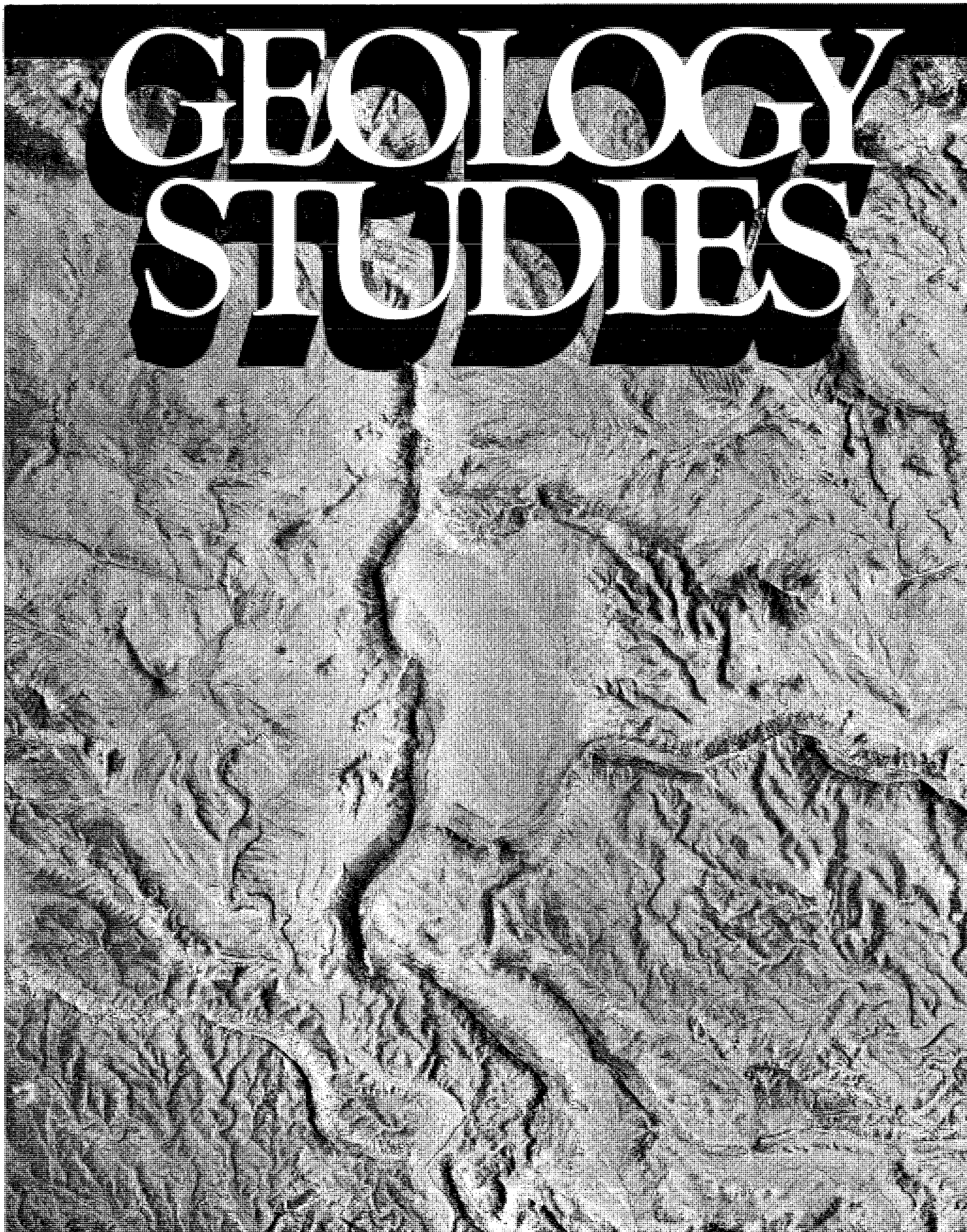
BRIGHAM YOUNG UNIVERSITY

GEOLOGY STUDIES



VOLUME 27, PART 1

AUGUST 1980

BRIGHAM YOUNG UNIVERSITY GEOLOGY STUDIES

Volume 27, Part 1

THE GLORY OF GOD IS INTELLIGENCE

Cover: Aerial photograph showing exhumed stream paleochannels in the Cedar Mountain Formation near Green River, Utah. Courtesy Daniel R. Harris.

A publication of the

Department of Geology

Brigham Young University

Provo, Utah 84602

Brigham Young University Geology Studies is published by the department. *Geology Studies* consists of graduate-student and staff research in the department and occasional papers from other contributors. *Studies for Students* supplements the regular issues and is intended as a series of short papers of general interest which may serve as guides to the geology of Utah for beginning students and laymen.

ISSN 0068-1016

Distributed August 1980

8-80 600 43937

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Preble Formation, a Cambrian Outer Continental Shelf Deposit in Nevada

M. N. REES[1] AND A. J. ROWELL[2]
[1]Indian Valley Colleges, Novata, California 94947
[2]University of Kansas, Lawrence, Kansas 66045

ABSTRACT.—The Preble Formation of north central Nevada is of Early to Late Cambrian age; its youngest beds may be Ordovician. The lower part of the formation consists predominantly of phyllitic shale with some sandstone and rare limestone beds that were deposited subtidally on the outer part of the continental shelf. By early Middle Cambrian time, differential subsidence had led to the development of a marginal-shelf basin in which a diversity of rock types accumulated. Shale remained an important constituent, but, although some sandstone and limestone were laid down by traction currents, others were deposited by gravity-flow mechanisms that produced a variety of deposits from turbidites to debris flows. By Late Cambrian time, or perhaps slightly earlier, relief was more subdued, and the upper beds of the Preble consist largely of phyllitic shale and hemipelagic limestone. During this time, there is some suggestion that carbonate mud may have been supplied from a shoal to the west, close to the continental shelf-slope break.

INTRODUCTION

The western continental margin of North America was initiated by one or more Precambrian rifting events (Stewart 1972, Gabrielse 1972, Burchfiel and Davis 1975). Rifting was accompanied by thermal expansion of the crust, erosion, and deposition of a clastic sedimentary wedge of late Precambrian and Early Cambrian age. Marine water inundated the continental margin as the crust slowly subsided in response to its more distant position from the rifting center, thermal contraction, and continued sedimentation. Consequently, the coarse sands of the clastic wedge gave way to a predominance of finer-grained terrigenous sediments on the outer shelf margin and to shoal-water carbonate platform sediments on the inner shelf (Stewart and Suczek 1977). This general pattern of geoclinal sedimentation persisted throughout the Cambrian and much of the remaining early Paleozoic. In Nevada, significant alteration in this depositional pattern resulted from the Antler orogeny during Late Devonian and Early Mississippian time when Precambrian and lower Paleozoic rocks were deformed as the westernmost rocks were thrust eastward as much as 145 km (Roberts and others 1958). These strata also have been affected by the numerous post-Antler orogenic events of the Cordillera.

In north central Nevada the clastic sedimentary wedge is represented by the Cambrian(?) Osgood Mountain Quartzite, a unit whose sedimentology has not been investigated in detail. It is succeeded by the shale and limestone sequence of the Preble Formation that accumulated on the outer part of the continental shelf (Rowell, Rees, and Suczek 1979). Although local thrusting is extensive, these two formations appear to be autochthonous or parautochthonous (Hotz and Willden 1964).

The Preble Formation is exposed in the Osgood Mountains, Edna Mountains, and Sonoma Range of Nevada (fig. 1). These outcrops are the most northwestern exposures of Cambrian shelf rocks in the Basin and Range Province and present a unique opportunity to examine sedimentation patterns and mechanisms active in the outer continental shelf of North America during the Cambrian.

The purpose of this paper is to describe the carbonate lithologies and age of the Preble Formation, discuss the modes of sediment transportation and deposition that produced it, and outline the salient features of its depositional history.

PREBLE FORMATION

Definition and Age

Argillaceous and calcareous rocks that overlie the Osgood Mountain Quartzite were named the Preble Formation by Ferguson, Muller, and Roberts (1951), who selected Emigrant Canyon, Golconda Quadrangle, as the type locality.

Initially, the formation was regarded as Middle or Late Cambrian in age (Ferguson, Roberts, and Muller 1952), a remarkably astute determination based on a few linguloid brachiopods. Subsequent work by Hotz and Willden (1964) substantiated this age. Palmer's identifications (in Hotz and Willden 1964) of collections from the Osgood Mountains showed the presence of both Middle and early Late Cambrian rocks. More recently, Rowell, Rees, and Suczek (1979) have extended the age span covered by the formation. These authors collected a late Early Cambrian *Bonnia-Olenellus* fauna from a thin limestone lens in Emigrant Canyon (locality T, fig. 2), and also reported a poorly preserved, late Dresbachian (Late Cambrian) trilobite fauna from thin-bedded dolomitic limestone in the same area (fig. 3). Erickson and Marsh (1974a) have suggested that upper beds of the formation may range into the Ordovician.

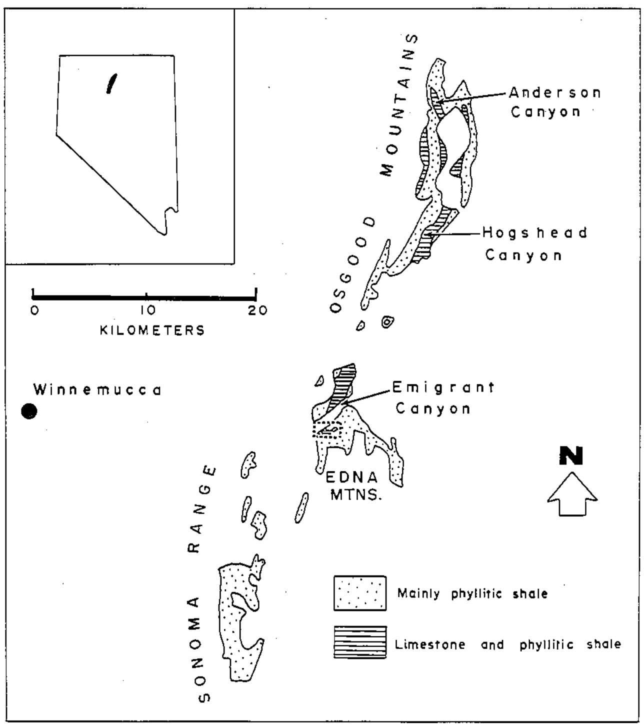

FIGURE 1.—Principal outcrops of Preble Formation (after Stewart and Carlson 1978) and index of localities mentioned in text. Small area outlined by broken line in Edna Mountains is shown in greater detail in figure 2. Insert index map of Nevada shows locality of area covered by map.

Thickness and Stratigraphic Subdivision

Although scattered collections of trilobites, brachiopods, and conchostracans permit modest control on the age of the formation, the stratigraphy is much more troublesome. In part the difficulty is due to the turbulent structural history of the region. In contrast to the relatively undisturbed, magnificently exposed Cambrian sequences of the eastern Great Basin, the Preble has suffered intense structural deformation and commonly is indifferently exposed.

The intensity of deformation is best revealed in the few well-exposed areas that possess distinctive marker horizons. Erickson and Marsh (1974a, b), for example, observed overturned folds with subhorizontal axial surfaces in the type locality of the formation on the south side of Emigrant Canyon. Our detailed map of some readily recognizable limestone units in a small part of this area (fig. 3) reveals a complex array of thrust recumbent-folds with minor fold axes normally plunging about 35° toward the south (fig. 4). It is difficult to be certain that this type of structure is typical of the area as a whole. The rocks involved are relatively thin limestone beds, never more than 12 m thick, in alternating sequence with phyllitic shale. The deformation of more massive carbonate sequences may have followed a different style, but unfortunately poor exposure in the region does not permit this possibility to be verified. However, the existence of this level of deformation, coupled with glimpses of similar effects elsewhere in the region, induces caution in trying to reconstruct any detailed stratigraphy of the Preble Formation.

The base of the formation crops out on the southeast side of the Osgood Mountains, where locally it has conformable contact with the underlying Osgood Mountain Quartzite. A normal stratigraphic contact with an overlying formation, however, has not been recognized anywhere in the area (Hotz and Willden 1964). This problem, coupled with the structural complications, makes determination of even the minimum thickness of the formation exceedingly difficult. Ferguson, Roberts, and Muller (1952) judged that it might be more than 3,600 m thick. Hotz and Willden (1964) estimated that some 1,500 m of beds were exposed in Hogshead Canyon, on the southeast side of the Osgood Mountains (fig. 1), in a section whose upper and lower limits are faulted.

Not only does structure preclude obtaining reliable estimates of the thickness of the formation, but it also imposes severe limits on elucidating a stratigraphy within it. This problem is reflected partially in the lack of detailed terminology. All the Cambrian System of the area, other than the basal clastic sequence, is referred to the Preble Formation. No previous author has proposed any formal subdivision, nor do we intend to do so. However, Hotz and Willden (1964) recognized three informal subdivisions that they traced along the southeast side of

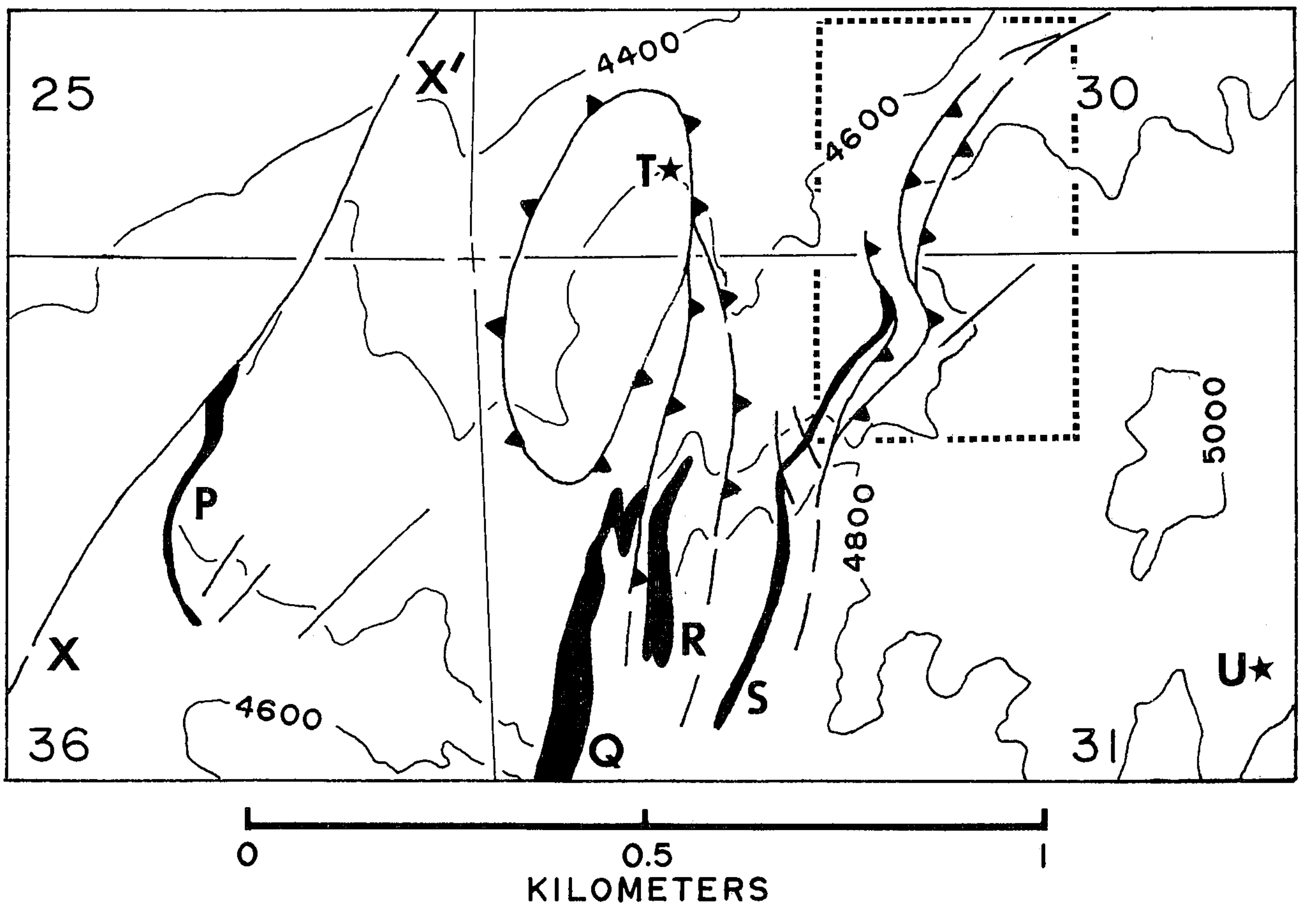

FIGURE 2.—Outcrop patterns of sediment gravity-flow deposits (carbonate conglomerate and associated grainstone) P-S, and principal faults in sections 25, 30, 31, and 36 in the Edna Mountains. Area enclosed by broken line is shown in more detail in figure 3. Localities T and U discussed in the text.

the Osgood Mountains. In a general way, these units strike northeast and become younger to the east. We are in broad agreement with their subdivision, but structure within each unit appears to be intense, and consequently, the thickness cited for them at best gives only an order-of-magnitude impression.

The lowest unit, some 850 to 1,400 m thick, is composed of contorted phyllitic shale and siltstone with minor amounts of quartzite and limestone. It is succeeded by the principal carbonate-bearing unit of the formation. This middle unit crops out as a broad belt that extends southwest from the northeast part of the Osgood Mountains to the Edna Mountains, south of Emigrant Canyon (fig. 1). Hotz and Willden (1964) considered that it consisted of approximately equal thicknesses of phyllitic shale and limestone, with minor quartzite, and was between 340 and 450 m thick. All the limited faunal information from this unit, both our own, discussed below, and that provided by Hotz and Willden (1964), suggests that these beds are Middle Cambrian, possibly extending into the lower Upper Cambrian. The upper unit of the formation recognized by Hotz and Willden (1964) consists of roughly 450 m of predominately phyllitic shale. In the Edna Mountains, alternations of thin phyllitic shale beds with thin-bedded dolomitic limestone carrying a sparse, poorly preserved upper Dresbachian trilobite fauna probably belong to this unit. As previously noted, its upper beds may be Ordovician (Erickson and Marsh 1974a).

INTERPRETATION OF LITHOLOGY AND DEPOSITIONAL SETTING

Although complex structure, metamorphism, poor exposure, and the problems of precise correlation combine to prevent detailed stratigraphic analysis, it is nonetheless possible to make some generalized statements about the regional setting and depositional regimes involved in the accumulation of the Preble Formation. These are heavily dependent on interpretation of carbonate lithofacies within a framework of modest faunal control. Furthermore, they are influenced by independent evidence suggesting that the western limit of continental crust lies close to the outcrop belt of the formation (Rogers and others 1974, Kristler 1978).

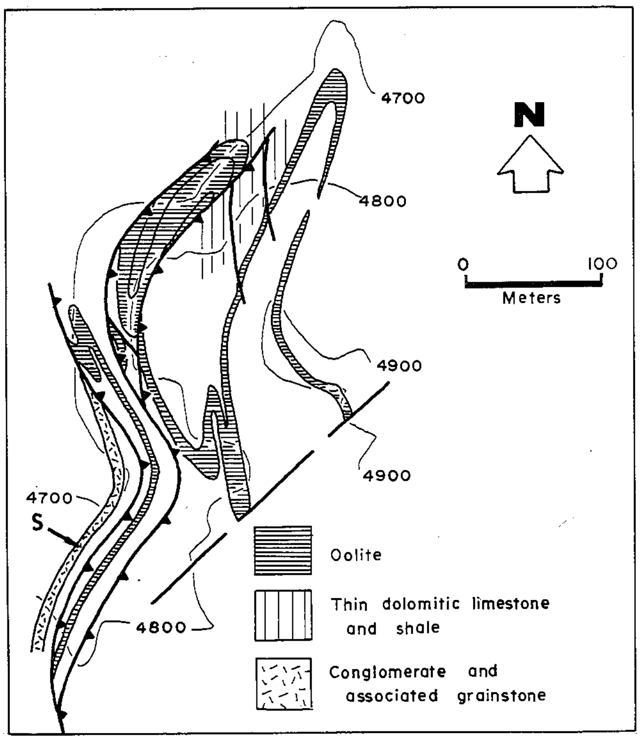

FIGURE 3.–Geological sketch map to illustrate complex structure in the Preble Formation on the south side of the Emigrant Canyon, Edna Mountains. Location of area shown in figure 2.

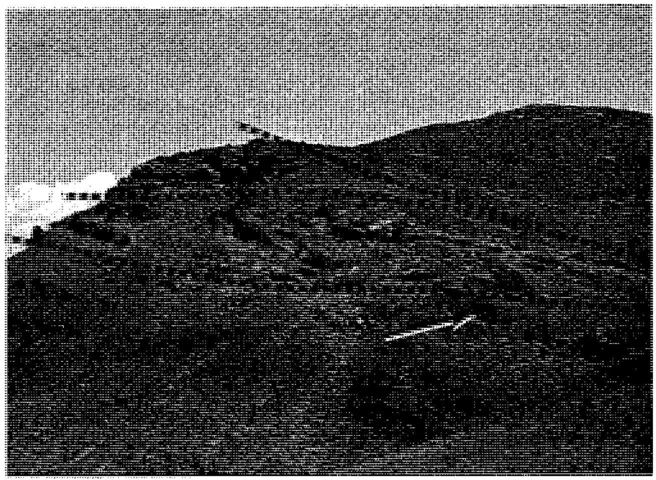

FIGURE 4.–Thrust recumbent-folds on the south side of Emigrant Canyon, Edna Mountains. Broken lines show thrust faults and the arrow indicates location of sediment gravity-flow deposit S as illustrated in a portion of figure 3.

Lower Preble Formation

The lower informal subdivision of the Preble Formation succeeds the Osgood Mountain Quartzite conformably (Hotz and Willden 1964), but there is no faunal control on the age of its lower beds. They are probably Early Cambrian if one may be guided by the age of the upper part of basal sandstone sequences elsewhere in central Nevada (Palmer 1971). The only local biostratigraphic control is a *Bonnia-Olenellus* fauna that occurs in a window in the Edna Mountains (locality T, fig. 2). In addition to species of *Bonnia* and *Olenellus,* the fauna includes the brachiopods *Hadrotrepta primaaea* (Walcott), *Eothele spurri* (Walcott), and *Paterina* sp. This is a characteristic late Early Cambrian assemblage (Rowell 1979).

Thin sandstone and limestone beds occur in the lower subdivision of the formation, but shale is the principal rock type. Commonly it is poorly exposed, but at most outcrops it is slightly metamorphosed and phyllitic. Hotz and Willden (1964) observed that it may be either siliceous or calcareous. Because primary fabric is obscured and the beds have yielded no fauna, virtually nothing can be said about the depositional setting of the shale other than that it was a low-energy environment. The beds seemingly accumulated on a shallow, subtidal part of the outer continental shelf, to the west of the principal area of sand deposition in western Utah. From time to time currents were strong enough to carry sand into the region. Similar currents must also have been active during the relatively brief intervals when limestone was deposited. The limestone is a bioclastic grainstone that forms lenses and beds 4 to 6 cm thick. It consists predominantly of trilobite fragments aligned nearly parallel to bedding (fig. 5) but also includes peloidal packstone intraclasts, inarticulate brachiopods, and uniden-

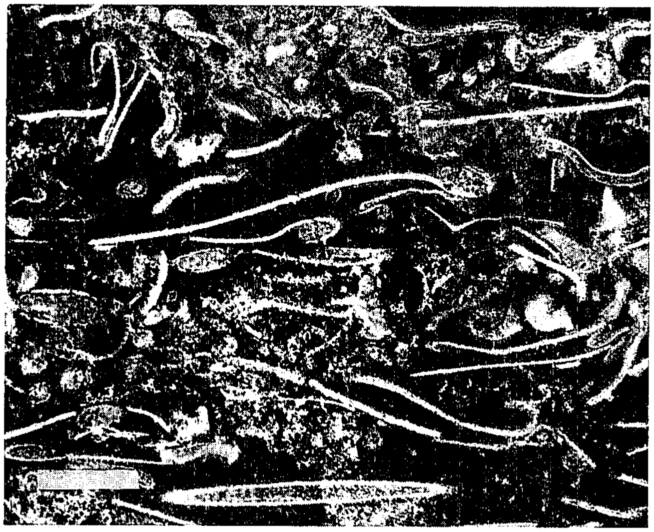

FIGURE 5.—A negative print of Lower Cambrian bioclastic grainstone from locality T in figure 2. Bar scale 1 mm.

tifiable echinoderm fragments. Characteristically, the rocks of this lithofacies are almost devoid of mud, and, although their fauna includes a considerable size range of individuals, the juvenile size fraction of the phosphatic brachiopods is missing. Lack of mud and smaller fossils, coupled with the irregular thickness and lenslike form of the beds, suggests that they are winnowed lag deposits.

The beds of the lower subdivision of the Preble are approximately contemporaneous with strata of the Pioche Shale of eastern Nevada. They differ most obviously from the latter in the relatively smaller percentage of limestone. Strata from both units accumulated on a clay-dominated area of the continental shelf. The differences between them probably reflect a slightly greater water depth and increased proximity to the shelf margin for the Preble beds.

Middle Preble Formation

The middle informal subdivision of the Preble Formation is more heterogeneous than either the lower or the upper one and includes a greater diversity of carbonate lithofacies. The majority of faunas recovered from it suggest an early or middle Middle Cambrian age; the fossils are rarely well preserved, and the taxa are relatively long ranging; thus, greater precision is not possible. What appears to be one of the upper beds of the subdivision, a limestone conglomerate and associated grainstone, has yielded a fauna whose age is within the range of middle Middle Cambrian to early Late Cambrian.

The lower part of this middle subdivision consists of about equal amounts of thick, interbedded phyllitic shale and limestone with rare sandstone. The majority of limestone at this stratigraphic level is either a grainstone or a packstone and commonly has a considerable quartz-sand content. Indeed, the relatively large percentages of subrounded quartz grains in much of the limestone, together with the occurrence of a few quartz sandstone beds, are characteristic features of the principal belt of carbonate rocks in the middle subdivision of the formation. Abundant quartz is not typical of most of the Middle Cambrian rocks of the central and eastern Great Basin, and its presence has some paleogeographic implications. The origin of this terrigenous material is not immediately obvious. It could potentially have come from the east, but the closest source in this direction would lie near the Wasatch Mountains of Utah. Sand would then have had to bypass a broad area of shallow-water continental shelf covering much of Utah and eastern Nevada. The Cambrian geology of this region is fairly well known and provides no hint of a bypass route. An easterly derivative thus seems unlikely. The most probable alternative is from the north or northeast, from the general area of the Salmon River Arch of Idaho (Armstrong 1975). This region is believed to have been a positive feature in Late Cambrian time and the probable source of the terrigenous detritus in the Worm Creek Quartzite and the Harmony Formation (Palmer 1971; Rowell, Rees, and Suczek 1979). It may also have served this function in Middle Cambrian time and have been the source, not only of the Cash Creek Quartzite of Idaho (Hobbs, Hays, and Ross 1968), but also of the quartz sand in this part of the Preble succession.

The sandstone beds are quartz arenites composed of well-sorted, subrounded, medium-sized sand. They are typically 10 to 20 m thick. Some are relatively featureless and provide few clues as to the depositional processes that produced them. Others reveal poorly preserved cross-bedding and were apparently transported and deposited by traction currents.

Current activity was also seemingly important during the deposition of much of the grainstone and packstone in this subdivision. Examples of these are best seen in the Hogshead Canyon region (fig. 1). The carbonate grains within the limestone are predominantly peloids, but intraclasts, ooids, and fragments of trilobites, echinoderms, and algae also occur. Quartz grains are interspersed with the allochems, and the amount of quartz varies from 0 to more than 50 percent. The quartz grains are angular to well rounded and range from coarse-sand to silt size. Most of the grains are embayed by calcite, and the displaced silica has formed thin secondary chert stringers. Individual beds are typically 2 to 10 cm thick, but some of the thinner ones are impersistent, even in a single small outcrop. The bases of the beds may be irregular, and rare cross-bedding is preserved. These packstones and grainstones appear to have been deposited by bottom currents in water of intermediate depth.

Not all the carbonate in this middle part of the formation was deposited by bottom traction currents. A variety of sediment gravity-flow mechanisms were responsible for many beds. Examples of these deposits are best exposed in the southern part of the Osgood Mountains and in the Edna Mountains on the opposite side of Emigrant Canyon. Although there may be a significant difference in age between rocks that were deposited predominantly by traction currents and those deposited by mass flow processes, our biostratigraphic resolution is inadequate to detect it.

Some of the packstone and grainstone beds are turbidites. The more quartz-rich ones are relatively thin, usually a few cm to a few tens of cm in thickness. They are laterally persistent and have parallel lower and upper surfaces. Characteristically, they are separated from one another by several cm of shale (fig. 6). A few appear to have parallel laminations. Other beds show graded units, up to 4 cm thick, with grains varying from medium-sand to silt size.

The quartz-free grainstone and packstone turbidites are similar to the quartzose ones except that they tend to have little or no shale between beds. Consequently, they form amalgamated units typically between 4 and 10 m thick. In addition, some of the quartz-free turbidites are relatively fossiliferous. *Pagetia* sp., *Prototreta* sp., and *Acrothyra* sp. are relatively common in the Edna Mountains at locality U (fig. 2). From the same lithofacies, north of Anderson Canyon, Palmer (in Hotz and Willden 1964) identified *Kootenia* sp. and *Wimanella* sp. Both these faunas are of Middle Cambrian age, and both are probably early or middle Middle Cambrian.

Carbonate conglomerate forms the most striking example of gravity-flow activity in the Preble, although volumetrically it constitutes only an insignificant fraction of the formation. It crops out north of Anderson Canyon as an isolated fault block but is best seen at the type locality in the Edna Mountains (fig. 2). At this latter locality, polymict conglomerate in association with quartz-free grainstone and packstone forms four mappable units.

Each unit seemingly commences with a 3 to 5-m-thick conglomerate. Its very base is always obscured by talus, but it appears to overlie shale. The succeeding beds of the unit consist of alternations of quartz-free grainstone or packstone with thinner conglomerate layers.

The basal conglomerate is laterally continuous for the length of the outcrop. With a few gaps between exposures, the maximum measured extent is about 700 m. The upper contact of these massive beds is usually sharp and flat except where clasts oriented perpendicular to bedding protrude from the upper surface. The clasts in most exposures show no preferred orientation or size grading (fig. 7), but one exception reveals imbrication and crude normal grading. Accurate assessment of clast orientation or size distribution is difficult, however, because the conglomerate is commonly fractured, brecciated, and cut by an abundance of white calcite veins.

The clasts are ellipsoidal to rectangular in outline with the long axis varying from 2 to 50 cm and the thickness varying from .05 to 10 cm. Clast composition is diverse, and the precentage of each lithic type varies from exposure to exposure. The common carbonate clast lithologies are laminated mudstone, oolitic grainstone, silty dolomitic mudstone, and peloidal packstone. The conglomerate is typically matrix supported but

FIGURE 6.–Outcrop of alternating carbonate turbidity deposits and shale at the south end of the Osgood Mountains. Scale 15 cm.

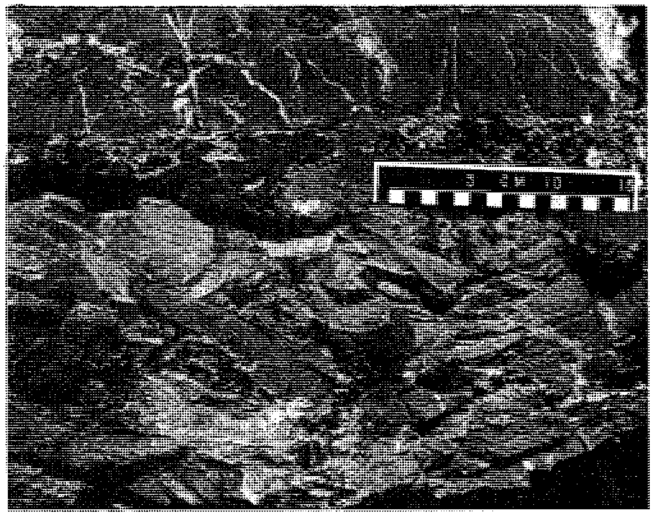

FIGURE 7.–Sediment gravity-flow deposit composed of polymict carbonate conglomerate and overlying grainstone in the Edna Mountains, unit S of figures 2 and 3.

is locally clast supported. The matrix is consistently composed of peloids and ooids in varying percentages, and argillaceous material is rare or absent.

The higher conglomerate beds within each unit are significantly thinner than the basal one and individually may be less persistent. They are commonly less than 1 m thick, and their bases may be flat or irregular. Some of them clearly infill small channels, one example having a maximum channel width of 90 cm and a depth of 30 cm. There is seemingly a difference in both fabric and composition between the laterally persistent conglomerate beds and those filling small channels. In the available two-dimensional view of the latter, the clasts typically show a slight preferred orientation parallel to bedding and rarely are also inversely graded. Furthermore, the conglomerate filling at least one small channel has a micrite matrix and clasts of siltstone, shale, carbonate mudstone, intraclastic packstone, oolitic grainstone, and bioclastic quartz arenite.

No identifiable fossils have been collected from the conglomerate or from clasts within it, but the quartz-free grainstone and packstone interbedded with the conglomerate are not uncommonly fossiliferous. Unfortunately the fauna has a relatively long stratigraphic range, and it is not possible to confidently determine whether the four mapped units in the Edna Mountains (P through S in fig. 2) represent one sequence tectonically repeated, four separate sequences, or any combination of the two.

Units Q and R (fig. 2) have both yielded a Middle Cambrian fauna. Collections from Q contain *Kootenia* sp. and *Linnarssonia* sp. Those from R are slightly richer and include the above two taxa together with fragmentary material of *Acrothyra* sp., *Prototreta* sp., and *Micromitra.* The association of *Acrothyra* and a species of *Linnarssonia* with a high apical process suggests that a middle Middle Cambrian age is probable for at least bed R. Bed P has not yielded a fauna. Fossils from S are enigmatic, being poorly preserved and consisting only of brachiopod fragments, which, in addition to unidentifiable acrotretids and lingulides, include *Curticia* sp. and probably *Canthylotreta* sp. This association suggests an early Late Cambrian or latest Middle Cambrian age, but the stratigraphic distribution of *Canthylotreta* is poorly known, and *Curticia* has been recorded from as low as the middle Middle Cambrian of Montana and Wyoming (Kurtz 1976). Thus it is at least possible that only one conglomerate unit occurs and that it is of middle Middle Cambrian age.

The matrix-supported clasts and the general lack of size grading or preferred clast orientation of the conglomerate are characteristics that most closely resemble those of deposits transported by debris flow (Hampton 1972, Middleton and Hampton 1973). Middleton and Hampton (1973), however, have noted that more than one mechanism is generally active in any one flow, and that one flow type may grade into another. Krause and Oldershaw (1979) have expanded this idea in their consideration of carbonate debris flows and have shown how carbonate turbidite, immediately overlying limestone conglomerate, is an integral part of the debris flow. They further suggest that carbonate debris flows may occur as sheet flows from steep banks and are not necessarily confined to channels. The limestone conglomerate and associated grainstone of the Preble seem to fit the model proposed by Krause and Oldershaw (1979). The conglomerate is disorganized and directly overlain by stratified carbonate grainstone that contains features indicative of turbidity deposits. Some small channels are filled by conglomerate, but the outcrops of the Preble are not sufficient to determine whether the more massive conglomerate units are sheets or large channel deposits. The polymictic clasts in the conglomerate indicate that the flows incorporated a variety of lithologies prior to deposition, either by crossing different depositional environments or by eroding vertically through different lithologies. Furthermore, the presence of ooids in the matrix and oolite clasts suggests that some of this material was transported from shoal water.

Ooids are also a distinctive feature of another rock unit in the Edna Mountains, a light gray oolite with orange-weathering dolomitic mudstone beds and lenses (figs. 8, 9). These carbonates are interbedded with thin lime mudstone and shale units, to form a sequence with a total thickness of approximately 3 m. Although thin, the sequence is locally an excellent marker horizon and was used to map the folds and thrusts shown in figure 3. Its stratigraphic position is not well established because no fauna has been recovered from it. Its structural associations suggest that it may be part of the middle subdivision of the formation, probably toward its upper part.

The oolite, like many other limestones of the middle subdivision of the Preble, is probably a resedimented deposit. For, although the ooids are thought to have formed in highly agitated water of approximately 3 to 5 m depth (Ball 1967), the rock itself does not bear evidence of deposition in a shoal-water environment. The oolite beds are 2 to 15 cm thick and show no trace of cross-bedding, but the upper surfaces of some are rippled. The upper surfaces are abruptly overlain by thin dolomitic mudstone layers or lenses. This couplet of oolite layer followed by mudstone is repeated numerous times to form sequences up to 1.5 m thick. The contrast between the ooids, which formed in a high-energy environment, and the mud, which must have accumulated under still conditions, is marked. Presumably the ooids were periodically transported from a high-energy shoal and deposited as thin beds in a quieter and probably deeper-water environment. The upper surfaces of some beds were rippled, perhaps by the currents that deposited them, and then a period of quiescence allowed pelagic carbonate mud to accumulate. The current that deposited the next thin bed of ooids lacked the energy to remove the muddy lime sediment. These currents could have transported ooids either seaward or shoreward, for both transport directions have been documented from recent carbonate environments (Ball 1967). Off-shoal transport may be initiated by tidal and storm surges, earthquakes, or collapses of bank edges. Consequently, a variety of gravity-flow mechanisms or traction currents may be responsible for sediment distribution. In the Preble, however, neither the direction nor the exact mechanism of ooid transport can be determined.

What then can be said about the depositional setting of the middle subdivision of the Preble? The sequence is predominantly Middle Cambrian in age, probably much of it is early or middle Middle Cambrian, but one debris bed may be as young as early Late Cambrian. The sequence was laid down seaward of the well-known successions of the eastern Great Basin.

FIGURE 8.–Oolite with interbeds and lenses of dolomitic mudstone. Rippled bedding surface in lower left of photograph.

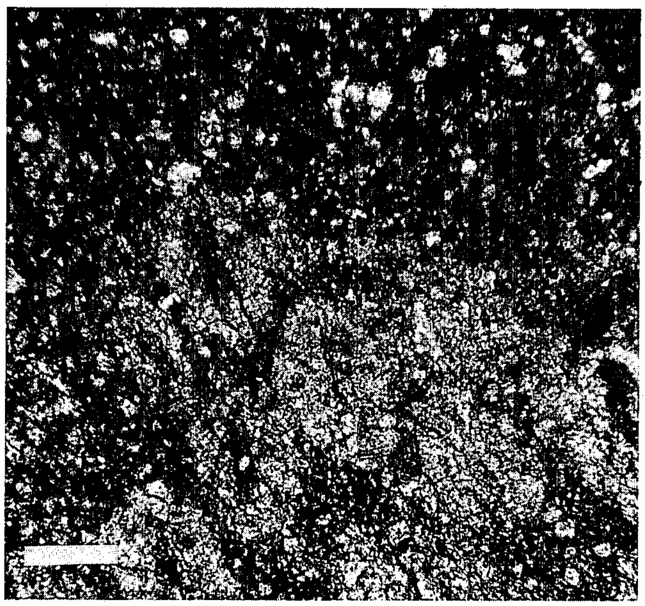

FIGURE 9.–Photomicrograph of contact between oolite and overlying dolomitic mudstone. Note that the ooids are deformed and their long axes are at a high angle to bedding. Bar scale .2 mm.

Much of the middle carbonate-rich subdivision of the Preble is probably contemporaneous with relatively shallow-water formations like the lower part of the Highland Peak (Kepper 1972), Pole Canyon, and Eldorado (Palmer 1971). At least one conglomerate is of approximately the same age as the Swasey Limestone and the upper part of the Pole Canyon Formation. The Preble, however, was clearly not part of this broad shoal-water complex, although some of its constituents may have been derived from it.

We envisage that sedimentation of the middle subdivision of the Preble occurred in a marginal basin that developed by differential subsidence on the outer continental shelf, probably in early Middle Cambrian time. Water depth was never great but was sufficient to inhibit the development of the characteristic features of shallow subtidal and peritidal carbonate deposits. The depositional environment fluctuated with time. The sea floor was periodically swept by currents able to transport and eventually deposit large quantities of quartz and carbonate grains. However, part of the basin margin had sufficient relief to allow gravity-flow mechanisms to operate, and both turbidites and debris-flow deposits accumulated. We have no evidence of the transport direction of the gravity-flow deposits. Their clast composition reveals that shallow-water deposits were contributing to them. They may have come from the east, for rocks of the appropriate facies and age are known in that direction; however, it is possible that they were derived from the west, from a carbonate shoal near the shelf margin. There is no Middle Cambrian evidence on which to refute or accept this latter suggestion, but there are Late Cambrian data consistent with the existence of such a shoal.

Gravity-flow transport seemingly ceased abruptly at the end of deposition of the middle subdivision of the Preble. Younger resedimented deposits are unknown in this formation. By Late Cambrian time, and possibly earlier, relief apparently was largely eliminated.

Upper Preble Formation

Rocks of Hotz and Willden's (1964) informal upper subdivision of the Preble Formation consist predominantly of phyllitic shale, but what appears to be part of the succession is comprised of alternations of shale and dolomitic mudstone. This latter association is rarely well exposed because the beds are typically slope forming, but it occurs in a 15-m-thick outcrop in the Edna Mountains that is bounded by thrust faults (fig. 3). The outcrop is composed of alternating 6 to 10-cm-thick dolomitic mudstone and 1 to 10-cm-thick shale beds (fig. 10). The mudstone is dark gray to black on a fresh surface and weathers to a characteristic rusty orange. It consists of about 50 percent fine-crystalline dolomite, about 40 percent fine-crystalline neomorphic calcite, and about 10 percent argillaceous clay. The upper and lower bedding surfaces of the dolomitic mudstone are typically sharp, flat, and parallel. Internally some beds show faint indications of bioturbation, but most are extremely homogeneous. The mudstone is commonly stylolitized, and both it and the shale are severely sheared. The dolomitic mudstones have yielded a small, poorly preserved trilobite fauna of late Dresbachian age (Rowell, Rees, and Suczek 1979). These rocks show resemblance to some of the Dunderberg Shale sequence, which is partially correlative. The greatest resemblance is with more westerly exposures of the Dunderberg Shale as at Tybo and Mount Hamilton in south central and central Nevada, but even these successions typically have thicker shale interbeds between the limestone layers. The source of the carbonate for these limestone beds is rather enigmatic. A primary pelagic source for carbonate material is not known to have been available in the lower Paleozoic, and presumably the carbonate mud was initially produced in a shallow-water environment. Since there are no indications that shallow-water conditions prevailed at this time where the Preble was deposited, the material had to be transported into the region. Such fine-grained carbonate can be moved from a shoal across the continental shelf by diffusion or advection. Alternatively, some form of lutite flow with suspension cascading might be invoked away from the margin of a carbonate bank (McCave 1972). Whatever the precise mechanism involved, periods of carbonate-mud deposition were interspersed with those in which argillaceous mud dominated.

It is possible that the carbonate mud was derived from the west, from a shoal area near the continental shelf break. Two lines of evidence suggest that a shoal may have existed during Late Cambrian time and formed the seaward limit of the marginal basin in which the middle and upper subdivisions of the Preble accumulated. The allochthonous Paradise Valley Chert, which now lies 15 km west of the Preble, is coeval with a portion of the upper Preble and was deposited on the continental rise as the Preble accumulated on the outer shelf (Rowell, Rees, and Suczek 1979). A carbonate bank along the Cambrian shelf-slope break, or a carbonate ridge and terrigenous basin topography, could effectively pond terrigenous shelf sediments and restrict sedimentation on the deep-water rise allowing pelagic biogenous silica to accumulate. Both Hotz and Willden (1964) and Rowell, Rees, and Suczek (1979) recovered an Upper Cambrian fauna of typical North American shelf species from poorly exposed, isolated limestone lenses within the Para-

FIGURE 10.–Upper Cambrian thin-bedded dolomitic limestone and shale in the Edna Mountains. The outcrop distribution of these rocks is illustrated in figure 3. Bar scale .5 m.

dise Valley Chert. The limestone lenses are composed of either carbonate breccias or, less often, laminated black limestone. The black nonfossiliferous limestone consists of 1 to 3-mm-thick laminae of alternating neomorphic microspar, with disseminated platy argillaceous material oriented parallel to bedding, together with well-sorted peloids and minor amounts of quartz silt. The breccias are the principal source of fossils from the Paradise Valley Chert. Their clasts are either dark gray to black, recrystallized lime mudstone or light gray bioclastic wackestone and packstone. The bioclasts are trilobites, inarticulate brachiopods, echinoderms, and algae. These breccias and their fauna suggest deposition from sediment gravity flows that originated in a shallower-water carbonate environment. If this interpretation is correct, the Paradise Valley Chert must subsequently have been thrust eastward over the sedimentary rocks representative of the Cambrian slope and over at least the outermost carbonate bank development, to come to rest nearly juxtaposed to the shelf-basin sediments of the Preble Formation.

Matti and McKee (1977) suggested a broadly analogous paleogeography for the Silurian and Devonian of central Nevada. In addition, a similar setting for the inferred marginal-shelf basin of the middle and upper Preble is to be found in the Jurassic and Cretaceous history of the outer continental shelf of eastern North America (Klitgord and Behrendt 1979, Schlee and others 1976). On the Atlantic shelf an irregular ridge and basin topography developed, which trapped large quantities of terrigenous sediment in shelf basins. Carbonate shoals subsequently developed on top of some of the ridges on the shelf and along the shelf margin. This shelf topography restricted sedimentation on the rise until Late Cretaceous time when the shelf basins filled, buried the ridges, and dispersed terrigenous sediment down the continental slope (Schlee 1976). This late phase is not recognized in the Cambrian of Nevada. The Paradise Valley Chert was succeeded by a flood of feldspathic sand that accumulated on the continental rise and is now the Harmony Formation (Rowell, Rees, and Suczek 1979). These sediments did not spill over from the Preble basin, but reflect the encroachment of a submarine fan that transported material from the northeast.

ACKNOWLEDGMENTS

We are indebted to our colleague R. A. Robison, who critically read an earlier version of the manuscript and to Judy Smyth, who uncomplainingly typed numerous drafts. The research was supported by Division of Earth Sciences, Natural Science Foundation, NSF Grants DES75-21499 and EAR75-21499 A01 to the University of Kansas.

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