fine sandstone. Bed shape of Rm sandstone ranges from tabular to lensoidal. Sandstone is predominantly parallel laminated. Laminae thickness ranges from 1 to 7 mm. Laminae of siliceous hematite- and limonite-bearing silty claystone were observed in thin section.

Planar, sheet-like beds of poorly sorted medium to coarse sandstone with scattered outsized clasts are common at CG-2MS. Thin, tabular sandy conglomerate beds are commonly present in the upper portion of the Rm unit, and are interpreted to be interfingering beds of the overlying Rc lithosome. In addition, matrix- to clast-supported, sandy conglomerate lenses and beds are scattered throughout the Rm unit and into the Ym unit at CG-2MS. These beds are also interpreted to be interfingering deposits of the Rc lithosome.

Siltstone and claystone are particularly abundant lithologies at CG-1MS. At this locality these fine-grained deposits predominate in the lower portion of Rm, and fine sandstone predominates in the upper portion. An average fine-grained rock weathers to a reddish color and consists of siliceous silty hematite-bearing mudstone. Laminae of hematite-bearing claystone are intercalated with silt laminae, and in cut slabs these laminae are seen to be disrupted.

White micrite to medium-crystalline marble beds are scattered through the lower and middle portion of the Rm unit at CG-1MS. The white marble beds contain rip-up clasts or red and green mudstone as well as more continuous laminae of mudstone that are concentrated near the top of the bed. The beds are up to 15 cm thick, but they have an average thickness of 3 cm. They have sharp planar top and bottom contacts and are traceable for only a few meters.

Green sandstone (Rm), yellow-orange, limonite-bearing marble (Ym), blue-gray limestone (Bls), and silty limestone are interbedded in the lower and middle portions of the Rm unit at CG-2MS. Parallel-laminated, yellow marble beds of the Ym lithosome are scattered up into the upper portion of the Rm unit at CG-2MS and SW-3MS.

At SW-3MS about 8 m of well-sorted fine sandstone and siltstone and pebble conglomerate below Rc are assigned to the Rm unit. The sandstone is generally calcitic, fine grained, and parallel laminated. Granule laminae and small-pebble conglomerate layers occur as lenses and tabular beds with scoured bases. Parallel-laminated, dark-red siltstone and pale-red sandstone near the base of the exposure at SW-3MS contain isolated lenses in the form of asymmetric current ripples that consist of dark-red siltstone.

Environment of deposition

The Rm lithosome is interpreted to be distal fan sheetflood deposits formed on an area of low topographic relief adjacent to a quiet marine environment and supratidal sabkha. Interbeds of Ym marble and Bls limestone indicate a low topographic relief such that short incursions of the shallow marine environment could take place. The reddish color, which is characteristic of this unit, implies oxidizing conditions during and after deposition.

The parallel, tabular, sheet-like nature of the fine-grained deposits and some conglomerate beds is similar to that described by several workers as sheetflood deposits on an alluvial fan (Bull, 1972; Turner, 1980; Gloppen and Steel, 1981). The parallel-laminated sandstone contains outsized clasts, which are cited by Gloppen and Steel (1981) as evidence of a sheetflood mechanism of deposition. Such sheetflood deposits form near the mouth of a channel on the distal portions of a fan, where a sudden drop in flow competence results as channel water becomes unconfined (Bull, 1972). Local scouring, observed at SW-3MS below coarse granular beds may be the result of one flood event truncating the finer suspension deposits of an earlier event (Turner, 1980, p. 134). Lenses of dark-red, fine-grained sandstone within pale-red, fine-grained sandstone at SW-3MS may have resulted during a sheetflood event when sediment-impoverished current ripples migrated across the fan surface.

Red conglomerate (Rc)

Lithology

The Rc lithosome consists of tabular to lensoidal beds of sandy conglomerate and sandstone that compose 60% and 40% of the unit, respectively. The Rc unit is broadly lens shaped and extends from an area south of the Cerro Gordo study area northward to about 1 km past the SW-3MS locality where it pinches out. Rc is essentially continuous along strike between CG-1MS and SW-3MS, but it pinches and swells in thickness. This variation in thickness is most apparent in the Cerro Gordo area where the unit varies along strike from a few meters to 30 m thick. The Rc unit at the SW-3MS locality is as thick as 150 m and is generally more uniform in thickness along strike than exposures to the south.

The basal contact of the Rc unit is defined as the base of the first major conglomerate above the Rm lithosome. The upper contact of the Rc unit is sharp and planar at CG-1MS where Gc (green conglomerate) overlies Rc. The contact is also sharp and planar at CG-2MS where Wc (white chert) overlies Rc, and at SW-3MS where Rss (red sandstone) overlies Rc.

In general, conglomerate of the Rc unit in the Cerro Gordo area is hinner bedded (averages 6 cm) and more closely packed at the base of ie unit, whereas it is matrix supported, somewhat thicker bedded verages 2.5 m), and coarser near the top. The contacts between sand-one and conglomerate beds are sharp and planar and are marked by an upt decrease in clast size without a separation plane.

Rc conglomerate beds in the SW-3MS area are much thicker bedded to 8 m-- than those in the Cerro Gordo area. Conglomerate beds at MS are capped by parallel-laminated, tabular beds of sandstone, tone, and less abundant claystone. Locally present, pebbly sand- lenses approximately 8 cm thick contained within the thick conglomerate beds at Swansea indicate a decrease in flow competence, and they imply that portions of these beds are amalgamated. The base of one of the conglomerate beds at SW-3MS is in erosional contact with the underlying parallel-laminated sandstone capping of the previous cycle. In general, clast size and bed thickness decrease upward in the Rc lithosome at SW-3MS.

Sandstone of the Rc unit weathers to pale yellowish brown (10YR6/2) and is grayish orange (10YR7/2) on a fresh surface. Sandstone ranges from well sorted to poorly sorted, and a wide range in composition has been observed (Table 4). The prominent lithologies include calclithite and chert arenite. Finer grained interbeds at the SW-3MS locality include calcitic subarkosic mudstone.

Conglomerate of Rc also weathers to pale yellowish brown (10YR6/2), but where concentrations of calcareous clasts occur, the rock is more of a grayish color. Rc conglomerate is generally bimodal and very poorly sorted (Table 5). An average conglomerate is coarsely sandy and granular to pebbly and consists of calcitic, submature, :hert-bearing calclithite. The conglomerate in most exposures is comosed mostly of limestone clasts and contains less abundant siliceous lasts such as chert and quartzite. Clasts are rarely larger than cm in largest exposed dimension. Volcanic clasts were not observed. is possible that volcanic constituents are present as comminuted ısts, now replaced by calcite and not recognizable. Conglomerate sts are recognizably imbricated (where outcrop exposure is such that ıvage-related clast alignment can be differentiated from primary mentologic alignment) and vary from clast supported to matrix suped. Limestone as well as siliceous clasts within Rc are rounded to

TABLE 4. PERCENT COMPOSITION RC LITHOSOME

sample	% terrigenous framework	% cement	Framework quartz	weathered feldspar	orthoclase	microcline	plagioclase	mica	chert	micrite	silty micrite	siltstone	volcanic	opaque	others
									Rock Fragments						
CG-1,10A	50	50	80	--	5	Tr	--	--	10	2	2	--	--	1	--
CG-1,12	70	30	35	--	5	--	--	--	37	2	--	1	--	1	--
CG-2	90	10	1	--	Tr	--	--	--	40	53	5	--	--	1	--
CG-2A	95	5	15	--	10	--	--	--	75	--	--	--	--	Tr	--
CG-2,10	90	10	81	15	2	--	--	--	Tr	--	--	--	2	Tr	--
CG-2,12	90	10	3	--	Tr	--	Tr	--	1	70	10	2	3	1	--
SW-7	80	20	Tr	--	Tr	--	--	--	70	30	Tr	--	--	Tr	--
SW-1,11	95	5	5	--	Tr	--	--	Tr	1	55	30	5	3?	1	--

Tr = Trace

TABLE 5. SUMMARY OF RC CONGLOMERATE COMPOSITION AND STRUCTURE

sample	percent pebble	percent sand	sorting	bimodal	imbrication	bed shape	cement	structural disruption	clast supported	Folk Classification
CG-1,11	15	85	poor	no	yes	tabular	calcareous	low	yes	pebbly and granular poorly sorted medium sandstone: micrite- and sparite-cemented chert-arenite.
CG-2A1	25	30	poor	yes	yes	tabular	siliceous	low	no	muddy pebble and granule conglomerate: siliceous immature chert-arenite.
CG-2A2	60	40	poor	yes	?	tabular	calcareous	moderate	yes	coarse sandy pebble conglomerate: calcitic submature chert-bearing calclithite.
CG-2A3	60	40	poor	no	yes	tabular	calcareous	moderate	yes	coarse sandy pebble congloemrate: calcitic submature chert-bearing calclithite.
SW-7	70	30	poor	yes	no	tabular	calcareous	low	yes	granule and pebble conglomerate: calcitic submature calclithic chert-arenite.
SW-3,2	75	25	poor	yes	no	tabular	calcareous	low	yes	granule and pebble conglomerate calcitic submature calclithic chert-arenite.
SW-3,3	75	25	poor	yes	no	tabular	calcareous	low	yes	granule and pebble conglomerate calcitic submature calclithic chert-arenite.

subrounded. These two clast lithologies generally are subequal in percentage with limestone slightly more abundant (Plate II). Limestone clasts in all cases are the largest in size of the clast population.

Environment of deposition

The conglomerate and sandstone of the Rc unit in the Cerro Gordo area are interpreted as longitudinal bar deposits that formed within a braided stream environment, as defined by Miall (1977, p. 12-14) in accordance with the growth sequence described by Leopold and Wolman (1957). Miall reports that longitudinal bar deposits are characteristically parallel bedded with grain size generally diminishing upward within the bar deposit. Most Rc conglomerate is parallel bedded and probably formed as a gravel sheet over which finer particles carried by a riffle flow were deposited. Rc is not cross bedded, and this characteristic is also indicative of longitudinal bar deposits in which avalanche faces are rare. The pinch and swell geometry of the Rc unit in the Cerro Gordo area may be related to uneven cutting of the stream channels. Alternatively the thickness differences may be related to channel avulsion. During a flood event, debris may have choked the active channel resulting in avulsion and subsequent abandonment of the stream channel. Channel switching and avulsion is abundant in fluvial distributary channels where shorter and steeper routes are produced as the sequence progrades seaward (Turner, 1980, p. 133).

The thick-bedded, matrix-supported conglomerates of the SW-3MS locality are interpreted as debris-flood deposits similar to those described by Miall (1970) for the conglomerate-sandstone facies of the Devonian Peel Sound Formation of Prince of Wales Island. As described by Miall these deposits have characteristics such as poor sorting and lack of a well developed pebble framework or clast orientation, similar to debris flows as described by Blackwelder (1928), Sharp and Nobles (1953), and Blissenbach (1954). Because the mud content is very low, however, the term debris flood is preferred. The overlying parallel-laminated, fine sandstone and mudstone probably were deposited during the waning stages of the flood event which deposited the underlying conglomerate. The matrix-supported conglomerate that commonly caps the Rc sequence in the Cerro Gordo area may also be a debris-flood deposit.

The Rc debris-flood deposits, as described above, are interpreted to have formed at a time when rivers operated at high energy levels. Similar to unit Rc, the conglomerate and sandstone facies of the Peel Sound Formation do not contain epsilon or alpha cross bedding (Allen, 1963, p. 101-104). These sedimentary structures are abundant within the deposits of meandering streams, and their absence indicates low-sinuousity streams. Low-sinuousity streams deposit a cycle of sedimentation during channel filling in a braided-stream environment (Moody-Stuart, 1966; Miall, 1970). This cycle begins during periods of high flow when the low-sinuousity, braided stream complex carries coarse sediments. During these periods the stream complex undergoes it's most dynamic and rapid evolution. Stream channels become clogged and new channels are formed during a flood event through avulsion. As flooding abates, flow competence decreases and the coarse sediments are deposited. Deposition within the low-sinuousity, braided-stream environment takes place by vertical accretion (Leopold and Wolman, 1957; Moody Stuart, 1966). Sandstone with scattered pebbles is deposited above the conglomerate sheet as flow continues to decrease in strength. During low-flow periods bar deposits are formed in major stream channels. Cyclic repetition of conglomerate fining upward to sandstone, and the presence of sandstone lenses interbedded with debris-flood conglomerate, is interpreted by Miall (1970, p. 131) to be evidence of waves of flooding. He interpreted these deposits to be formed on the edge of an alluvial fan, at the distal end of floods that deposited detritus on the fan. The debris-flood and braided-stream deposits of the Rc lithosome are interpreted to have formed in a similar environment in the midfan to fan-base area.

The Rc unit is closely associated with the Rm unit. These units together represent braided-stream and debris-flood deposits in the channelized portions of the midfan which prograded and are superimposed over sheet-flood deposits which formed in the interchannel portions of the distal fan environment. These deposits, together with Ym sabkha deposits, are very similar to the carbonate-sulphate intertidalites of the Windsor Group, Maritime Provinces, Canada, as described by Schenk (1975). He describes an environment in which an alluvial fan was formed adjacent to supratidal and intertidal flats. Intercalation between Ym, Rc, and Rm deposits probably reflects flood events when nonmarine deposits spilled off the fan across the sabkha or subsidence events when the sabkha environment transgressed over the edge of the fan.

Green conglomerate (Gc)

Lithology

The Gc lithosome is most prominent in the Cerro Gordo area. The unit occurs as lenses that become increasingly discontinuous northward. It disappears entirely from the sequence just south of the SW-2MS locality. The maximum observed thickness of Gc is 50 m at CG-1MS.

The Gc unit consistently occupies the same stratigraphic position above the Rc lithosome. Wc (white chert) usually overlies Gc, but locally Rss (red sandstone) overlies the Gc unit (Plate III). The upper and lower contacts of the Gc unit have undergone significant differential slip or are faulted in most places where they are exposed, and they are commonly covered by alluvium. Therefore the stratigraphic nature of the Gc unit contacts is uncertain.

The unit consists of approximately 90% sandstone and 10% sandy conglomerate and conglomerate. Colors range considerably and vary vertically and laterally within the section. Dominant weathered colors are between dusky yellow green (5GY5/2) and grayish green (10GY5/2). Fresh colors are pale green (10G6/2) with mottling of light olive brown (5Y5/6).

In general, conglomerate and sandy conglomerate are predominantly ıatrix supported and have a tabular or broadly lensoidal bed form. ome concentrations of clasts which resemble channel features were ɔserved locally. The conglomerate is poorly sorted and has clasts ıich range from small pebble to large cobble size. Clasts are subunded to well rounded and include volcanic rock, white marble, gray blue-gray limestone, brown fine sandstone, light-gray micritic lime-ne, and some very altered calcite-chlorite rock. Limestone and :anic clasts are the largest of the clasts, but rarely are larger ı 15 cm.

Locally, at the CG-1MS area, the upper portion of the Gc unit is very well bedded and the beds have an average thickness of 10 cm with a range of from 4 to 60 cm. These beds fine upward from a basal, poorly sorted and matrix-supported, sandy, pebble to cobble conglomerate, to dark-green siltstone. Separation planes bounding these fining-upward sequences are sharp, planar, and do not seem erosional. Clasts of the conglomerate have a disorganized appearance and some flat clasts are standing on end relative to the depositional surface.

Samples of Gc studied in the laboratory consist of granular and pebbly coarse sandstone and are calcitic submature calclithite- and chert-bearing volcanic arenites to volcanic-bearing calclithites (Table 6, 7). The identification of the primary nature of the altered calcite-chlorite rocks was difficult. The terrigenous framework of Gc samples is flattened into the plane of cleavage, and individual clasts commonly are indented by adjacent clasts. This structural texture, in combination with alteration, makes individual clasts difficult to recognize. Gc samples from the Cerro Gordo area are particularly deformed. Rare traces of porphyritic texture in the calcite-chlorite clasts were noted in thin section samples from the Cerro Gordo area. Farther north, near SW-3MS the Gc lithosome is not as structurally deformed. A porphyritic texture is clearly recognizable in thin section samples of these rocks (Table 7, sample SW-25A). Because the calcite-chlorite clasts of the Gc rocks in the Swansea area have recognizable volcanic texture, and because larger volcanic clasts have been recognized in the Gc rocks of the Cerro Gordo area, all calcite-chlorite clasts in the latter area are interpreted to be volcanic.

TABLE 6. SUMMARY OF GC CONGLOMERATE COMPOSITION AND STRUCTURE

sample	percent pebble	percent sand	sorting	bimodal	imbrication	bed shape	cement	structural disruption	clast supported	Folk Classification
CG-1,23	25	75	poor	yes	?	?	calcareous	high	no	granular coarse sandstone: calcitic submature calclithic volcanic-arenite.
SW-25A	40	60	poor	yes	?	?	calcareous	high	yes	sandy pebble conglomerate: calcitic submature chert-bearing volcanic-arenite.

TABLE 7. PERCENT COMPOSITION OF GC LITHOSOME

sample	% terrigenous framework	% cement	Framework					Rock Fragments						
			quartz	weathered feldspar	orthoclase	plagioclase	mica	chert	micrite	silty micrite	siltstone	volcanic	opaque	others
CG-1,24	90	10	1	2	--	1	--	Tr	45	--	--	49	1	--
CG-1,27A	50	50	2	40	--	5	Tr	--	50	--	2	Tr	Tr	--
CG-2,48	90	10	--	--	--	59	--	--	--	--	--	40	1	--
SW-25A	95	5	--	--	--	--	--	3	Tr	1	--	96	Tr	--

Environment of deposition

The Gc unit is interpreted as debris-flood deposits formed within channels on the middle to outer portions of an alluvial fan. Gc deposits are similar to debris-flood deposits of Rc in that they are poorly sorted and lack a well developed pebble framework or clast orientation. The fining-upward textures locally observed in the Gc lithosome are interpreted to have formed during the waning stage of flood events similar to the debris-flood described by Miall (1970) and the subaerial flow described by Gloppen and Steel (1981, p. 53, fig. 4). Fining-upward textures such as those observed within the Gc unit also may form from a fluid debris flow (Harms and others, 1975).

Although Gc is similar to Rc debris-flood deposits, there are three basic differences which distinguish these lithosomes from each other: 1) Gc deposits are composed mostly of debris-flood deposits whereas Rc deposits are composed of only a small portion of debris-flood deposits, and are composed mostly of braided-stream deposits; 2) Gc deposits are green, as opposed to the reddish color of Rc, indicating that they were subjected to a reducing environment during and/or shortly after deposition; 3) Gc deposits contain volcanic detritus whereas Rc is composed of only sedimentary detritus.

Volcanic detritus within the Gc unit is the lowest volcanic debris in the stratigraphic section of the Cerro Gordo area. Influx of volcanic debris would have coincided with the first appearance of volcanoes within the region. The appearance of volcanoes might have increased cloud cover and rainfall, thus raising groundwater level and producing the reducing environment which characterized the Gc lithosome.

Olive shale (Osh)

Lithology

The Osh lithosome is 15 m thick and is exposed for approximately 200 m along strike in the area of CG-1MS where it overlies Gc and underlies Wc. The lower and upper contacts of Osh are faulted, hence the stratigraphic nature of the unit contacts is not known. Although this unit composes only a very minor amount of the sequence studied, it is so different from the surrounding lithosomes that it warrants discussion.

The lithosome consists of approximately 85% calcitic silty claystone, 10% fine- to coarse-grained sandstone and siltstone, and 5% pebble conglomerate. Muscovite is present in amounts to 3%. Osh weathers pale olive (10YG5/2) and is pale green (5G7/2) on fresh surface.

The Osh unit is less resistant than adjacent units, and an erosional trough follows much of its exposure. The Cerro Gordo road cut follows a portion of this trough, and spill fill from road excavation covers a portion of the unit (Plate I). The greatest percentage of the sandstone beds are scattered through the lower portion of the unit and ccur as tabular-shaped beds 0.5 to 8 cm thick. Sandstone beds range rom poorly sorted to moderately sorted and are interbedded with fine andy siltstone and silty claystone. Siltstone beds range from poorly rted to moderately sorted and are interbedded with fine sandy siltone and silty claystone. Siltstone beds have an average thickness of proximately 5 cm. Siltstone also occurs in the claystone as laminae m 0.5 to 7 mm thick. Claystone occurs in beds to 0.5 m thick, but to cleavage disruption internal stratification of these beds can- be determined in outcrop.

Coarse sandy granule and pebble conglomerate occurs as tabular-shaped beds to 15 cm thick in the middle portion of the Osh lithosome. These conglomerate beds contain predominantly rounded clasts, are clast supported, and consist of calcitic submature calclithite.

Environment of deposition

Osh deposits may have formed in a playa environment, but the only criterion used for this interpretation is the fine grain size, which Blissenbach (1954, p. 188) cites as a criterion for easy recognition of playa deposits within coarser alluvial fan deposits. It seems however, that the placement of the adjacent Gc lithosome within the middle fan environment indicates a slope too steep for a playa environment. These fine-grained deposits might also be overbank deposits formed in the interdistributary areas of the alluvial fan, but as discussed in the Rss unit section, the interdistributary areas associated with Gc channels contained red, rather than green deposits. Conversely, the Osh lithosome may have formed within a main channel as a channel-plug deposit. This hypothesis seems likely because Osh deposits overlie the Gc lithosome, which is interpreted to have formed within a channel. Conglomerate beds within the predominantly fine-grained deposits represent minor stream flow within the channel. The greenish color of the Osh deposits indicates a reducing environment, which would be found in the plugged channel more likely than in the overbank areas.

White chert (Wc)

Lithology

This unit is present at both the Swansea and Cerro Gordo areas and occupies several stratigraphic positions within the nonmarine rocks

(Plate II). The unit is broadly lensoidal and seems to interfinger with adjacent lithosomes. Unit contacts commonly are covered or faulted, but where exposed are sharp and planar. The lithosome, where measured, varies in thickness from 15 to 56 m. The Wc unit weathers mottled yellowish gray (5Y7/2) and is white (N9) and medium light gray (N6) on fresh surfaces.

The Wc lithofacies is very altered and is both very calcareous and siliceous. The matrix of the rock consists of a siliceous mineral with the texture of chert, but with an elongation of grains parallel to cleavage. This siliceous material composes as much as 94% of the framework of Wc samples (Table 8). The matrix shows mass extinction and first order gray birefringence.

The unit contains up to 5% granules, pebbles, and cobbles of blue-gray limestone. In thin section, poorly sorted sand grains and granules are matrix supported, and together with a trace of silt, compose as much as 20% of Wc samples. Some euhedral grains resemble feldspar phenocrysts in shape, but they are now composed of calcite. Calcite composes about 11 to 55% of the Wc samples as cement, vug fillings, nd as phenocryst(?) replacement.

Pebble and cobble concentrations which resemble channel fill tructures were observed locally, but these concentrations are rare, d the unit is characteristically structureless. At rare localities the Swansea area the deposits at the lateral margins of the Wc units interbedded with adjacent Rss (red sandstone) strata. At these alities Wc occurs as tabular beds of sandy pebble conglomerate and dstone with an average thickness of 6 cm.

TABLE 8. PERCENT COMPOSITION OF WC LITHOSOME

sample	% terrigenous framework	% cement	Framework: quartz	weathered feldspar *	orthoclase	microcline	plagioclase	chert	mica	Rock Fragments: chert	micrite	silty micrite	siltstone	volcanic	opaque
CG-1,37	95	5	Tr	--	--	Tr	--	94	--	4	--	2	--	--	--
CG-2,44	95	5	3	6	--	Tr	--	89	--	--	--	2	--	--	--
SW-5A	95	5	--	50	--	Tr	--	--	--	--	--	50	--	--	--
SW-36	95	5	Tr	10	--	Tr	--	70	--	10	10	--	--	--	Tr

* Possible phenocrysts now replaced by calcite
Tr = Trace

Environment of deposition

The environment of deposition of these rocks is not clear, mostly due to the fact that the primary lithology cannot be determined. The possible phenocrysts and the highly siliceous composition suggest that this unit may be a very altered tuff. The release of silica and the deposition of hydrated silica during weathering and diagenesis of tuffaceous rocks may result in conversion of tuff into a dense flinty rock which resembles chert (Pettijohn, 1975, p. 308). If these rocks were derived from a tuffaceous or ignimbritic parent material, then reworking is implies by the presence of limestone clasts, the rare channel features, and the bedded nature of the unit. Vessel and Davies (1981), who describe ignimbrite flows on proximal fans in an active fore-arc basin, indicate that these flows extend down the fan as lobe-shaped bodies sometimes localized in a channel. The deposits are then reworked on the fan surface. One difference between the reworked ignimbrite deposits described by Vessel and Davies and the possibly analo-ous Wc deposits is the lack of volcanic clasts in the Wc deposits.

An alternative interpretation for these deposits is that they present calcrete deposits. Several lines of evidence suggest that arid climate characterized the area during the time of deposition of se deposits (see Provenance). When insufficient water is present to iltrate through soil, calcium carbonate may accumulate. If the axis deposition shifts on an alluvial fan long enough, a series of soil iles will result, each profile representing a time interval of no sition (Bull, 1972, p. 65). The presence of abundant calclithic logies and an arid climate are conditions favorable for calcrete its to form. Both of these conditions probably were present at the time of deposition of Wc.

An exposure of Wc unit north of the SW-2MS locality, however, rests with apparent conformity atop volcanic flow rock. Calcrete would be expected to form on the calclithic portions of the alluvial slope and not on volcanic flow rock which would act as a moisture barrier. Furthermore, a calcrete formed on volcanic rock would have included grains of the volcanics. Also, no evidence of unaltered nodules or ghosts of nodules was observed, which requires 100% alteration to chert if they were calcrete deposits. Finally, phenocrysts would not have been preserved within a calcrete soil. These considerations suggest that interpretation of these deposits as reworked tuffs or ignimbrites rather than calcrete deposits is more tenable.

Red sandstone (Rss)

Lithology

The Rss unit consists predominantly of fine sandstone and is present only south of SW-2MS (Plate III). The unit is 22 m thick in the Cerro Gordo area, 175 m at the SW-3EMS locality, and interfingers with Rgss just north of SW-6EMS. The Rss unit occurs at several stratigraphic positions relative to other volcanic clast-bearing lithosomes, but it always occurs stratigraphically above units Rc and Rm (Plate III). In the Cerro Gordo area the Rss unit also usually occurs above the Wc unit. In the Swansea Wash area, however, Rss interfingers with Wc, and locally overlies Vcg just south of the Rss northern limit of exposure.

The Rss lithosome consists of fine sandstone and mudstone (90%), granule and pebble conglomerate (7%), and less abundant pebble and cobble conglomerate (3%). The sandstone is predominantly very fine grained and parallel laminated, and contains low-angle (less than 10^0) cross bedding. The cross beds have a high variability in orientation. Sandstone beds range in thickness from 1 to 6 cm and average 2 cm. An average sandstone is calcitic, well sorted, silty, and consists of immature hematite- and chert-bearing quartz arenite (Table 9). Sandstone weathers grayish red (5R4/2) and is pale red (5R6/2) on fresh surfaces.

Granular coarse sandstone and pebble conglomerate occur as tabular-shaped beds with an average thickness of 5 cm which are interbedded with fine sandstone. Tabular pebble and cobble conglomerate is usually matrix supported and weathers grayish red (5R4/2). A typical conglomerate consists of calcitic and hematitic submature volcanite-bearing calclithic chert-arenite (Table 9). Pebble conglomerate also occurs as lenses to 1.5 m thick, which generally are clast supported.

Volcanic flow breccia or a thin sill with a flow breccia appearance occurs within the lower portion of the Rss unit in SW-3MS (Plate II). Only two of these breccia beds were observed, and both were approximately 1.5 m thick.

Environment of deposition

The Rss deposits are interpreted as waterlaid deposits of small, braided channels in the interdistributary portions of an alluvial fan. Bull (1972) reports that sheets of sand, silt, and gravel deposited by a network of small, braided channels are common in alluvial fan deposits. Sheetlike deposits reported by Bull are similar to the Rss unit which consists of as much as 90% parallel-laminated fine sandstone. Deposition within these small channels may also have been on low lon-

TABLE 9. PERCENT COMPOSITION OF RSS AND VCG LITHOSOMES

unit	sample	% terrigenous framework	% cement	Framework: quartz	weathered feldspar	orthoclase	plagioclase	mica	Rock Fragments: chert	micrite	silty micrite	siltstone	volcanic	opaque	others
RSS	CG-1,38	60	40	Tr	--	--	--	--	100	--	--	--	--	Tr	--
	CG-2,53	90	10	Tr	5	--	--	--	38	27	--	--	25	5	--
VCG	SW-22	95	5	19	10	--	Tr	--	Tr	15	18	--	37	1	--

Tr = Trace

gitudinal bars. These longitudinal bars would be much smaller than those described for the Rc distributary channel deposits, and generally of finer grain size. The low-angle cross beds observed within the Rss unit may have formed on the lee side of such low longitudinal bars, possibly during falling water levels. Bluck (1974) reports that cross stratification of high variability can originate as flow competency drops and flow separates around the bar and existing accretion topography, with the result that cross stratification will show dispersion. Very fine-grained deposits within this unit may have formed on such bars during waning stage flow or as overbank deposits.

Rss deposits occur adjacent to the Gc and Vcg channel deposits and are interpreted to have formed in the midfan to fan-base interdistributary areas between these large channel deposits.

Volcanic-clast conglomerate (Vcg)

Lithology

The Vcg unit is broadly lens shaped, being approximately 50 m thick at SW-6EMS and thinning to the north and south of that locality. The lower contact of the unit is an unconformity. The unit overlies, from north to south, Rgss, Bls, Hm, Rss, and Wc, and is conformably overlain everywhere by Rss.

The Vcg unit consists of approximately 40% conglomerate and sandy conglomerate and 60% fine to coarse sandstone. Overall the unit is coarsest at the base and generally fines upward to the overlying Rss unit.

The lower portion (10 m) of the Vcg lithosome consists of very poorly sorted calcitic chert-bearing volcanic arenite boulder conglomerate and much less abundant sandstone which weathers overall to grayish red (5R4/2) (Plate II). The conglomerate is structureless and clast supported. Clasts are moderately rounded to rounded, and larger clasts, volcanic in composition, are up to 120 cm across.

At the SW-6EMS locality the basal boulder conglomerate is overlain by a 40-m-thick sequence of sandstone and pebble conglomerate which weathers light brownish gray (5Y6/1). Fining-upward beds of sandy pebble conglomerate to fine to coarse sandstone up to 60 cm thick are present within this sequence. Fining-upward beds average 15 cm thick and commonly contain imbrication structures of flat-shaped clasts. This imbrication indicates a very consistent northeast direction of current flow with an average of N60^{o}E (Fig. 4). An average sandy pebble conglomerate is calcitic and consists of submature siltstone-bearing volcanic-arenite (Table 9).

Environment of deposition

The basal boulder conglomerate of the Vcg unit is interpreted to be a flood deposit formed within a somewhat confined channel, similar to those described by Vessel and Davies (1981, p. 42) which occur in the midfan and fan-base areas of alluvial fans prograding from an active volcanic region. They report that during flood events very poorly sorted boulder conglomerate is deposited within confined stream channels. These streams can overflow their banks and strew boulders and cobbles over the floodplain or interdistributary deposits in an analogous manner.

Vessel and Davies further report that low-stage flow occurs within umerous, unstable, wide, shallow, braid channels in the midfan to fan-

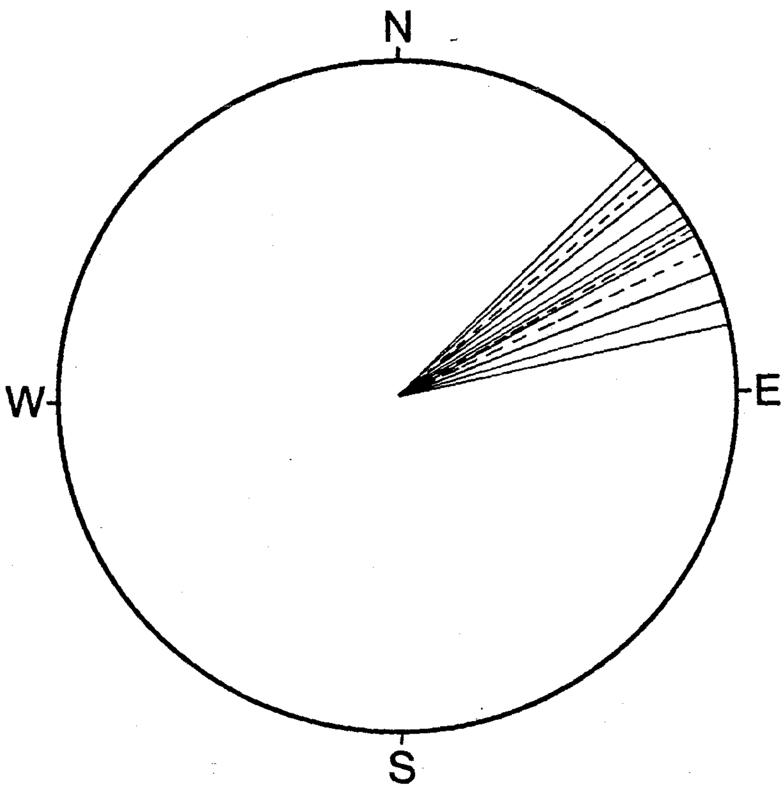


Figure 4. Distribution of current vectors showing inferred downcurrent flow directions measured from Vcg imbrication structures. A total of 18 data points is shown, dashed lines indicate more than one pebble with that imbrication orientation. Vectors are corrected for regional folding that assumes a fold axis of 30°, N30°W (G. C. Dunne, pers. comm.).

base areas. The fining-upward beds within the Vcg unit, which overlie the basal conglomerate, are interpreted to be such low-stage braided-channel deposits. The fining-upward textures may have formed by vertical accretion on bars or in low channels during waning-stage flow.

Red and gray sandstone (Rgss)

Lithology

The Rgss unit generally consists of fine sandstone and pebble conglomerate and is exposed from an area near SW-6EMS northward to Union Wash (Plates I, II, III). Overall the unit is 4 to 65 m thick, being thinnest in the northern Union Wash area, and thickest in the southern Swansea Wash area. Rgss is intruded and removed by granitic rocks of middle to late Mesozoic age north of SW-1MS and south of UW-16EMS (Plates I, II). The unit is covered by alluvium at its northern limit (Plate II) and interfingers with Wc and Rss, and is in erosional contact with Vcg deposits at its southern limit, near SW-6EMS (Plate III).

The Rgss unit overlies Bls in the southern exposures with seemingly planar contact. This observation is inferred by the continuity of thickness of the underlying Bls unit. However the exact point of contact is commonly covered. In the Union Wash area, where exposure of the contact is good, beds of the Hm unit are progressively truncated below the Rgss unit. An unconformity is recognizable at the most southerly Union Wash section, UW-16EMS, but apparently occurs within a section of interbedded marine and nonmarine strata (Rgss and Hm). Supratidal sabkha deposits (Ym), which represent a transitional environment between marine and nonmarine strata, are not present below the Rgss unit and may have been stripped away.

The Rgss unit consists of approximately 75% sandstone and 25% sandy conglomerate. It commonly weathers grayish red (5R4/2) and is pale red (5R6/2) on fresh surface. Conglomerate beds within Rgss contain mostly limestone clasts, and this consitituent lends a gray color to outcrops.

A typical sandstone is calcitic and submature and consists of chert-bearing sublitharentite to subarkose (Table 10). A sample from the Union Wash area (UW-5, Table 10) consists of chert-bearing calclithite. Sandstone commonly contains up to 30% micrite cement (SW-2,9, Table 10), and more rarely up to 55% micrite cement which orthochemically supports the grains (SW-1,14, Table 10). Hematite and limonite also occur as cement in abundances up to 10%.

Sandstone of the Rgss unit commonly is parallel laminated, the lamination formed by variation of hematite abundance and grain-size change. Laminations vary in thickness from 0.25 mm to 1.0 cm and at SW-2MS dip in various directions within isolated outcrops not too severely disrupted by cleavage. The variation of lamination dip direction might indicate folding, which is known to mildly affect this portion of the section, or it might be cross bedding. At the SW-1MS locality faint traces of bifurcating laminations which consist of concentrations of hematite are rarely present.

Sandstone in the upper portion of the unit at the SW-2MS locality contains isolated outsized clasts up to 20 cm in longest dimension. These clasts include limestone, small rounded quartzite, and angular calcareous fine sandstone lithologies.

Conglomerate of the Rgss unit generally weathers to a grayish color. The average conglomerate is a calcitic submature calclithic sandy

TABLE 10. PERCENT COMPOSITION OF RGSS LITHOSOME

sample	% terrigenous framework	% cement	Framework					Rock Fragments						
			quartz	weathered feldspar	orthoclase	plagioclase	mica	chert *	micrite	silty micrite	siltstone	volcanic	opaque	others
SW-2,9	70	30	75	--	10	--	Tr	5	--	--	--	--	10	--
SW-1,14	45	55	90	5	Tr	--	--	5	--	--	--	--	--	--
UW-3,16	60	40	Tr	--	--	--	--	5	90	5	--	--	--	Tr
UW-5	90	10	Tr	--	--	--	Tr	40	60	Tr	--	--	Tr	Tr
UW-1	92	8	1	--	Tr	--	--	40	30	28	--	--	1	Tr
UW-4,10	85	15	--	--	--	--	--	72	--	Tr	--	28?	--	Tr

* Includes silty and sandy chert
Tr = Trace

pebble conglomerate. Chert-arenite is a common conglomerate lithology of the Rgss unit in the Union Wash area (Table 11). Overall, limestone clasts are the most abundant clast type in Rgss conglomerates with chert the next most abundant (Plate II). Volcanic clasts and more rarely quartzite clasts occur in less abundance. Clast size varies greatly throughout the unit, the largest being boulder size (83 cm) noted in the SW-1MS locality, and the smallest ranging down to small pebble size.

Conglomerate is usually clast supported and commonly occurs as lens-shaped units interbedded with sandstone. Sandstone-conglomerate bed contacts are sharp and usually planar and consist of abrupt changes in clast size without a coincident separation plane. Sandy conglomerate beds are generally about 3 m thick in the southern portion of the Swansea area, where the beds are more resistant and protrude from talus covered slopes. At SW-1MS conglomerate beds occur at the base of the Rgss unit, and the beds decrease in thickness upward from 4 m to 1 m. Clast size at this locality also decreases upward from boulder size to small pebble sizes. The conglomerate generally is poorly sorted and tabular bedded at SW-1MS with some beds amalgamated and others separated by thin pebbly sandstone beds that have an average thickness of 0.3 m. The upper portion of Rgss at this locality is mostly sandstone (Plate I). Thin matrix-supported to clast-supported pebble beds that are generally tabular in shape and rarely bifurcate are present in this sandy portion.

Exposures of gray Rgss conglomerate just north of the intrusive rocks have characteristics similar to conglomerate of the Rgss unit to the south, in the Swansea area. This conglomerate, as at localities

TABLE 11. SUMMARY OF RGSS CONGLOMERATE COMPOSITION AND STRUCTURE

sample	percent pebble	percent sand	sorting	bimodal	imbrication	bed shape	cement	structural disruption	clast supported	Folk Classification
UW-3,16	40	60	poor	no	no	?	calcareous	moderate	yes	coarse sandy granule conglomerate: calcitic submature calclithic chert-arenite
UW-1	70	30	poor	yes	?	?	calcareous	moderate	yes	sandy pebble conglomerate: calcitic submature calclithic chert-arenite
UW-4,10	80	20	moderate	no	no	?	calcareous	low	yes	coarse sandy granule and pebble conglomerate: siliceous submature volcanite(?)-bearing chert-arenite

between SW-2MS and SW-1MS, lies directly on marine strata. Very disrupted pebble and granule conglomerate which, except for very rare parallel bedding and channel structures, has no preserved sedimentary structures overlies this gray conglomerate. Northward of UW-16EMS the gray conglomerate pinches out and the granule conglomerate with almost no preserved sedimentary structures unconformably overlies the marine strata (Hm) (Plate I).

Environment of deposition

The Rgss unit is interpreted to be an assemblage of alluvial fan deposits. Individual units of this assemblage, such as channel deposits and interdistributary deposits are not as thick and well exposed as those of alluvial fan deposits to the south, such as Rc and Rss. Because of this, detailed lithosome subdivision was not possible and the Rgss alluvial fan assemblage was mapped as one unit. Composition of the Rgss deposits is different than that of fan deposits to the south, and this difference is a key factor in the delineation of this second alluvial fan assemblage. Rgss deposits contain volcanic debris (Tables 10, 11) and thus formed after volcanic eruption. However, Rgss deposits contain considerably less volcanic debris than post-eruption lithosomes of the southern alluvial fan and more calcareous and chert debris.

Rgss conglomerate of the Swansea area is generally clast supported and sandy, occurs as lenses within a predominantly sandstone section, and is interpreted to be stream channel and bar deposits. These conglomerates exhibit parallel bedding and intercalations of sandstone similar to the braided stream deposits described by Bull (1972). Horizontal bedding within these deposits indicates that these conglomerates may have originated as longitudinal bars similar to the bar deposits described by Miall (1977, p. 14). These deposits are interpreted to have formed within small, braided channels in the interdistributary portions of the alluvial fan, similar to the environment described for the Rss lithosome.

Conglomerate and sandstone at the SW-1MS locality are significantly different from conglomerate beds elsewhere within the unit. The conglomerate at this locality is thick bedded and matrix to clast supported, with some conglomerate beds amalgamated. The base is erosional, and the conglomerate contains boulder-size clasts. This thick sequence of conglomerate and sandstone is interpreted to represent a large bedload distributary channel deposit formed on the midfan to fan-base area, similar to the Vcg channel deposit. Miall (1970) describes similar poorly sorted, structureless conglomerate beds and has interpreted them to represent debris-flood deposits formed by waves of flooding. The sandy sequence which overlies the basal boulder conglomerate at SW-1MS, as with the Vcg unit, is interpreted to have formed during low-stage flow. As described by Vessel and Davies (1981), low-stage flow channel deposits form within the general confines of the larger channel incised during the flood event.

Parallel-laminated sandstone composes the predominant portion of the Rgss unit in the Swansea area. Sandstone which encloses the conglomerate beds at the SW-2MS locality is interpreted as sheetflood deposits formed in the interdistributary areas of the fan, similar to those described by Bull (1972). Outsized clasts present within the sandstone at this locality may have formed when a distributary channel overflowed its banks and strewed boulders and cobbles over the interdistributary floodplain area in a fashion similar to that described by Vessel and Davies (1981). Parallel-laminated sandstone which caps the SW-1MS sequence may also be in part sheetflood deposits formed by overbanking onto the interdistributary areas of the fan, at a time when the SW-1MS channel described above was abandoned.

Granule and pebble conglomerates at the UW-3MS and UW-4MS areas have erosional lower contacts, and, except for occasional channel-fill structures and very rare parallel bedding, no sedimentary structures are preserved. It seems that Union Wash Rgss conglomerates were probably deposited by small streams onto a quiet-water, shallow marine environment.

Volcanic rocks

Volcanic rocks that cap the sequence commonly are difficult to distinguish from the reddish sedimentary rocks of the clastic sequence, particularly those of Rss. This difficulty in large part is due to the presence of pervasive cleavage, which disrupts the rocks and their textures.

Volcanic rocks were recognized in thin section as being composed of subhedral feldspar laths set in an aphanitic or siliceous and calcitic altered matrix. Plagioclase occurs as subhedral laths 0.1 mm to 0.8 mm across. Laths in one sample were observed to have a bimodal size distribution. Most feldspars are thoroughly altered to sericite(?) and replaced by calcite. The feldspars are rarely concentrically zoned and sometimes albite twinning is preserved. Where possible the An content of these twinned crystals was measured optically using the method of Kerr (1959) and found to range from An29 to An46, values typical of volcanic rocks of intermediate composition, such as rhyodacite, latite, and andesite. Traces of possible pyroxene crystals were observed, but in all cases they are too altered and replaced for clear identification.

The groundmass is altered to chert and calcite and in many cases traces of limonite and hematite are revealed in reflected light. Elongated vugs filled with calcite and chert observed in one sample may be flattened vesicles.

A conspicuous, reddish-weathering andesite with abundant large phenocrysts of feldspar occurs prominently in the area of SW-6EMS. This flow has been termed informally the "popcorn andesite" by Ward Smith (pers. comm., 1979). A similar flow crops out across Cerro Gordo Road to the south. Although bedded sandstone was observed locally within the "popcorn andesite", indicating the presence of more than one flow or sill, the "popcorn" is a very distinctive unit and may serve as a continuous datum for future stratigraphic studies.

Tuff and tuffaceous rocks were looked for but not found unless represented by the Wc unit. Tuffaceous sediments are reported to be an important component of the clastics described by Vessel and Davies (1981), and it seems they should be present in the clastics of the Inyo Mountains transitional sequence. Tuffaceous sediments may be present in the Inyo Mountains, but are so thoroughly altered and calcified that they cannot now be recognized.

Chemical analyses of four samples from the volcanic rock sequence indicate an alkalic composition (Abbott, 1972). These volcanic rocks are similar in composition to broadly coeval alkalic plutons in the

Inyo and White Mountains and may be genetically related to them (Dunne and others, 1978).

PROVENANCE

Pebble composition data (Plate II) were collected from the coarser clastic strata throughout the study area. Sedimentary rock types, abundant as clasts within the entire clastic sequence, include calcite marble, limestone, calcareous sandstone, chert, quartzite, and siliceous mudstone(?), with calcite marble being the most abundant type. Volcanic clasts are present in Gc, Rss, Vcg, and Rgss, but the disruption of textures and the alternation and replacement of mineral grains make identification difficult. Volcanic detritus may be present in the Rc unit, but, if so, is comminuted and calcitized, and therefore not recognizable. Clasts of intrusive rock were looked for, but not observed.

Silicification and calcitization are processes that were closely linked during the diagenetic and metamorphic history of these rocks. It is difficult to determine petrographically which of these processes occurred first. Because of these complications in determining primary clast composition, a much generalized grouping was used for clast counts. Clasts within the clastic rocks of the Triassic sequence have been grouped into three categories: calcareous, siliceous, and volcanic (Plate II). A total of 1,900 clasts was counted from slab samples of conglomerate, in accordance with the procedures outlined in the introduction to the stratigraphy section. The results of this analysis are illustrated on Plate II and are summarized in Table 12. In most cases calcareous rock fragments are the most abundant type with siliceous clasts subordinate.

The calcareous rock fragments are generally subround and are the softest of the clast population. These calcareous fragments are rela-

TABLE 12. PERCENT COMPOSITION CONGLOMERATE SLAB SAMPLES

Sample	Percent	Composition	Group
CG-1,11	94%	siliceous	RC
	6%	calcareous	RC
CG-2A1	100%	siliceous	RC
CG-2A2	50%	siliceous	RC
	50%	calcareous	RC
CG-2A3	46%	siliceous	RC
	54%	calcareous	RC
SW-7	71%	siliceous	RC
	29%	calcareous	RC
SW-3,2	53%	siliceous	RC
	47%	calcareous	RC
SW-3,3	57%	siliceous	RC
	43%	calcareous	RC
SW-22A	36%	siliceous	VCG
	64%	volcanic	VCG
SW-22B	39%	siliceous	VCG
	2%	calcareous	VCG
	59%	volcanic	VCG
SW-6B	32%	siliceous	VCG
	9%	calcareous	VCG
	59%	volcanic	VCG
SW-2,11	100%	calcareous	RGSS
SW-1,11	9%	siliceous	RGSS
	78%	calcareous	RGSS
	13%	volcanic	RGSS
SW-1,13	4%	siliceous	RGSS
	92%	calcareous	RGSS
	4%	volcanic	RGSS
SW-4	11%	siliceous	RGSS
	86%	calcareous	RGSS
	3%	volcanic	RGSS
UW-3,16	56%	siliceous	RGSS
	44%	calcareous	RGSS
UW-1	63%	siliceous	RGSS
	37%	calcareous	RGSS
UW-4,10	58%	siliceous	RGSS
	42%	volcanic(?)	RGSS
CG-23	24%	siliceous	CG
	53%	calcareous	CG
	23%	volcanic	CG
SW-25A	12%	siliceous	CG
	1%	calcareous	CG
	87%	volcanic	CG

tively immature, and together with the easily erodible volcanic clasts, some of which are very large in the Vcg unit, indicate a nearby rugged source area, and/or an arid to semi-arid climate. Siliceous clasts of chert and quartzite are also commonly subrounded to rounded. Because these clasts are more durable than the calcareous rock fragments, a textural inversion is present. This suggests that the siliceous clasts are in large part second generation and that they may have been derived from the same source that provided the calcareous rock fragments. Conversely, they may represent a more distal extrabasinal source.

Volcanic clasts were not observed within the Rc unit. The Gc unit which overlies these deposits, however, is rich in volcanic detritus. Unless there is a significant percentage of volcanic debris that is not recognizable within the Rc unit, a change in provenance is represented by these two different clast populations. As shown by the line of correlation of Plate II of the first appearance of volcanic clasts within the sequence, the Rc and Rm units are devoid of volcanic debris. This leads to the interpretation that these deposits preceeded the eruption of volcanoes in the area.

Dolomite clasts were not recognized within the clastic rocks, and they are either not present or have been calcitized. Because dolomite is a very characteristic lithofacies of the lower Paleozoic rocks of this area, their absence suggests upper Paleozoic source rocks for transitional sequence conglomerates. This indicates that the erosion represented by the clastic rocks in the study area was restricted, and did not reach deep stratigraphic levels. The Owens Valley and Keeler Canyon Formations of late Paleozoic age are known to have undergone erosion during Permian time as documented by unconformities at the base of the Triassic section and within the Permian section in the Inyo Mountains (Stone and Stevens, 1980). These formations, as described by Merriam (1963, p. 27), are composed of lithofacies similar to the clast lithologies observed within the clastic sequence. The Owens Valley Formation also contains conglomerate, some of which Merriam reports to be very siliceous, which could have been the source of the second generation siliceous clasts. The close proximity, known erosion, and correct lithofacies of these Pennsylvanian, Permian and Early Triassic formations suggest that they may have comprised much if not all of the sedimentary provenance.

Quartz grains are of great variety and of varying degrees of alteration and replacement. Mobilization of quartz is evident by numerous chalcedony- and megaquartz-filled fractures, vugs, and intergranular spaces. Within some samples of the clastic section, such as CG-1, 10A (Table 5), all types of quartz as defined by Folk's empirical classification system (1974) can be found except high grade metamorphic types. However, it is not possible in many cases to differentiate between quartz types that are primary and reflect source geology, and quartz types that are a product of recrystallization, replacement, and structural strain (producing secondary undulose extinction patterns).

ENVIRONMENTAL SUMMARY AND PALEOGEOGRAPHY

Stratigraphic study indicates that a shallow marine sea, represented by Bls and Hm deposits, as well as underlying Early Triassic strata, existed in the area of the southern Inyo Mountains during the Early Triassic. The exact nature of the marine environment represented by Bls and Hm is not clear. However, sedimentary structures and textures indicate that the environment was subject to tidal and wave influence. A supratidal sabkha environment existed landward of this shallow marine sea and is preserved in the Cerro Gordo area as the Ym lithosome.

Shallow marine environments in the Cerro Gordo area existed adjacent to a northeasterly prograding alluvial fan complex (Rc, Rm). This fan, here named the Cerro Gordo fan, and the adjacent marine environment are illustrated in Figure 5A. The highland source for the alluvial deposits was rugged, nearby, and composed of upper Paleozoic and/or Early Triassic sedimentary rocks. Uplift of this highland is interpreted to represent an early phase of the initiation of a volcanic arc and associated deformation in the region. Volcanoes may have been present in the region at this time, but detritus from them did not reach the drainage system of this fan. Uplift may have occurred by arching or faulting, as is depicted in Figure 5A. North of the Cerro Gordo fan, in the northerly Swansea and Union Wash areas, uplift produced erosion which removed the sabkha deposits and a portion of the marine rocks and formed an unconformity.

Volcanic detritus present above the Rm and Rc lithosomes in the Cerro Gordo fan, and above the unconformity to the north indicates either the first appearance of volcanoes in the region or the first

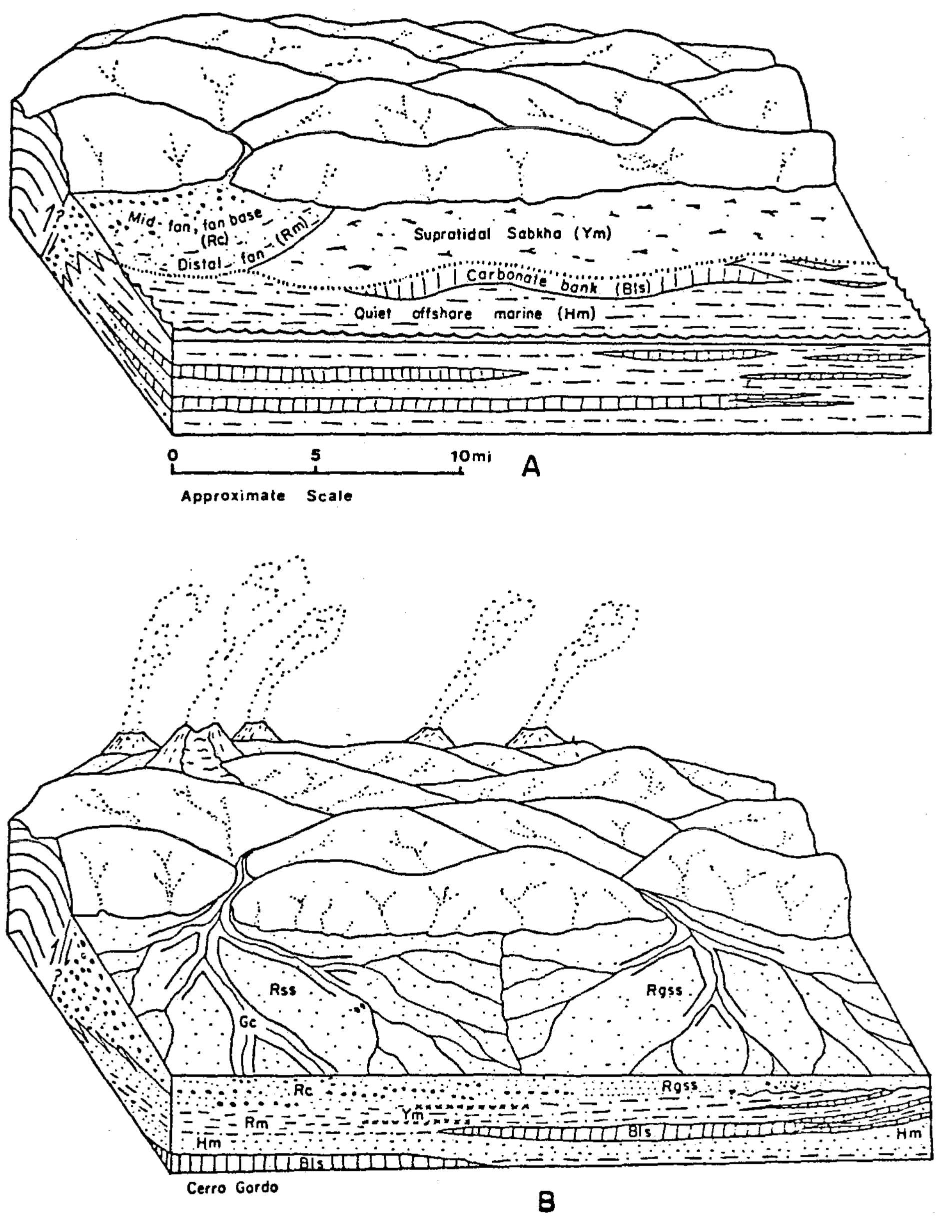


Figure 5. Paleogeographic reconstructions of the late Early Triassic marine to terrestrial environments, southern Inyo Mountains, California. Figure 5A shows a view southwestward showing the incipient volcanic arc prior to volcanic eruption. Figure 5B shows a view southwestward after volcanic eruption.

arrival of detritus from existing volcanoes (Figure 5B). The influx of volcanic debris onto the Cerro Gordo fan was accompanied by a change in lithosome color, from oxidized red (Rc, Rm) to reduced green (Gc). This change indicates a higher groundwater table, perhaps a result of increased rainfall possibly induced by volcanism. The Cerro Gordo fan continued to develop following the appearance of volcanic debris. Several channels of the fan may have been active at the same time. Those that became inactive were either silted up, as with the Gc channel overlain by Osh deposits, or were buried under Rss interdistributary deposits. Ignimbrite or tuff deposits settled across the fan and were subsequently reworked by streams. Flood events resulted in incision of new channels, such as the Vcg channel, and major deposition on the fan.

Rgss deposits comprise a different alluvial fan assemblage north of the Cerro Gordo fan. This fan, here named the Swansea fan, was formed contemporaneously with the post-eruption lithosomes of the Cerro Gordo fan. The Swansea fan deposits generally contain less volcanic debris than the post-eruption Cerro Gordo fan deposits. The Swansea fan was traversed by large distributary deposits such as that preserved at SW-1MS. Additional channel deposits may have been present in the area now occupied by granitic rocks.

In general, the nonmarine rocks are conformable above the marine rocks in the southern portion of the study area, and are unconformable in the northern portion. The erosional unconformity, most pronounced in the Union Wash area, below the Rgss unit, records a period of emergence. This period of uplift may have been associated with swelling prior to volcanic eruption. Intercalation between marine and nonmarine strata in the Union Wash area indicates that this northern area was subject to tectonic activity producing periodic marine incursions. The Cerro Gordo fan, however may not have been subject to as much tectonic unrest as the area of the Swansea fan. In the Cerro Gordo area subsidence of the basin and uplift of the highland were balanced such that the marine and nonmarine environments existed side-by-side. Deposition of the Swansea and Cerro Gordo fans culminated when volcanic flow rocks covered the area as the volcanic arc continued to develop.

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