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MARGIN OF THE NORTH AMERICAN CONTINENT IN NEVADA DURING LATE CAMBRIAN TIME

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ABSTRACT. Deep-water deposits of Cambrian age are not well known in western North America. New data from north-central Nevada allow improved chronocorrelation of some formations and permit recognition of a Late Cambrian outer shelf to continental rise sequence in this structurally complex region. The outer shelf environment is represented by the Early to Late Cambrian Preble Formation, which consists predominantly of phyllitic shale with some limestone units. Locally, thin disorganized debris-flow deposits suggest proximity to a paleoslope. The Paradise Valley Chert of Late Dresbachian age is contemporaneous with part of the Preble Formation. This formation is regarded as primarily a pelagic radiolarian deposit that accumulated on the lower slope or continental rise some distance to the west of the shelf margin. The thick feldspathic sequence of the overlying Harmony Formation is characterized by graded beds and amalgamated sandstone which are interpreted as proximal turbidites. Collectively, these turbidites formed the middle part of a submarine fan on the continental rise. The terrigenous part of the Harmony was derived from the Precambrian of the Salmon River Arch of central Idaho. The formation's derived fauna of North American shelf trilobites reveals its Franconian and Trempealeauan age. It is probably coeval with the upper part of the Preble Formation, which was being laid down in shallower water to the east.

The present juxtaposition of these outer shelf, slope, and continental rise deposits is due to thrusting. The magnitude of displacement is unknown but may be as little as a few tens of kilometers. Data fail to support the contention that any of the formations are part of an obducted sequence from areas unrelated to North America.

INTRODUCTION

Early Paleozoic sedimentation in the Cordilleran geocline produced stratigraphic sequences of markedly different aspect: Roberts and others (1958) have been followed by most later authors in distinguishing an eastern carbonate (miogeoclinal) assemblage separated by a narrow transitional assemblage from a western siliceous (eugeoclinal) assemblage. Our present understanding of these assemblages and the structural evolution of the orogen have been brought together in an actualistic model in which the geocline was initiated by one or more Precambrian rifting events (Stewart, 1972; Gabrielse, 1972; Burchfiel and Davis, 1975). Rifting was associated with thermal expansion and the development of a clastic wedge. Subsequent erosion and thermal contraction caused marine inundation of the continental margin (Stewart and Suczek, 1977). Some authors have suggested that during early Paleozoic time a marginal sea

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developed, bounded on the west by the Klamath island arc system (Burchfiel and Davis, 1972, 1975; Churkin, 1974). Others, such as Stewart and Poole (1974), have proposed an open oceanic basin adjacent to the stable continental margin during most of the early Paleozoic. In their model a subduction zone and associated island arc system may have developed in the Devonian. As yet there is no clear indication of the timing of the initiation of a marginal sea or even that it ever existed. Later development of this orogen does not immediately concern us.

Although the principal features of the Late Precambrian and Cambrian part of the eastern miogeoclinal assemblage have been documented (Late Precambrian-Early Cambrian [Stewart, 1970], Cambrian [Armstrong, 1968; Palmer, 1971; Robison and Rowell, 1976]), knowledge of events in the transitional and siliceous assemblages during this interval is limited. It has been proposed that the Upper Cambrian Hales Limestone of the transitional assemblage in the Tybo region of south-central Nevada (fig. 1) was deposited on the continental slope (Cook and Taylor, 1975; Taylor and Cook, 1976; Cook and Taylor, 1977). The siliceous and volcanic assemblage of the Scott Canyon Formation of north-central Nevada, near Battle Mountain (fig. 2), is commonly regarded as being of entirely Early and ?Middle Cambrian age, a deep-water deposit that was subsequently thrust far to the east (Roberts and others, 1958; Roberts, 1964; Stewart, 1972). However, Devonian radiolaria have been tentatively

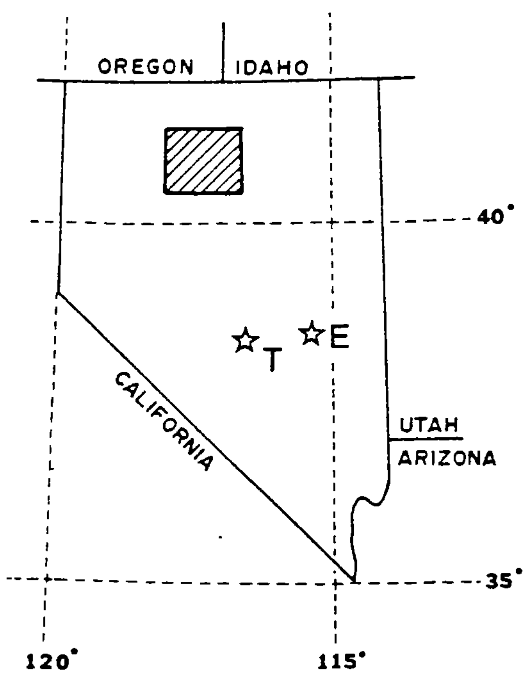

Fig. 1. Index map showing location of figure 2 (as shaded rectangle) relative to Nevada. The two stars show the location of Tybo (T) and the Egan Range (E).

recognized from cherts within the formation, and both the stratigraphy and structure of the Scott Canyon Formation are still inadequately understood (Stewart and Suczek, 1977). In general, the model of depositional environments of the transitional and western siliceous assemblages has been developed primarily for post-Cambrian rocks, and the events recorded in the Cambrian sequences of north-central Nevada have not been fully integrated into it.

We have studied three formations, the Preble, Harmony and Paradise Valley Chert which have been variously referred to the transitional and western assemblages (for example, Roberts and others, 1958; Stewart and Poole, 1974). We offer a new interpretation of the chronostratigraphic relations between these formations and relate the rocks to a sedimentological model of the outer shelf, slope, and continental rise of the North American continent.

DISTRIBUTION OF CAMBRIAN OUTCROPS

Cambrian rocks of north-central Nevada occur within the complex belt of folds and thrusts associated with the numerous orogenic phases of the Cordillera (for example, Hotz and Willden, 1964; Gilluly and Gates, 1965; Roberts and others, 1958; Silberling, 1975). The principal outcrops are in the Osgood, Edna, Hot Springs, and Sonoma Ranges near the town of Winnemucca, and on Battle Mountain, to the south-

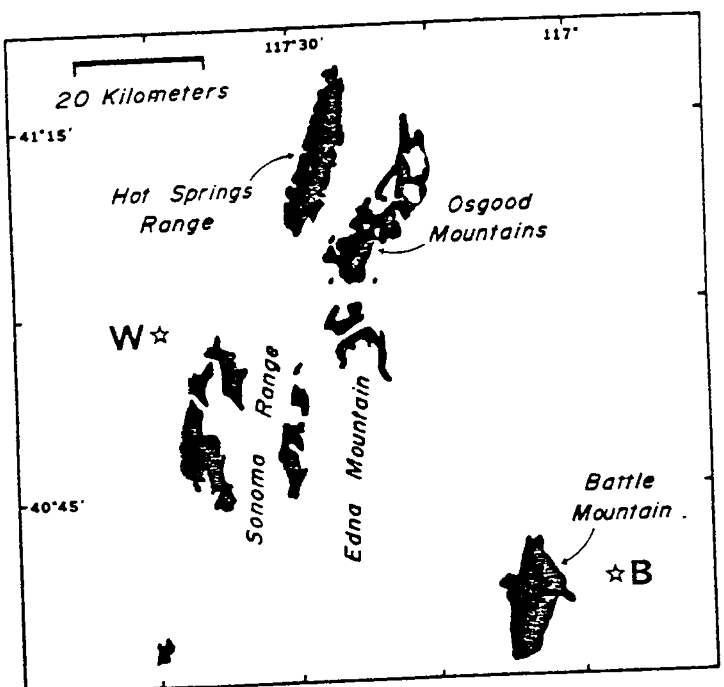

Fig. 2. Map of location of major outcrops of Cambrian rocks in north-central Nevada (based on Stewart and Carlson, 1976).

west of the town of that name (fig. 2). Throughout the remainder of the text "Battle Mountain" refers to the mountain range. Details of the areal distribution of these Cambrian outcrops are shown on the recent geological map of the region (Stewart and Carlson, 1976). In spite of the structural complexity, there is no evidence suggesting extensive horizontal movement of either the Osgood Mountain Quartzite or the Preble Formation. Locally, the Preble Formation is thrust, but elsewhere in the Osgood Mountains it has normal contact relations with the underlying quartzite (Hotz and Willden, 1964). Both formations appear to be autochthonous or parautochthonous. Over much of the region, the Harmony Formation has been caught up in thrust slices associated with the Late Devonian-Early Mississippian Roberts Mountain Thrust (Roberts and others, 1958; Silberling, 1975) and has also been involved in later thrust movements, particularly in the Sonoma Range. On Battle Mountain, the Harmony rests in thrust contact with the Scott Canyon Formation, which is itself allochthonous (Roberts, 1964). In the Hot Springs Range, there is no direct evidence of thrusting of the Harmony Formation or the underlying Paradise Valley Chert. The structural relations are concealed by alluvium, and consequently it is possible to maintain that the Harmony in this range is autochthonous. Gilluly and Ferguson (*in* Roberts and others, 1958) concluded, however, that these outcrops were also allochthonous, as was later implied by Stewart and Poole (1974). We consider that the stratigraphic data discussed below support this latter interpretation.

PREBLE FORMATION

Stratigraphy.—The Osgood Mountain Quartzite, the distal part of the basal clastic wedge of the miogeocline (Stewart and Suczek, 1977), is overlain with seeming conformity by the Preble Formation in the Edna and Osgood Mountains (Ferguson, Muller, and Roberts, 1951; Hotz and Willden, 1964). The latter formation is severely deformed and regionally metamorphosed. Locally, as in Emigrant Canyon in the Edna Mountains, the type locality of the Preble, the beds exhibit overturned folds with subhorizontal axial planes (Erickson and Marsh, 1974a). Elsewhere, the phyllitic shale of the Preble bears two sets of cleavage (Hotz and Willden, 1964). The level of structural complexity combined with generally poor exposures precludes detailed stratigraphic analysis of the formation. Although Hotz and Willden (1964) and we have estimated thicknesses of parts or all of the formation, the severe folding and faulting cast doubt on any estimated values. With our present level of knowledge, it would be virtually impossible to detect even extensive repetition of unfossiliferous phyllitic shale by thrust faulting. Nonetheless, the basic sequence discussed by Hotz and Willden (1964) is supported by our studies. We have added some significant faunal control, and the lower part of the formation is considerably older than previously recognized. The lower part of the formation, which appears to be between 900 and 1300 m thick, is predominantly phyllitic shale with thin siltstone and quartzitic

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sand beds (Hotz and Willden, 1964) and rare thin limestone layers. This part of the sequence is overlain by a 600 m thick limestone, which is best exposed on the east side of the Osgood Mountains. The limestone is seemingly much thinner in the Edna Mountains to the south, and its lower beds either pass laterally into shale, or, more probably, are cut out by thrusting. Above the limestone, an estimated 500 m of phyllitic shale is present in the Osgood Mountains, but its upper limit is faulted. Nowhere in the region are younger beds definitely known to be in normal stratigraphic contact with the Preble.

Although thin sections of Preble limestone commonly show bioclastic fragments, pervasive recrystallization makes recognizable fossils extremely difficult to recover. Hotz and Willden (1964) demonstrated that the Preble ranged in age from at least the Middle Cambrian to early Late Cambrian. We have collected a late Early Cambrian fauna belonging to the *Bonnia-Olenellus* Zone from a thin limestone in the lower part of the formation in the Edna Mountains. The fauna includes undetermined species of both *Bonnia* and *Olenellus* together with the brachiopod *"Acrothele" spurri* Walcott. The youngest Cambrian fauna previously known from the formation was obtained from a float block in the Osgood Mountains. From this material, Palmer (*in* Hotz and Willden, 1964) recognized the lower part of the *"Crepicephalus"* Zone.

We have found fragments of a brachiopod best referred to *Curticia* sp. in the upper limestone unit exposed on the south side of Emigrant Canyon in the Edna Mountains. This genus is not known to range outside the *"Crepicephalus"* Zone in the Great Basin but has been recorded from the Middle Cambrian in Wyoming and Montana (Kurtz, 1976). At this locality, the *Curticia*-bearing beds are overlain by younger strata. The contact is clearly a low angle fault, probably a thrust (pl. 1-A), but the overlying 15 m sequence of shale and thin, sparsely bioclastic carbonate mudstone yielded a small silicified fauna some 3 m above its base. The preservation of the material is poor, but the specimens are pterocephaliids and indeterminate agnostoids. The fauna cannot be dated more precisely than from the lower part of the Pterocephaliid Biomere (Palmer, 1975, personal commun.), but it is clearly younger than the *"Crepicephalus"* Zone and probably belongs to the interval *Dicanthopyge*-lower *Dunderbergia* Zone. This is the youngest Cambrian fauna presently recorded from the Preble. However, Ross (*in* Erickson and Marsh, 1974b) has noted graptolites of probable Ordovician age from beds in the Edna Mountains that have been mapped as Preble. It is difficult to ascertain whether these beds are indeed Preble, or whether they are part of a small infaulted or thrust block of Ordovician genetically unrelated to it.

Depositional environment.—Little can be gleaned about the depositional environment from the metamorphosed argillaceous rocks. The limestone is heavily sheared and recrystallized, but its primary fabric and constituents are generally recognizable. Most of it is thin to medium bedded, poorly sorted, intraclastic, and peloidal packstone (pl. 1-B); other

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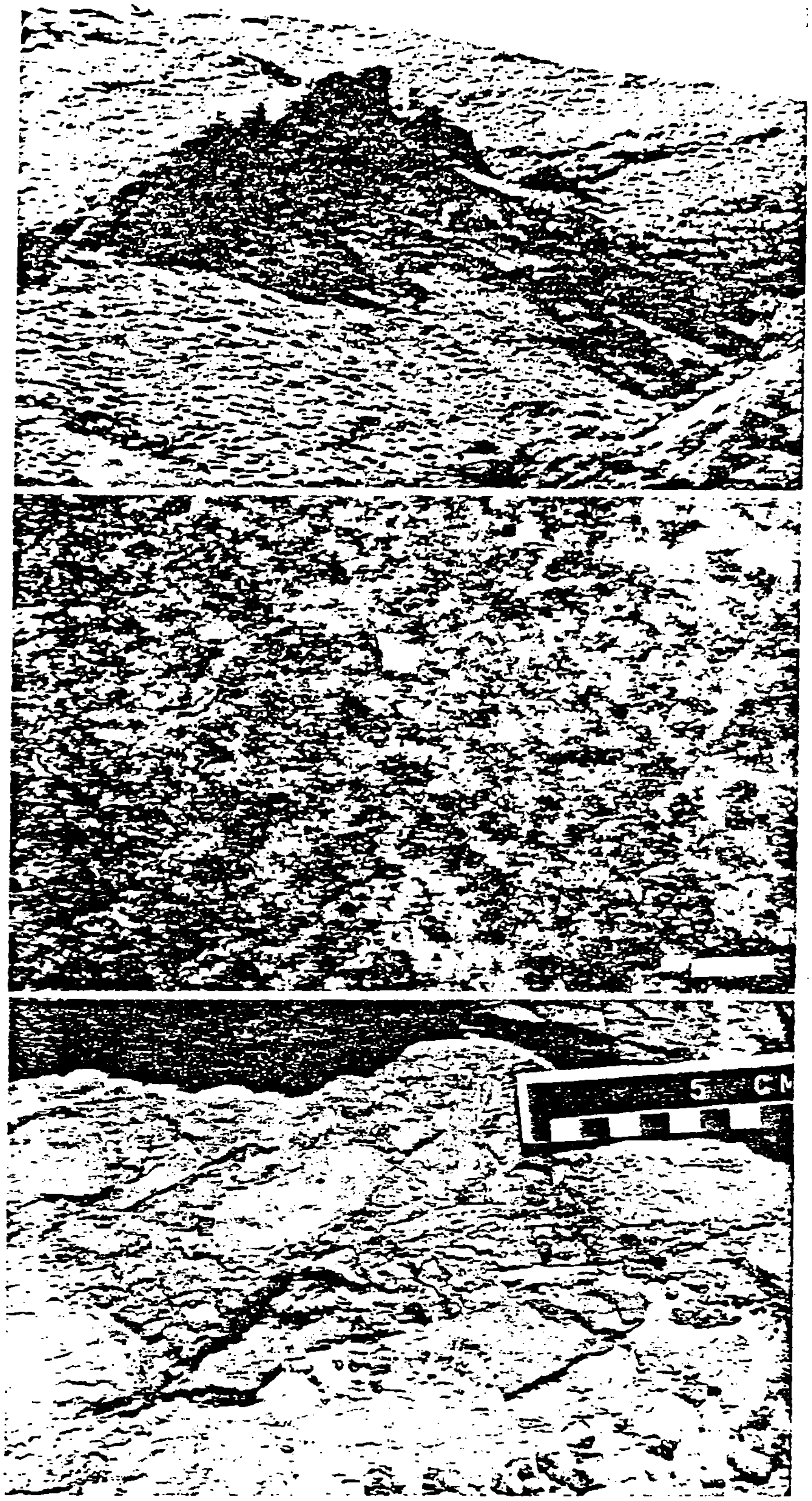

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B. Photomicrograph
Canyon, east side of Hot Sp

C. Debris-flow deposit
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beds consist of oolitic intraclastic grainstone. This limestone reflects somewhat different energy levels but is interpreted as having formed from *in situ* and current-supplied material. Within the carbonate sequence, however, some of the beds are clearly the product of gravity flows. In the *Curticia*-bearing beds of the Edna Mountains, a 2-m thick debris-flow deposit contains carbonate clasts up to 0.6 m in one dimension that are chaotically distributed in an ooidal matrix (pl. 1-C). This unit is overlain by a succession of thinner debris beds and ooidal grain-flow deposits.

None of the limestone examined contains characteristics of deep-water sediment, nor, at the other extreme, were any lithofacies found that are common in peritidal deposits. We conclude that the majority of the carbonate in the Preble Formation accumulated in an outer shelf environment, and that much of the material was transported there by tidal and seasonal currents, possibly aided by storm-generated surges. This is basically the mechanism advocated by Bein and Weiler (1976) for transport of sediment across the Cretaceous platform of the eastern Mediterranean region. The presence of the Edna Mountain debris beds, together with others of unknown age within this formation on the western side of the Osgood Mountains, implies proximity to a paleoslope. Contorted beds and other features characteristic of extensive gravity-flow movements are unknown in the Preble, but it is possible that the allodapic units accumulated on the upper part of the continental slope near the shelf-slope break. The geographic location of these beds is close to the position of the cratonic margin inferred on other grounds by Rogers and others (1974).

PARADISE VALLEY CHERT

Stratigraphy.—The Paradise Valley Chert crops out only in the Hot Springs Range. It has an apparent thickness of 150 m, but its true thickness is unknown, because its base is not exposed (Hotz and Willden, 1964), and the formation exhibits numerous folds. It is overlain in seeming conformity by the Harmony Formation (Silberling and Roberts, 1962; Hotz and Willden, 1964), but exposures of strata near the boundary are poor, and the possibility cannot be eliminated that the two formations are in low-angle fault contact. There is no direct stratigraphic information on the relationship of the Paradise Valley Chert to older beds.

The majority of the formation consists of well-bedded dark chert in beds 5 to 50 cm thick which are commonly separated by thin layers of siliceous shale (Hotz and Willden, 1964). Fossils have been recorded from limestone layers within the chert, but the detailed stratigraphic relationships of the unfossiliferous limestones are obscure, although they

A. Preble Formation, south side of Emigrant Canyon, Edna Mountains; upper beds in cliff are part of the Pterocephaliid Biomere and are separated by a low angle fault from older strata with *Curticia* sp.

B. Photomicrograph of peloidal packstone from Preble Formation, Hogshead Canyon, east side of Hot Springs Range. Bar is 200 μm.

C. Debris-flow deposit, Preble Formation, south side of Emigrant Canyon, Edna Mountains.

have been described by Hotz and Willden 1964) as forming lenses and thin beds. Palmer (*in* Hotz and Willden, 1964) identified faunas that indicate a Dresbachian age; part of the sequence belongs to the "*Crepicephalus*" Zone and part to the overlying *Aphelaspis* Zone. *Glyptagnostus reticulatus* occurs in at least two beds (Palmer, *in* Hotz and Willden, 1964). This is a rather rare but cosmopolitan species (Palmer, 1962), and its presence suggests that the depositional site had ready connection with the open ocean. Other components of the total fauna include two species of *Olenaspella* that are known only from North America and which occur typically in "outer detrital belt" rocks (Palmer, 1965).

Depositional environment.—Wise and Weaver (1974) have argued that the immediate source of silica for most bedded chert is biogenic and that the formation of chert involves a diagenetic maturation from opaline silica through cristobalite to quartz. A volcanic source for the silica in bedded chert cannot be dismissed out-of-hand (Calvert, 1974), but no trace of replaced volcanic material has been observed in the Paradise Valley Chert (Hotz and Willden, 1964). This chert consists predominantly of microcrystalline quartz whose mean crystal size is in the order of 5 μm (pl. 2). Furthermore, volcanism of Late Cambrian age is unknown in western North America. Radiolaria have not been confidently recognized in the chert, but some ellipsoidal quartz bodies of the appropriate size range occur and may represent the deformed remnants of such organisms. We consider it probable that radiolaria were the source of silica in this formation, as they were in the Ordovician Vinini Formation (Stanley, Chamberlain, and Stewart, 1977). Thus we interpret the chert of the Paradise Valley Chert as primarily a pelagic deposit.

Jurassic and younger bedded chert imply deposition in deep water below the carbonate compensation depth. This is not a necessary paleobathymetric conclusion for older bedded chert. Prior to the rise of the diatoms and coccoliths, such beds could accumulate in shallow as well as deep water (Garrison, 1974). The lithology of the Paradise Valley Chert shows that there was a very low imput of terrigenous sediment and that accumulation occurred in a region of high primary productivity. The agnostoid fauna indicates that there was no barrier separating the depositional site from the open ocean, but the species of *Olenaspella* imply ready contact with the shelf of the North American continent. These conditions suggest that the Paradise Valley Chert accumulated on a continental rise or possibly a lower slope setting, some distance to the west of the outer shelf sediment of the Preble Formation.

HARMONY FORMATION

Stratigraphy.—The Harmony Formation crops out in large areas of the Sonoma Range, Hot Springs Range, and on Battle Mountain. Small thrust sheets occur elsewhere in the region, as in the Osgood Mountains. The formation seemingly overlies the Paradise Valley Chert conformably, but its top is unknown. Palmer's faunal identifications (*in* Hotz and Willden, 1964) indicate a middle and late Late Cambrian age (Franc-

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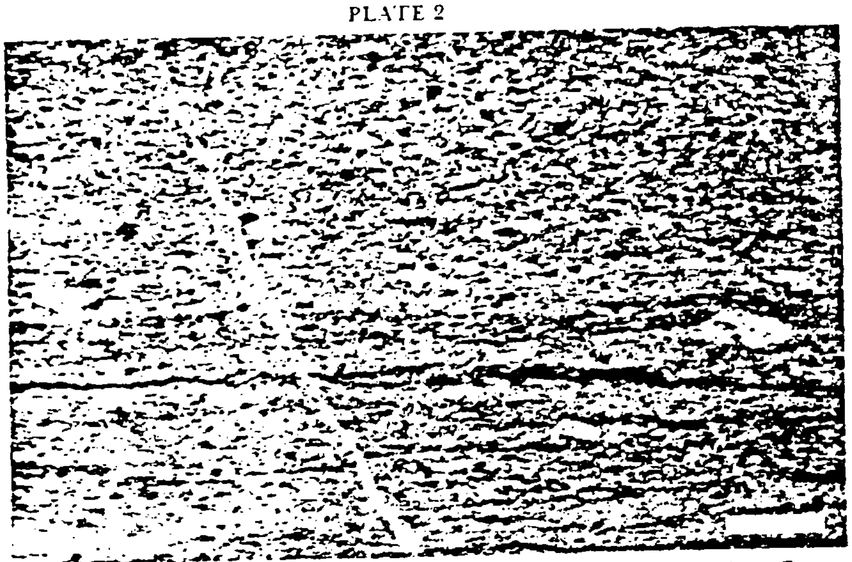

A. Photomicrograph of Paradise Valley Chert, west side of Hot Springs Range. Bar is 200 μm.

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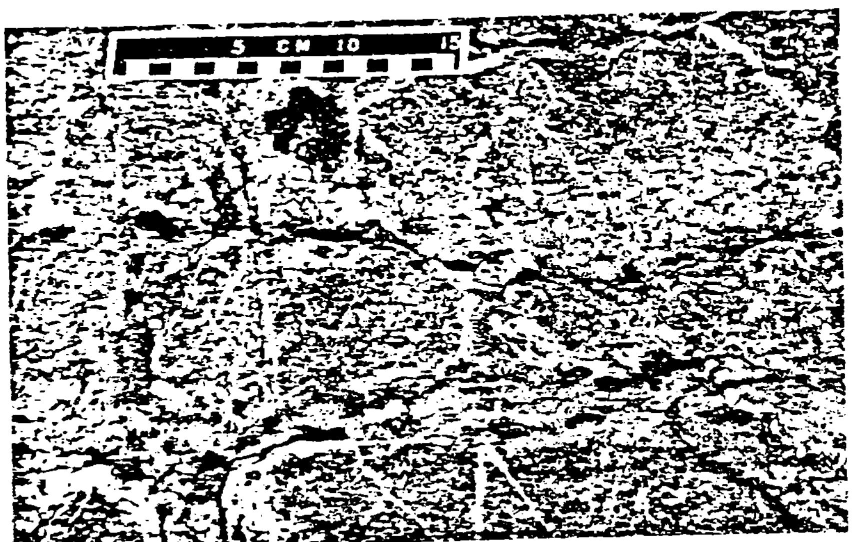

B. Outcrop of Harmony Formation, west side of Hot Springs Range, amalgamated, normally graded sandstone.

onian and Trempealeauan) for the Harmony. Its upper beds could conceivably be younger.

The basal 25 to 50 m of the formation is shale, and the remainder of the unit shows a considerable degree of lithologic homogeneity across the region. As described from the various mountain ranges (Roberts and others, 1958; Roberts, 1964; Hotz and Willden, 1964; Gilluly and Gates, 1965; Silberling, 1975; Suczek, 1977), it consists predominantly of thick to very thick, coarse and medium grained, graded feldspathic sandstone interbedded with lesser amounts of shale, laminated and rippled siltstone, and relatively rare limestone. Locally, conglomeratic layers are developed with quartz pebbles up to 2 cm in diameter. Most authors have commented on the poor sorting of the sandstone and the presence of angular to subrounded quartz grains together with a relatively high percentage of feldspar. The amount of matrix is variable as all rock types from sandstone to shale are found. Lithic fragments include chert, shale, and quartz–mica aggregate.

Depositional environment.—The rocks have usually been interpreted as the product of various types of sediment gravity flows including turbidity flows. Over much of the area many of the beds have the characteristics of classical proximal turbidites (facies C of Walker and Mutti, 1973). Individual sandstones may be laterally persistent (Hotz and Willden, 1964), sandstone-shale ratios are typically high, and in Bouma terminology the beds are AE. Sole markings are rare, but the bases of many of the graded beds are erosional. Large channels are developed in a few places and attain apparent widths of up to 250 m and depths of 70 m. Channels are infilled with coarse-grained sandstone beds, which are usually amalgamated (pl. 3). The latter beds are perhaps best regarded as examples of Walker and Mutti's facies B_2, but the maximum grain size approaches that of their facies A_4, "organized pebbly sandstones."

These facies associations strongly suggest that the Harmony was deposited in the proximal part of a submarine fan. Such a position is consistent with Stewart and Poole's (1974) recognition that the formation forms part of a continental rise sequence. What is known of variations in thickness of late Franconian and Trempealeauan beds across the geocline shows considerable similarity with those of Tertiary beds across some present-day passive continental margins. In a cross section across the continental shelf, slope and rise extending eastward from Cape Hatteras (Emery and others, 1970, fig. 38), Tertiary beds on the shelf thicken gradually to about 1000 m near the shelf-slope break and then thin abruptly over the slope. At the foot of the slope, rather disturbed Tertiary beds are about 2000 m thick; they maintain this thickness for over 200 km oceanward. This continental rise sediment consists of turbidites, slumped material, and pelagic sediment; some of the latter rests directly on oceanic basement (Emery and others, 1970, fig. 22). In the late Franconian and Trempealeauan of Nevada, the shoal-water carbonate of the shelf is approx 540 m thick in the Egan Range (Cook and Taylor, 1977). Similar thicknesses are recorded for the contemporaneous Notch Peak Formation of Utah, farther to the east (Hintz, 1973). Along the continental slope the beds thin abruptly. Cook and Taylor (1977) observed only 130 m of beds of late Franconian and Trempealeauan age deposited in this environment near Tybo, in the Hot Creek Range. In contrast, the estimated thickness of the Harmony Formation is 1000 to 2000 m, and, in so far as is known, this thickness of sand and shale

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accumulated during the same time interval. We conclude that these beds of the Harmony Formation are broadly analogous with the Tertiary continental-rise sediment of the Atlantic margin of the United States, and that, like the latter, they have prograded oceanward over pelagic sediment.

Provenance.—Although there is general agreement on a granitic source for the sediments of the Harmony, there is less uniformity of opinion on the location of the source. Erickson and Marsh (1974a) have suggested a local origin from an uplift between the Sonoma Range and Battle Mountain. As Silberling (1975) noted, there are structural difficulties with this interpretation, and we find it difficult to reconcile with our understanding of the depositional regime. Stewart and Poole (1974) reviewed the possible sources for the Harmony and recognized several alternatives. One possible source of the material is from the west. Ketner (1977) has recently argued that the Harmony Formation, and indeed all the Lower Paleozoic western assemblage detrital rocks, were derived from this direction. He considered that this sediment came from an uplift in northwestern Nevada, an uplift that was initiated in Cambrian times and which subsequently migrated eastward. Ketner's model has several attractive features and offers ready explanation of some paradoxical aspects of sandy Ordovician units, but we find it difficult to reconcile with the available data for the Cambrian. There is no evidence of the needed granitic continental basement in this part of the state (Rogers and others, 1974), and furthermore, the Preble Formation is essentially devoid of feldspar, yet must have accumulated very close to the site of the proposed uplift. Two aspects of the faunal information do not fit readily with Ketner's model. The deep-water fauna on the continental slope at Tybo did not live in an infrashelf basin (Taylor and Cook, 1976). This *Hedinaspis-Charchaqia* fauna is part of the Chiangnan Faunal Province which is known from basinal assemblages from southern and northwestern China, South Korea, and eastern Alaska (Taylor, 1976). It is a deep-water oceanic fauna. The fauna of the Harmony Formation is derived (Stewart and Suczek, 1977), and its noncosmopolitan elements are all shallow-water North American taxa. It seems much more probable that these forms were transported from the North American continent rather than from an unknown westward source that was separated from the continent by deeper water off the continental slope (Taylor and Cook, 1976). We also find it difficult to accept that the material was derived from the east and transported westward across the shelf. Beds of Late Cambrian age are reasonably well known in eastern Nevada and western Utah, and they provide no indication of the presence of coarse feldspathic terrigenous detritus. The alternative that seems most attractive to us is a derivation from the north or northeast, as suggested by Palmer (1971) and Stewart and Suczek (1977): we consider that the source was probably a westerly extension of the craton in central, and possibly, western Idaho (fig.3).

PALEOGEOGRAPHY IN THE LATE CAMBRIAN

Available stratigraphic data in the northeastern Great Basin are consistent with the source area for the Harmony sands being in Idaho. Two mutually exclusive models of Cambrian paleogeography have been proposed for Idaho. In one of them, shallow seas are thought to have been present in a continuous broad sweep from southeastern Idaho into Washington (Lochman-Balk, 1970, 1972). The sediment deposited was subsequently largely removed by pre-Middle Ordovician erosion. The alternative model depicts a more complex situation in which a Cambrian land area existed in central and eastern Idaho (Ross, 1962). Armstrong (1975) has termed this uplifted region the Salmon River Arch (fig. 3); geographically it approximates the Devonian high area earlier called the Lemhi Arch by Sloss (1954). Armstrong (1975) has argued that it is a pre-Belt feature which remained a positive element throughout much of the lower Paleozoic. He considered it to have formed a northwesterly directed prong of the craton deflecting the inner margin of the miogeocline during Cambrian times. There is no doubt about the existence of small islands in southwest Montana during the Middle Cambrian (Robinson, 1963; Graham and Suttner, 1974), but the evidence for the Salmon River Arch as a positive feature in the Cambrian is still equivocal. Pre-Middle Ordovician uplift and erosion was undoubtedly extensive in Idaho (Scholten, 1957, 1960), but on balance, recent stratigraphic evidence suggests that the Cambrian was never deposited over much of the eastern and central part of the state. In this region, dated Cambrian rocks are known only from a small area near Clayton, where Middle Cambrian shale and siltstone overlie the Cash Creek Quartzite, which is feldspathic in its lower part (Hobbs, Hays, and Ross, 1968). We believe that this sand accumulated as near-shore sediment derived from the Salmon River Arch. In the southern Lemhi and Lost River ranges, on the southwestern flank of the Salmon River Arch, some of the rocks tentatively assigned to the Cambrian (Beutner and Scholten, 1967) have yielded a Lower Ordovician fauna (Ruppel, Ross, and Schleicher, 1975). These rocks lie with slight angular unconformity on the Wilbert Formation which is regarded as Precambrian Z. Further north, the Wilbert Formation is overstepped, and the Lower Ordovician rests on Precambrian Y (Ruppel, Ross, and Schleicher, 1975). We find it difficult to imagine that a normal miogeoclinal Cambrian sequence was deposited in this region and was entirely removed in earliest Ordovician times. The evidence, although not absolutely compelling, strongly supports the notion of a land area in east-central Idaho during the Cambrian and is consistent with Armstrong's (1975) Salmon River Arch. Further data corroborating the existence of the arch as a positive feature in Franconian time occur in northeast Utah and southeast Idaho. The Worm Creek Quartzite Member of the St. Charles Formation (Haynie. ms; Armstrong and Oriel. 1965) is feldspathic and locally an arkose. It is crossbedded and thickens markedly toward the north and northwest (Wakeley, 1975; Trimble and Carr, 1976). Presumably it was deposited by traction currents in a shallow-

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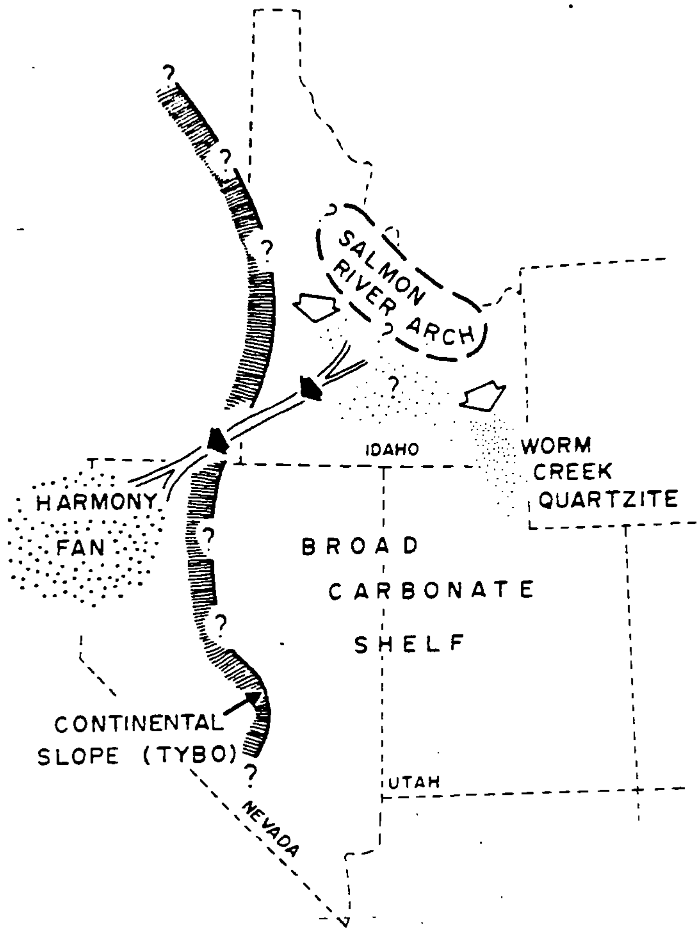

Fig. 3. Diagrammatic, nonpalinspastic reconstruction of major features of the paleogeography of the northern Great Basin in Franconian time, depicting inferred relationship of the Harmony Formation, Worm Creek Quartzite, and the Salmon River Arch. Open arrows, traction currents of the shelf dispersal system; solid arrows, turbidity currents.

water environment from a source area in this direction. If Armstrong (1975) was correct in his conclusion that some of the granite on the arch is perhaps 1500 m.y. and much older than the Idaho batholith, then the mineralogy of this region would be compatible with it being the source of both the Harmony sand and that of the Worm Creek Quartzite. It is conceivable, although less likely, that the source was itself a feldspathic sandstone on the arch.

Our views on the probable origin of the Harmony Formation are summarized diagramatically in figure 3. We imagine feldspathic sand from the granite of the Salmon River Arch being swept toward the south by tide-driven currents or longshore drift on the shelf and eventually being transported by gravity turbidity flows along a submarine canyon to accumulate on the middle fan of the continental rise. Present geographical distances would involve transportation in the order of 400 km, but extensive eastward movements have been suggested for both northeastern Nevada and east-central Idaho. In the latter area, displacements in the order of 160 km have been postulated (Harrison, Griggs, and Wells, 1974; Ruppel, 1975), and the Wells Fault of northern Nevada is considered to have dextral displacement on the order of 65 km (Thorman, 1970). Consequently, it is impossible to give realistic estimates of the distance between probable source and final depositional site.

CONCLUSIONS

The Paradise Valley Chert and Harmony Formation have commonly been regarded as younger than the Preble. Our understanding of their chronostratigraphic relationship is shown in figure 4. Part of the Preble is coeval with part of the Paradise Valley Chert. It is probable that its upper beds are contemporaneous with some or all of the Harmony Formation. The diagram shows the simplest successional relationship between the Harmony and the Paradise Valley Chert. Exposures are poor, and we recognize the possibility that these formations are in fault contact. We consider that the Preble Formation is essentially autochthonous and accumulated on the outer shelf and upper slope, whereas the Paradise Valley Chert and Harmony were deposited in deeper water of the continental rise–lower slope farther to the west. The Paradise Valley Chert is primarily a pelagic deposit, the Harmony a proximal turbidite. The arrival of the coarse terrigenous clastics of the Harmony Formation signified renewed uplift of the source region, which was probably the Salmon River Arch. This may have been accompanied by a change in the current pattern on the continental shelf to the south of the arch.

We consider it unlikely that the Paradise Valley Chert and the Harmony Formation are autochthonous. The nearest outcrops of the Preble Formation are only some 20 km from the chert. Steep slopes and rapid facies changes are possible in continental slope and rise environments, but we prefer another explanation in this case. The Paradise Valley Chert contains relatively small amounts of terrigenous silt and clay, yet shale is the dominant rock type in the Preble. We find it difficult to accept that the clay could be so effectively ponded in a distance of only a few kilometers. The alternative is that the Paradise Valley Chert and Harmony Formation were thrust from the west. We conclude that all the Harmony in the mountain ranges around Winnemucca and Battle Mountain is allochthonous. It is difficult to assess the minimum distance of tectonic transport of the Paradise Valley and Harmony. Sedimentological restraints would be satisfied if it were in the order of several tens of kilometers. We believe there are no convincing data to support the hypothesis that these formations are part of an obducted sequence derived from continents or island areas unrelated to North America. Our interpretation of the facies relationships in the Cambrian sequence of north-central Nevada leads us to conclude that these beds were all deposited along the margin of the North American continent.

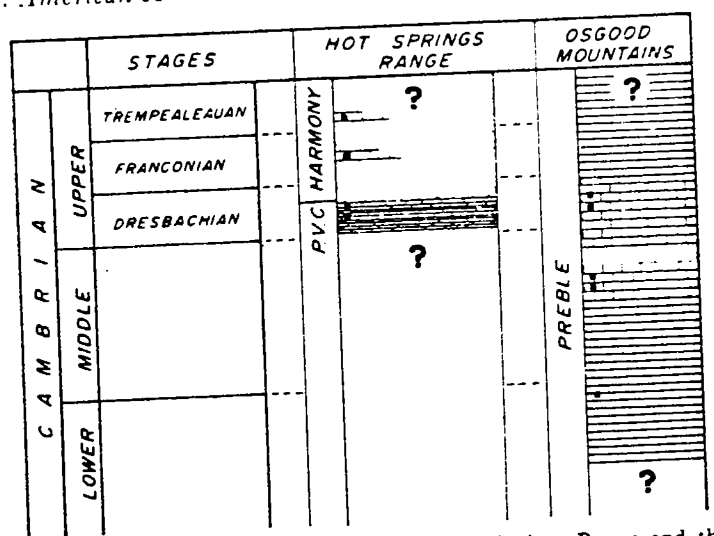

Fig. 4. Chronocorrelation of sequences in the Hot Springs Range and the Osgood Mountains. Black squares are approximate positions of faunal control. The queries beneath the base of the Paradise Valley Chert and Preble Formation signify uncertainty in the age of the base of the formations. The Preble Formation is underlain by the Osgood Mountain Quartzite. Sections not to scale.

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