DAVID BLOOM

FLYSCH DEPOSITS OF ANTLER FORELAND BASIN, WESTERN UNITED STATES

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ABSTRACT

In Late Devonian and Mississippian times, as much as 4500 m (15,000 ft) of well-bedded neritic and bathyal marine, flyschlike mudstone, siltstone, sandstone, conglomerate, and subordinate impure limestone was deposited in a subsiding, elongate, foreland basin (exogeosynclinal trough) on the continental shelf (Cordilleran miogeocline) east of the Antler orogenic belt and west of the cratonic platform. The term Antler flysch is applied to these Upper Devonian and Mississippian, and related Lower Pennsylvanian, homotaxial deposits that filled the Antler foreland basin in the western United States. The major source of siliceous flysch sediments in the foreland trough was terrigenous detritus derived from a rising cordillera to the west composed of strongly deformed Devonian and older oceanic rocks that during the Antler Orogeny was deformed and subsequently obducted eastward onto the outer carbonate shelf as the Roberts Mountains Allochthon. Significant amounts of westerly derived detritus in Upper Devonian deposits reflect early Antler orogenic activity along the continental margin. Recurring uplift of the cordillera followed Antler obduction, as indicated by the presence of chert and quartzite detritus derived from the allochthon in Mississippian and Pennsylvanian deposits of the foreland basin.

Continued orogenic compressive stress that was directed continentward during the Mississippian and Pennsylvanian resulted in a general eastward shift in sites of thick sedimentation. Near the end of Antler flysch deposition in Late Mississippian time, clastic sediments filled the foreland trough and spread eastward across the carbonate shelf onto the craton. Retarded subsidence of the foreland basin and significant decrease in volume of detritus from the reduced cordillera in latest Mississippian time are evidenced by widespread carbonate deposition in the Pennsylvanian.

Most of the flysch sediment within the foreland basin was deposited in a relatively deep-water trough by sediment gravity flows originating in relatively shallow water. Proximal and distal turbidites, debris-flow deposits, and hemipelagic deposits are recognized in the Antler flysch; these facies and their associations in the flysch trough indicate a complex system of submarine slope-fan-basin floor environments.

INTRODUCTION

This paper is concerned with one of the most significant flysch sequences in the western United States. The site of flysch deposition was a linear structural depression that developed in the Upper Devonian and Mississippian continental shelf owing to cratonward compression during Antler orogenic deformation along the western margin of North America. The linear depression is referred to as the Antler foreland basin or exogeosynclinal trough and is synonymous with exogeosyncline of Kay (1947, 1951). It was filled with as much as 4500 m (15,000 ft) of flysch sediment, and was flanked on the west by an orogenic highland and on the east by a carbonate shelf. Owing to the importance of Antler flysch in the interpretation of Upper Devonian and Mississippian sedimentation, paleogeography, and paleotectonics, some generalized results of field studies are presented in this paper in advance of a more detailed report.

The term "flysch" as used herein follows the definition proposed by Hsü (1970) and designates interbedded coarse and fine sediments deposited in a marine geosynclinal environment. Siliceous sediments predominate but impure lime sediments or calcareous flysch locally form a significant part. Although sedimentary structures are important in the recognition of flysch, they are not included in its definition. Turbidite and other sedimentary structures reflect modes of sediment transport and deposition but are not necessarily restricted to flysch basins. Tectonic framework has a direct effect on flysch sediments. In order to form a thick flysch sequence, a rapidly rising source area and a subsiding complementary basin or trough seem essential.

The term Antler flysch is used herein for Upper Devonian, Mississippian, and related Lower Pennsylvanian homotaxial flysch deposits that filled the Antler foreland basin or exogeosynclinal trough on the continental shelf or Cordilleran miogeocline cratonward of the Antler orogenic belt or highland in the western United States. Flysch deposits of the Antler foreland basin or exogeosynclinal trough in the western United States occur in a generally north-trending sinuous belt 160 to 320 km (100 to 200 mi) wide for a distance of about 1600 km (1000 mi), from southern California to northeastern Washington (fig. 1).

Available geologic information on the Cordil-

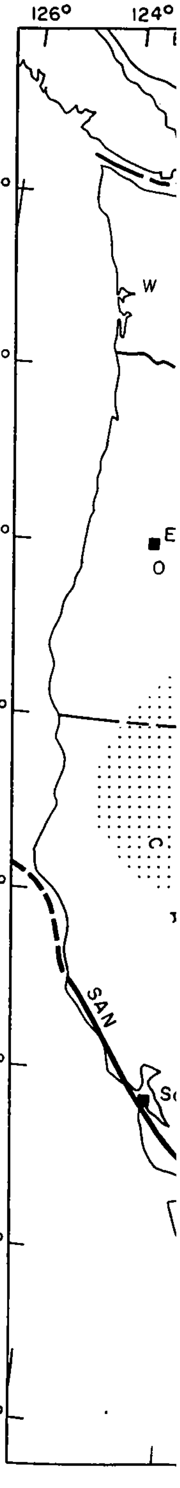

FIG. 1.—Index map
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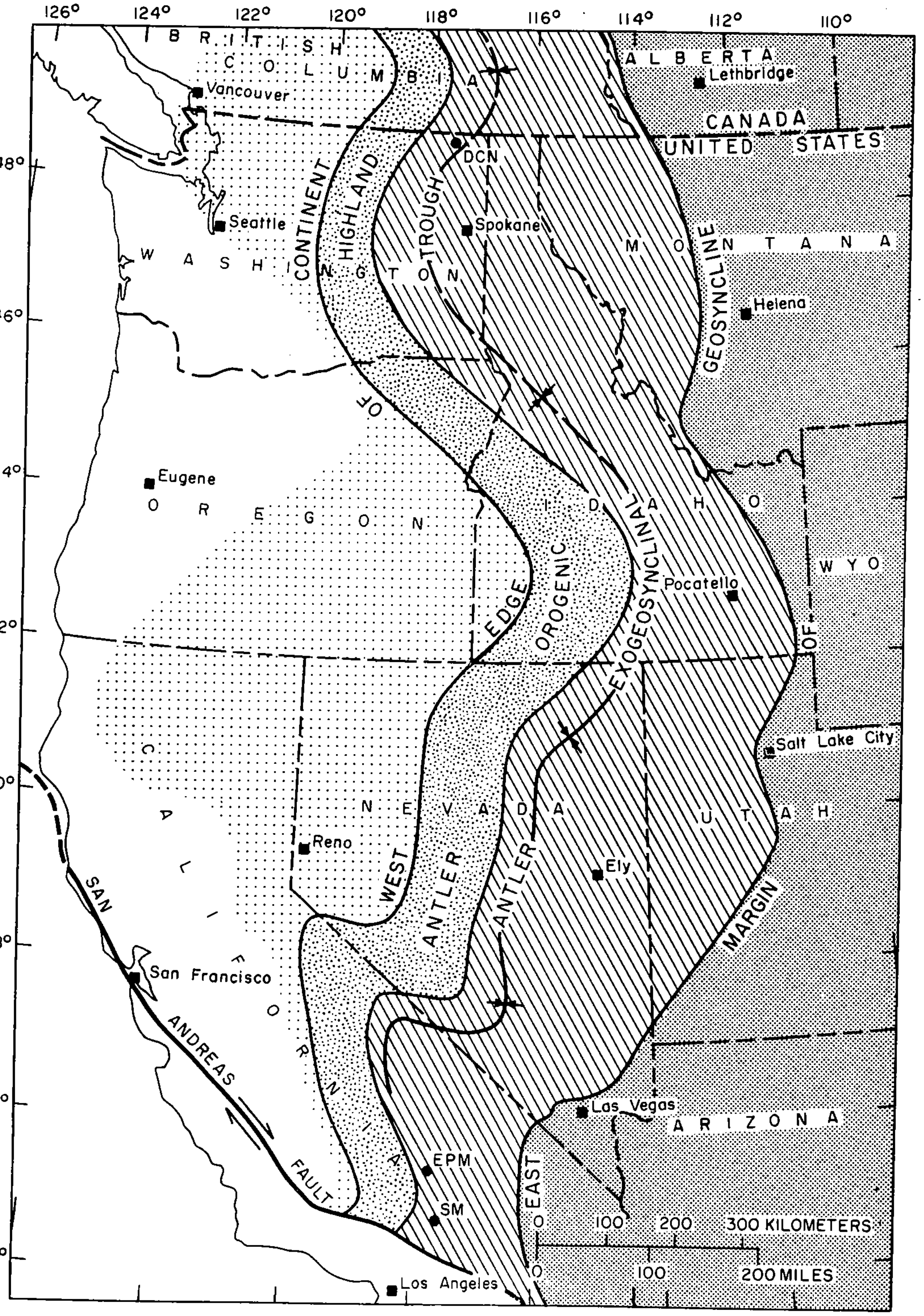

FIG. 1.—Index map of western United States showing Upper Devonian and Mississippian structural and depositional framework (partly restored). Cratonic platform in compact stippling; Devonian continental shelf in hatching and random stippling; oceanic area in diffuse stippling. Antler orogenic highland developed on outer continental shelf in latest Devonian time. SM, Shadow Mountains; EPM, El Paso Mountains; DCN, Deep Creek—Northport area.

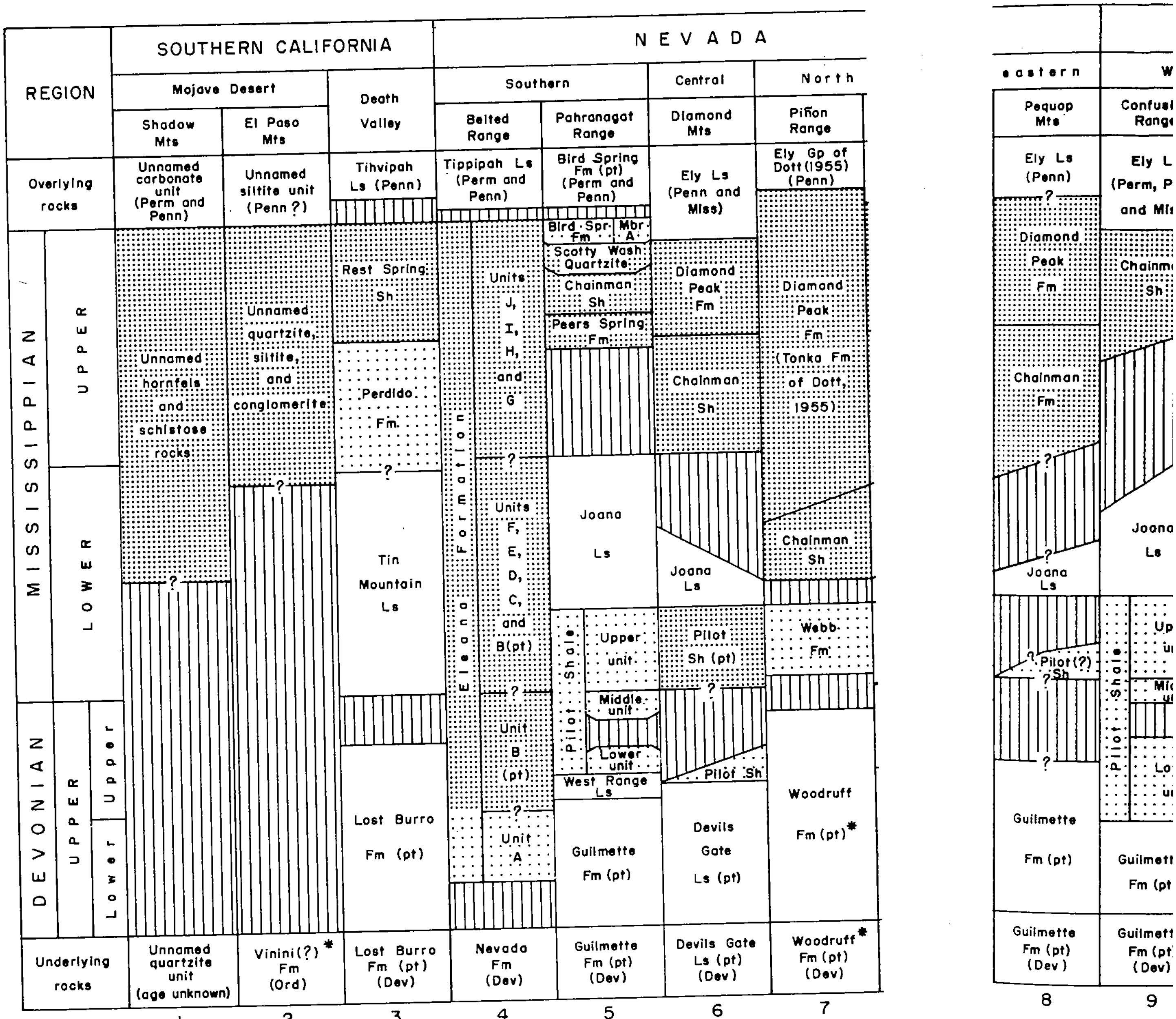

FIG. 2.—Generalized chart showing stratigraphic position and some local names applied to Antler flysch (stippled) and associated rocks in the western United States. Hatching indicates strata absent because of nondeposition or erosion. Compact stippling indicates that strata consist mostly of orogenic sediments; diffuse stippling indicates that strata consist of either minor orogenic sediments or mostly of reworked orogenic sediments. Asterisk (*) indicates allochthonous eugeosynclinal- and transitional-facies rocks in Roberts Mountains Allochthon. Sources of data: 1. Troxel and Gundersen (1970); F. G. Poole and J. H. Stewart (unpub. data); 2. Poole (unpub. data); 3. McAllister (1952); Mackenzie Gordon, Jr., and Poole (unpub. data); 4. Poole, Houser, and Orkild (1961); Poole, Orkild, Gordon, and Duncan (1965); Gordon and Poole (1968); Ekren, Anderson, Rogers, and Noble (1971); Poole and Gordon (unpub. data); 5. Reso (1963); Sandberg

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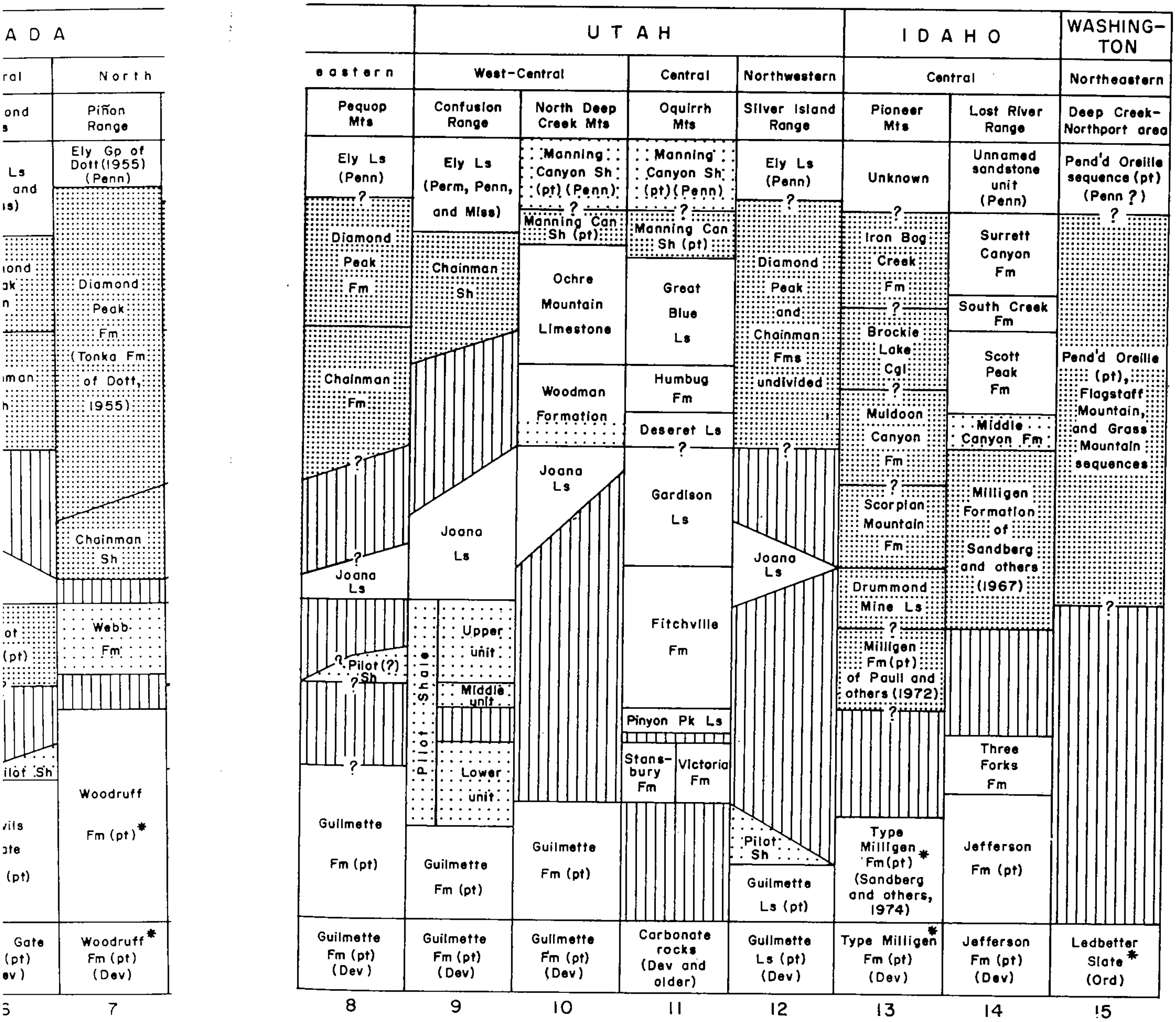

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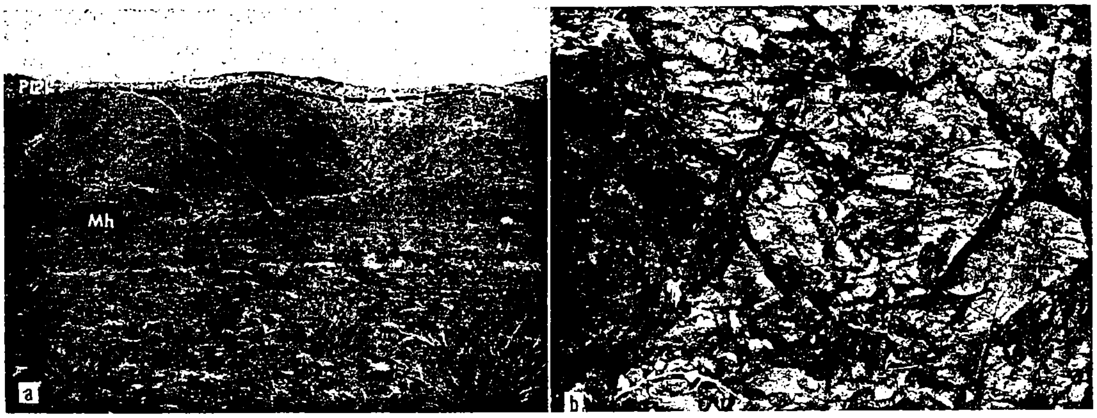

FIG. 3.—Unnamed flysch deposits in Shadow Mountains, southwestern Mojave Desert, southern California. *a*, Metamorphosed dark-colored flysch (mostly hornfels of Mississippian age, Mh) overlain by light-colored limestone (mostly calcite marble of Pennsylvanian and Permian age, PIPl). *b*, Tectonically stretched quartzite pebbles in a dark-colored conglomeratic quartzite bed within the "schistose rocks" map unit of Troxel and Gundersen (1970).

leran region of western Canada indicates that the Antler flysch belt continues from the Kootenay Arc area of southern British Columbia northwestward through British Columbia, and possibly into Yukon territory. In the southwestern United States the Antler flysch belt is truncated by the Cenozoic San Andreas fault in southern California (fig. 1). The flysch sequence has not been recognized in the Salinian structural block west of the San Andreas fault, and its absence indicates an offset of at least 650 km (400 mi) northwestward beyond the present continental margin.

Upper Devonian and Mississippian Antler flysch exposed in the western United States is known under many different formal and informal stratigraphic names (fig. 2, stippled units). Lithologic descriptions of several sedimentary units assigned to the Antler flysch may be found in the publications listed in sources of data for figure 2. Flysch deposits recently recognized in southern California and inferred in eastern Washington will be discussed briefly here because they are not described elsewhere in the literature.

Southernmost exposures of the Antler flysch occur in the western Mojave Desert of southern California. In the Shadow Mountains (fig. 1) northwest of Victorville, brown fine-grained and minor coarse-grained detrital sedimentary rocks herein assigned to the Antler flysch have been metamorphosed to hornfels, schist, and thin marbles (fig. 2, col. 1). This unnamed metamorphosed flysch sequence (fig. 3a), which is estimated to be a few thousand feet thick, was mapped as "hornfels" and "schistose rocks" by Troxel and Gundersen (1970). Tectonically stretched quartzite-pebble conglomerates (fig. 3b) occur in some thin units of coarse-grained flysch. Overlying the flysch sequence is a thick succession of metamorphosed carbonate rocks (fig. 3a) that are similar in lithology to the Bird Spring Formation (Permian and Pennsylvanian) of the southern Great Basin. In the northwestern Mojave Desert, a fine- to coarse-grained flysch sequence as much as 1,500 feet thick occurs within the Garlock Formation (Dibblee, 1967; formerly the Garlock Series of Dibblee, 1952) in the El Paso Mountains (fig. 1). This flysch consists of brown interbedded quartzite and siltite and subordinate argillite and conglomerite (fig. 4) that is correlative with the Antler flysch (fig. 2, col. 2). The flysch sequence overlies strongly deformed Ordovician oceanic rocks provisionally assigned to the Roberts Mountains Allochthon.

Northernmost exposures of the Antler flysch in the western United States occur in the Deep Creek-Northport area of northeastern Washington (fig. 1). In this area, dark-gray to black argillite and subordinate siltite, quartzite, impure limestone, and conglomerate were grouped into major rock units and referred to informally as Grass Mountain, Flagstaff Mountain, and Pend 'd Oreille sequences by Yates (1964, 1971); they were provisionally assigned to the Carboniferous (fig. 2, col. 15). The Grass Mountain, Flagstaff Mountain, and part of the Pend 'd Oreille sequences seem to be flyschlike in character and herein are provisionally considered to represent Antler flysch.

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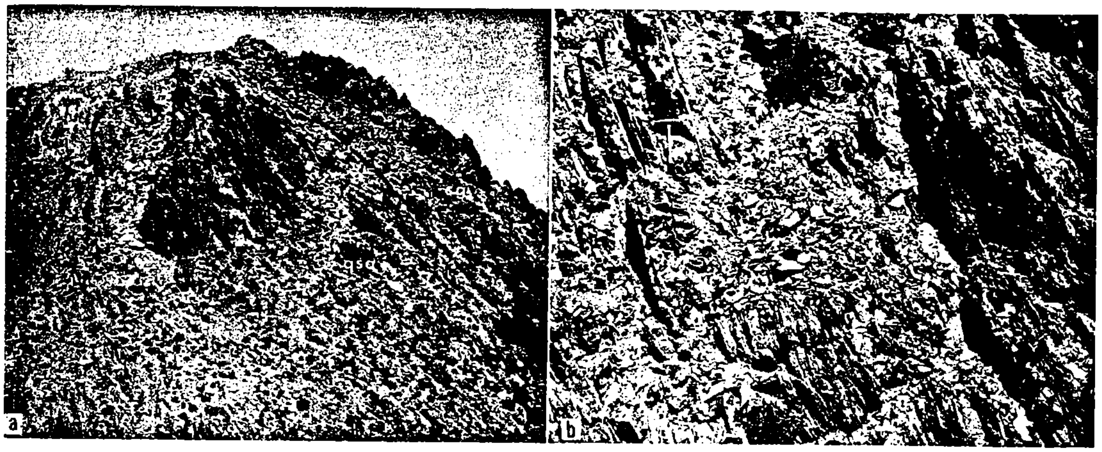


FIG. 4.—Unnamed flysch deposits in El Paso Mountains, northwestern Mojave Desert, southern California. *a,* Cyclically interbedded quartzite, siltite, and argillite unit (qsa) overlain by chert-pebble conglomerite (cg). Ledge-forming conglomerite unit is about 7.5 m (25 ft) thick. *b,* Closeup of cyclical unit showing thin turbidite beds of quartzite-siltite (hammer on one of thicker beds) separated by interturbidite beds of laminated argillite-siltite.

GEOLOGIC SETTING

Figure 1 shows the structural and depositional framework for the Upper Devonian and Mississippian Antler flysch in the western United States, based on both present and restored facies distributions. The Devonian miogeosyncline or continental shelf extended from the outer edge of the craton or stable platform (compact stippling) westward to the outer edge of the continent. The synclinal axis depicted on the continental shelf, in front of the Antler orogenic highland, represents the axial trace of the Antler foreland basin or exogeosyncline.

The snakelike bending of the Antler orogenic highland and exogeosynclinal trough is believed to be mainly the result of Mesozoic and Cenozoic oroflexural bending. The prominent bending along the California-Nevada state line is clearly oroflexural bending related to the Walker Lane dextral strike-slip structural zone. Prominent eastward bending of Antler structural and depositional features in northeastern Nevada and southwestern and central Idaho is believed to be due mainly to large-scale oroflexural bending and overthrusting (see Stewart and Poole, this volume). Some of the curvature of the highland may reflect the configuration of the Paleozoic continental edge.

The Antler orogenic belt and exogeosynclinal trough, where they trend northwesterly between central Idaho and central Washington, coincide approximately with two regional lineaments known as the Trans-Idaho Discontinuity (Yates, 1968) and the Olympic-Wallowa Lineament (Raisz, 1945; Wise, 1963; and Skehan, 1965). The Trans-Idaho Discontinuity has been interpreted by Yates (1968) and Jones, Irwin, and Ovenshine (1972) as a northwest-trending sinistral transcurrent fault zone. The subparallel Olympic-Wallowa Lineament, which is located 75–150 km (50–100 mi) farther southwest and which trends northwest from west-central Idaho through northeastern Oregon into west-central Washington, also has been interpreted by many geologists as a sinistral strike-slip fault and by Skehan (1965) as the surface expression of a deep crustal boundary reflecting the change from continental crust on the northeast to oceanic crust on the southwest. The Olympic-Wallowa Lineament nearly coincides with a segment of the inferred western edge of the middle Paleozoic continent shown in figure 1.

FLYSCH SEDIMENTATION

The axial portion of the Antler foreland basin contains a flysch sequence whose thickness is generally 1500 to 3000 m (5000 to 10,000 ft) but locally is in excess of 4500 m (15,000 ft). Lithologic sequences and thicknesses vary areally, indicating a complex system of submarine fan and basin floor environments. Sedimentary features within the flysch sequence provide insight into provenance, mechanisms of sediment transport, and environments of deposition.

Lithology and Provenance

The Antler flysch is composed principally of (1) hemipelagic mudstones, siltstones, and minor limestones; (2) turbidite sandstones, siltstones, and minor conglomerates and limestones; (3) massive, ungraded to poorly graded (disorganized) conglomerates and pebbly sandstones; and (4) crudely stratified, graded (organized) conglomerates and pebbly sandstones. Generally mudstone and siltstone are more abundant than sandstone, but at certain intervals sandstone and conglomerate or limestone beds dominate.

Shaly mudstone and fine-grained siltstone units, randomly distributed in the flysch succession and intercalated cyclically between turbidite beds, probably represent fine sediment that was introduced into the flysch basin by density currents and then deposited from dilute suspension. These mudstones and siltstones generally contain horizontal meandering trails that belong to Seilacher's (1964) *Nereites*-facies. Many black mudstones, siltstones, and certain impure limestones contain as much as a few percent organic carbon and disseminated pyrite or marcasite that suggest an environment of restricted circulation in these parts of the flysch basin. These hemipelagic and low-density turbidity current deposits are similar to facies G of Walker and Mutti (1973).

Most thin-bedded sandstones, conglomerates, coarse-grained siltstones, and detrital limestones in the flysch succession contain sedimentary structures characteristic of turbidites described by Bouma (1962), Walker (1967), and other workers. An outcrop of siliceous fine-grained flysch near the axis of the Antler foreland basin seen in figure 5a is a sequence of cyclical sandstone and siltstone turbidites and mudstone interturbidites in the Chainman Shale (Upper Mississippian) in central Nevada. Generally, the silt and sand grains in the flysch are composed of quartz, chert, and quartzite. Sparse sand-sized grains of feldspar have been seen in some thin sections of siliceous flysch rocks. Many graded conglomerate, sandstone and limestone beds contain displaced fossil fragments of shallow-water organisms. An outcrop of calcareous fine-grained flysch near the axis of the Antler foreland basin seen in figure 5b is a sequence of cyclical impure limestone turbidites and spicular limestone interturbidites in the Drummond Mine Limestone (Lower Mississippian) of Paull and others (1972) in central Idaho.

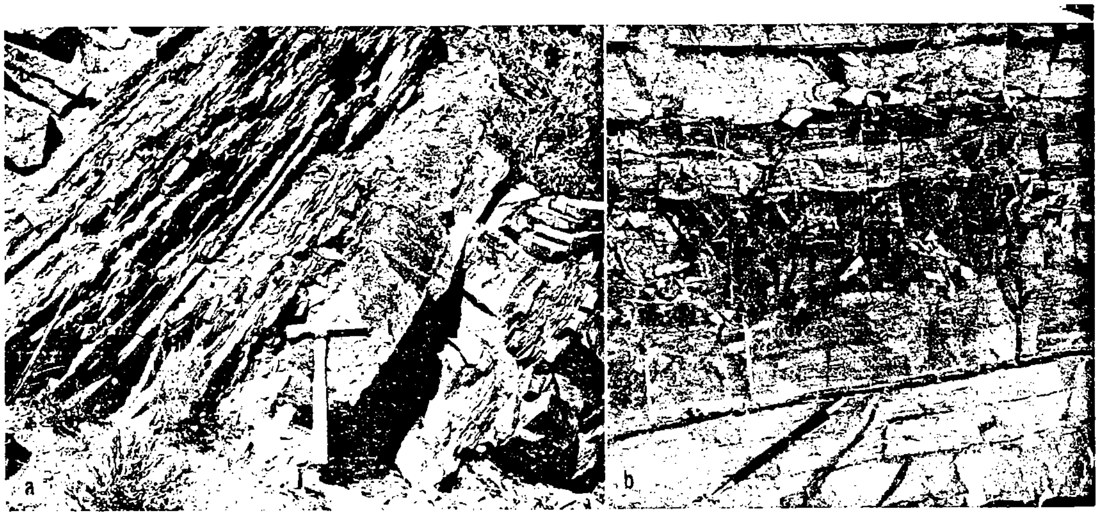
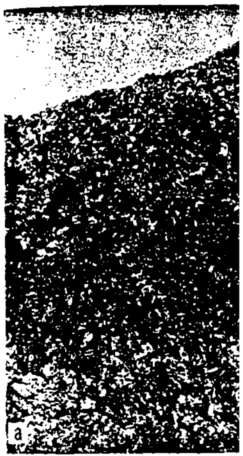


FIG. 5.—Lithology and bedding features of turbidite sequences in fine-grained flysch. *a,* Interbedded sandstone to coarse-grained siltstone turbidites (ledges) and mudstone interturbidites (recesses) of siliceous basinal flysch in the lower part of the Chainman Shale, Diamond Mountains, central Nevada; hammer is on a sandstone turbidite bed; stratigraphic top is to the right (overturned section). *b,* Interbedded impure limestone turbidites (dark-colored interval above pencil) and light-colored spicular limestone interturbidites of calcareous flysch in the lower part of the Drummond Mine Limestone, Pioneer Mountains, central Idaho.

Gravels in conglomerate, conglomeratic sandstone, siltstone, and mudstone generally are composed of subrounded to rounded chert, quartzite, and sparse limestone or dolomite, and of angular to subrounded intraformational "rip-up" clasts of argillite and siltite. Most gravels are of pebble to small cobble size, but locally sparse boulders are conspicuous. Outcrops of siliceous coarse-grained flysch deposits along the west margin of the Antler foreland basin are shown in figure 6. These coarse-grained flysch deposits occur within a southeast-trending submarine channel about 300 m (1000 ft) wide and 150 m (500 ft) deep at the base of the Diamond Peak Formation in north-central Nevada. Figure 6a shows a massi



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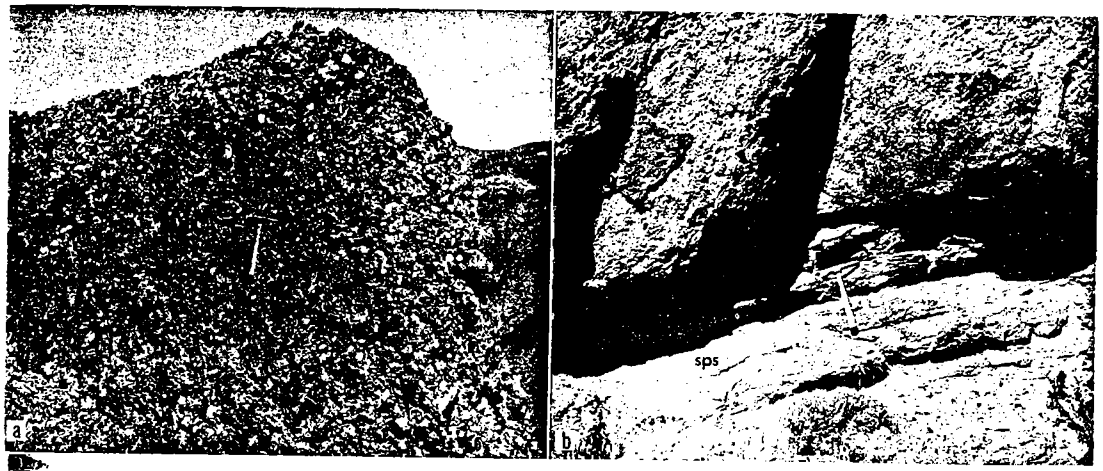

FIG. 6.—Lithology and bedding features of coarse-grained flysch debris-flow deposits in a submarine channel in the lower part of the Diamond Peak Formation, Piñon Range, north-central Nevada. *a*, Massive gravelflow conglomerate composed of quartzite and chert clasts. *b*, Bedded sandstone and pebbly sandstone units (sps) overlain by scouring massive conglomeratic sandstone (cgs).

ure 6a shows a massive disorganized gravelflow conglomerate in the lower medial part of the channelfill and figure 6b shows a bedded sandstone and pebbly sandstone unit overlain by a scouring massive disorganized conglomeratic sandstone in the upper medial part of the channelfill. An isolated rounded quartzite boulder 1 m (3 ft) across was seen in the coarse conglomerate unit pictured in figure 6a. Some pebbly mudstone-siltstone units also occur locally in the Antler flysch.

The major source of siliceous flysch sediments in the Antler foreland basin was terrigenous detritus derived from a rising cordillera to the west. Chert and quartzite detritus in the flysch deposits is similar to Devonian and older eugeosynclinal cherts and quartzites in the Roberts Mountains Allochthon exposed along the Antler orogenic belt. A general easterly decrease of grain size and coarse/fine sediment ratio in the siliceous flysch sequence also indicates that detritus was shed toward the craton from lands to the west.

The major source of calcareous flysch sediments in Lower Mississippian (Kinderhookian) limestone turbidite sequences—such as the Camp Creek sequence of Ketner (1970) and the correlative Tripon Pass Limestone of Oversby (1973) in northeastern Nevada, and the Drummond Mine Limestone of Paull and others (1972) in central Idaho—was limestone detritus probably derived mainly from the west edge of the shallow-water carbonate shelf or bank near the eastern margin of the Antler foreland basin. Current sole marks suggest a southwest direction of transport for the Camp Creek limestone turbidites (Ketner, 1970). Paleocurrent directions have not been determined from the turbidite sequences in the Tripon Pass and Drummond Mine Limestones.

Sedimentary Structures and Sediment Transport

"Bouma sequences" of internal sedimentary structures in thin-bedded sandstones, conglomerates, siltstones, and limestones, displaced shallow-water organisms in graded beds, and sole markings indicate that turbidity currents were an important process for relatively deep-water sedimentation in the Antler foreland basin. Bouma (1962) defined a complete turbidite as one which contains a graded division (A), lower division of parallel lamination (B), division of current ripple lamination and/or convolute lamination (C), upper division of parallel lamination (D), and pelitic division (E). Some turbidites of the Antler flysch contain divisions A-D of the ideal Bouma sequence (fig. 7a); however, most turbidites examined contain an incomplete Bouma sequence beginning with division B or C (fig. 8). Interturbidite pelitic division E usually occurs between major turbidite sequences. Figure 7 shows examples of complete Bouma sequences of sedimentary structures in sandstone and limestone turbidites; figure 7a represents a sandstone turbidite (A-D) and 7b represents a limestone turbidite (A-D). The specimen pictured in 7b is from the lower unit of the Pilot Shale, which is believed to contain a significant amount of early flysch. Figure 8 shows examples of incomplete Bouma sequences of sedimentary structures in sandstone and impure limestone turbidites; figure 8a repre-

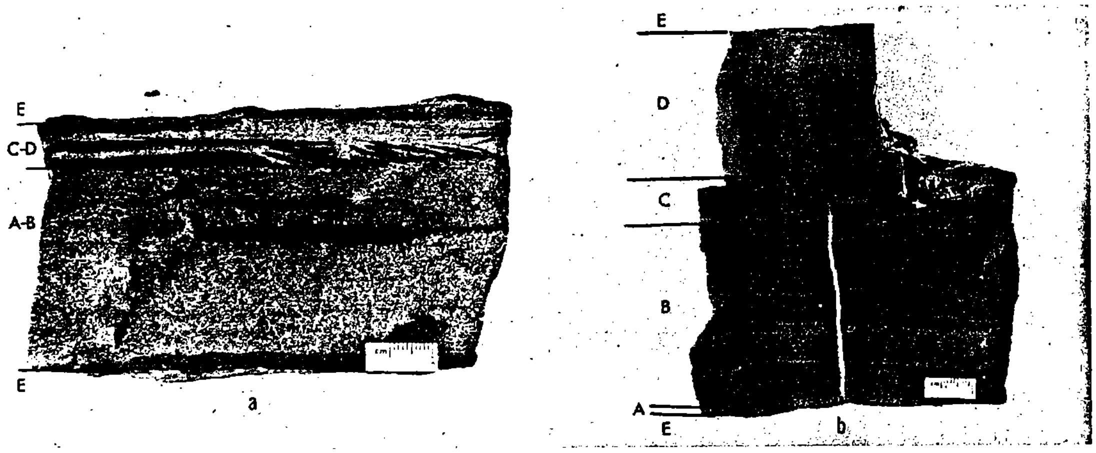

FIG. 7.—Internal structure of proximal turbidite beds showing complete Bouma sequences. *a,* Specimen of coarse to fine sandstone turbidite sequence showing graded and horizontal laminae of divisions A and B, current ripple laminae of division C and parallel laminae of division D, and interturbidite pelitic division E with meandering trails of *Nereites* community; dark-gray areas are iron oxide stains; specimen from Chainman Formation, Pequop Mountains, northeastern Nevada. *b,* Specimen of impure limestone turbidite sequence showing graded thin sandy layer of division A, horizontal laminae of division B, current ripple laminae and minor convolute laminae of division C, and upper parallel laminae of division D; interturbidite shaly calcsiltite of division E (not attached to specimen) contains styliolinids and tentaculitids; specimen from lower unit of Pilot Shale, Leppy Range, Nevada, near Utah State line.

sents a sandstone turbidite (B-D) and 8b represents two amalgamated calcarenitic sandstone-siltstone turbidites (B-D underlain by C). Interturbidite mudstones and siltstones of Bouma division E shown in figure 7a contain meandering trails of the *Nereites* community and those shown in figure 7b, styliolinids and tentaculitids.

Many sandstone turbidites contain sole markings including scour marks (mainly flute casts) and tool marks (mainly groove casts). Figure 9 illustrates two current structures commonly found as sole marks on sandstone beds in unit C of the Eleana Formation in southern Nevada. These flute and groove casts occur on the lower parallel laminated division B of incomplete Bouma sequences.

Many chert-pebble and quartzite-pebble conglomerates and pebbly sandstones are stratified and show grading with clast orientation and imbrication. These organized conglomerates and pebbly sandstones are similar to facies A2 and A4 of Walker and Mutti (1973).

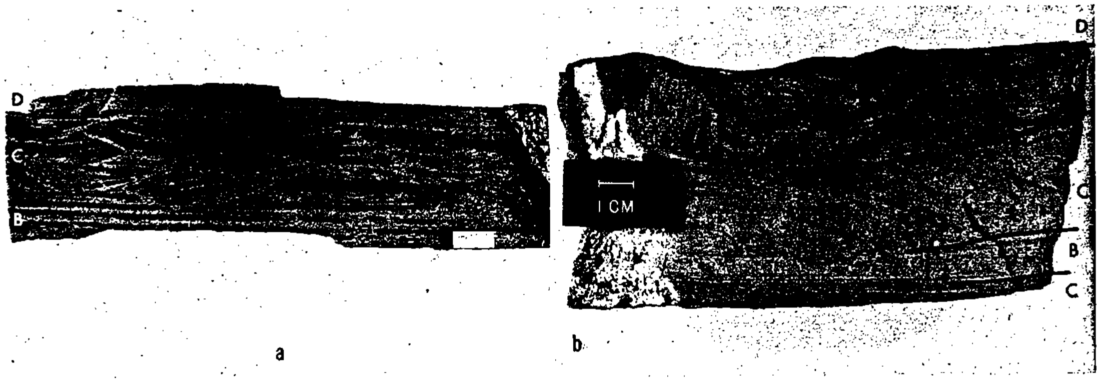

FIG. 8.—Internal structure of distal turbidite beds showing incomplete Bouma sequences. *a,* Polished slab of sandstone turbidite showing horizontal parallel laminae of division B, current ripple laminae of division C, and upper parallel laminae of division D; specimen from unit C of Eleana Formation, Belted Range, south-central Nevada. *b,* Specimen of amalgamated limy sandstone-siltstone turbidite sequences showing current ripple laminae of division C directly overlain by horizontal parallel laminae of division B, current ripple laminae, wavy and convoluted laminae of division C, and thin upper parallel laminae of division D; specimen from base of Scorpion Mountain Formation, Pioneer Mountains, central Idaho.

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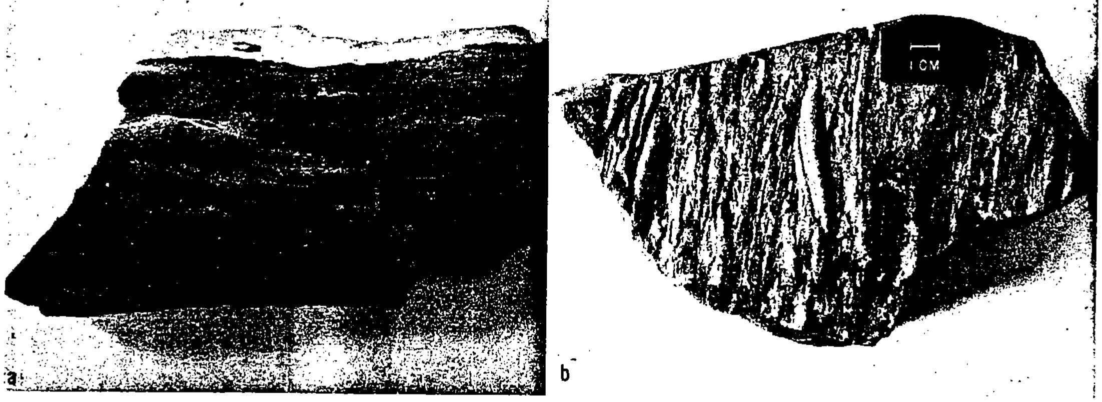

FIG. 9.—Current sole markings on lower parallel laminated distal turbidite sandstone of incomplete Bouma sequence; specimens from unit C of Eleana Formation, Belted Range, south-central Nevada. *a,* Flute casts. Arrow indicates current direction. *b,* Striation and groove casts.

Thick sandstones and conglomerates show sedimentary structures different from those within the thin-bedded sandstones of the flysch succession where it is dominated by mudstone and siltstone. The Bouma sequence is not applicable to disorganized and many organized conglomerates and pebbly coarse-grained sandstones. Many thick conglomerates (fig. 6a) and pebbly sandstones (fig. 6b) along the west margin of the Antler foreland basin are massive to irregularly bedded, commonly scoured, and ungraded to poorly graded. These disorganized conglomerates and pebbly sandstones are similar to facies A1 and A3 of Walker and Mutti (1973).

Several transport mechanisms can be inferred for the coarse- and fine-grained flysch sediments filling the Antler foreland basin. Most of the sediments in the flysch trough are believed to have been transported by sediment gravity flows (Middleton and Hampton, 1973), mainly debris flows and density currents, that moved sediment from shallow-water environments flanking the foreland basin to deep-water environments forming a foreland trough in the axial portion.

Internal sedimentary structures and sole markings of many thin beds of sandstone, coarse-grained siltstone, and detrital limestone indicate deposition by turbidity currents. Bouma (1962) and Walker (1967) have pointed out that turbidites which begin with division B or higher divisions represent more distal deposition than those which begin with division A. Walker (1967) studied the variability of turbidite sequences in several formations and related them to the flow regimes of depositing currents. He described several differences between proximal and distal turbidity-current flow. Bouma and Hollister (1973) defined proximal turbidites as turbidites that initially result from high flow regime conditions, whereas distal turbidites are totally deposited under low flow regime conditions. They emphasized the fact that varying conditions may force one current to travel far into a basin before significant deposition begins, while another current may lack the properties to travel very far. Consequently, some distal turbidites may be deposited near the source, whereas some larger flows may deposit a proximal turbidite far into the basin; however, it seems logical to expect more proximal turbidites nearer the source.

The thick-bedded pebbly sandstones and conglomerates may have been deposited by a mechanism differing from a turbidity current. Many beds are massive and contain sedimentary structures different from those in the thin-bedded sandstones. Some of these massive sandstones and conglomerates exhibit features comparable to debris flows in modern submarine channels described by Normark (1970), Haner (1971), Nelson and Kulm (1973), and other workers. Thick, poorly graded gravels, sands, and pebbly sands are common deposits in submarine canyons, and in channels incised into the upper part of submarine fans (Haner, 1971). Hampton (1972) has suggested that turbidity currents may originate from submarine landslides and debris flows by incorporation of water and sufficient agitation.

Unsorted pebbly and cobbly mudstones and siltstones occur locally in the flysch succession in the Antler foreland basin. Such rocks may have originated from rapid deposition of sand and gravel on top of water-saturated mud (Crowell, 1957) that subsequently moved downslope forming a chaotic mixture of mud, sand, and gravel; they belong to facies F of Walker and Mutti (1973). These deposits, which reflect unstable slope conditions, are common locally in the Antler flysch along the western margin of the foreland basin.

Fossils and Paleoecology

Fossil animals and plants in the flysch succession provide important clues regarding depositional environments and bathymetry in the Antler foreland basin. The most common fossils in the fine-grained siliceous and calcareous Antler flysch are meandering indigenous grazing trails and displaced fragments of shallow-marine invertebrates and vascular land plants. Most of the meandering trails (fig. 10) belong to the *Nereites*-facies or community described by Seilacher (1964, 1967) and, according to him, indicate a deep-water marine environment. Meandering trails of the *Nereites* community are confined to nonturbidite mudstones, siltstones, and impure limestones; they are especially common in pelitic units between major turbidite sequences. Sparse horizontal *Scalarituba* trails (fig. 10f) and *Zoophycos* burrows occur in some flysch units. Various land plant fragments (fig. 11) occur sparingly to commonly in both fine and coarse detrital sediments in the flysch basin. These plants are abraded and commonly show a preferred orientation; they obviously were washed into the marine basin from a land area, presumably the Antler mountainous terrane to the west. Local concentrations of plant debris have produced some thin layers of carbonized wood and sparse thin seams of coaly material.

Although meandering trails of the *Nereites* community, siliceous sponge spicules, and radiolarian tests suggest bathyal marine environments, neritic marine environments in other parts of the flysch basin are evidenced by the local abundance of shallow-water benthonic fauna containing pelmatozoans, bryozoans, brachiopods, pelecypods, trilobites, and corals. Shallow-water marine invertebrates and land plants occur sparingly in fine- to coarse-grained siliceous and calcareous flysch sediments, but commonly it can be demonstrated sedimentologically that they were transported into deeper water by wave action and density currents. The occurrence of invertebrate fossils in sandstone and limestone turbidites intercalated with mudstones and siltstones containing indigenous meandering trails of *Nereites* community indicates that the invertebrates were transported by density currents from their shallow-water living sites. Most land plants found in the Antler flysch are believed to have floated basinward, where they became waterlogged, sank, and became incorporated in the flysch succession. Many plants in the flysch basin may have been redistributed by sediment gravity flows.

Summary of Depositional Environments

Much of the flysch sediment within the Antler foreland basin was deposited in deep water by turbid flows originating in relatively shallow water. Proximal and distal turbidites, debris-flow deposits, and hemipelagic deposits are recognized in the flysch sequence. Alluvial and deltaic environments must have occurred along the eastern margin of the Antler highland; however, deposits characteristic of these environments have not been positively identified.

Many shaly mudstone- and siltstone-dominated sections in the medial portion of the Antler foreland basin contain both distal and proximal turbidite sequences comparable to modern middle and outer submarine fan deposits and basin plain deposits.

Sedimentary features of thick sandstones, pebbly sandstones, and ungraded to poorly graded conglomerates along the western margin of the Antler foreland basin indicate deposition as debris flows resembling those found in modern submarine canyons and in channels of modern submarine inner fans and channels incised into middle fans. Some thin beds of coarse-grained sandstone, conglomeratic sandstone, and organized conglomerate associated with fine-grained flysch facies in the medial part of the foreland basin may represent deposits in submarine inner fan and middle fan systems.

Many shaly mudstone, fine-grained siltstone, and micritic limestone units in the foreland basin are inferred to represent very fine-grained sediment deposited from dilute suspension. Most of the mud may have entered suspension through turbulence associated with turbidity current movement and then was deposited by normal hemipelagic sedimentation. These fine-grained flysch units commonly contain horizontal meandering trails assignable to the *Nereites*-facies indicative of a quiet, bathyal environment.

Antler flysch turbidite facies and facies associations indicate that debris flows and turbidity currents originating in coastal waters near the west margin of the Antler foreland basin adjacent to the highland flowed eastward down

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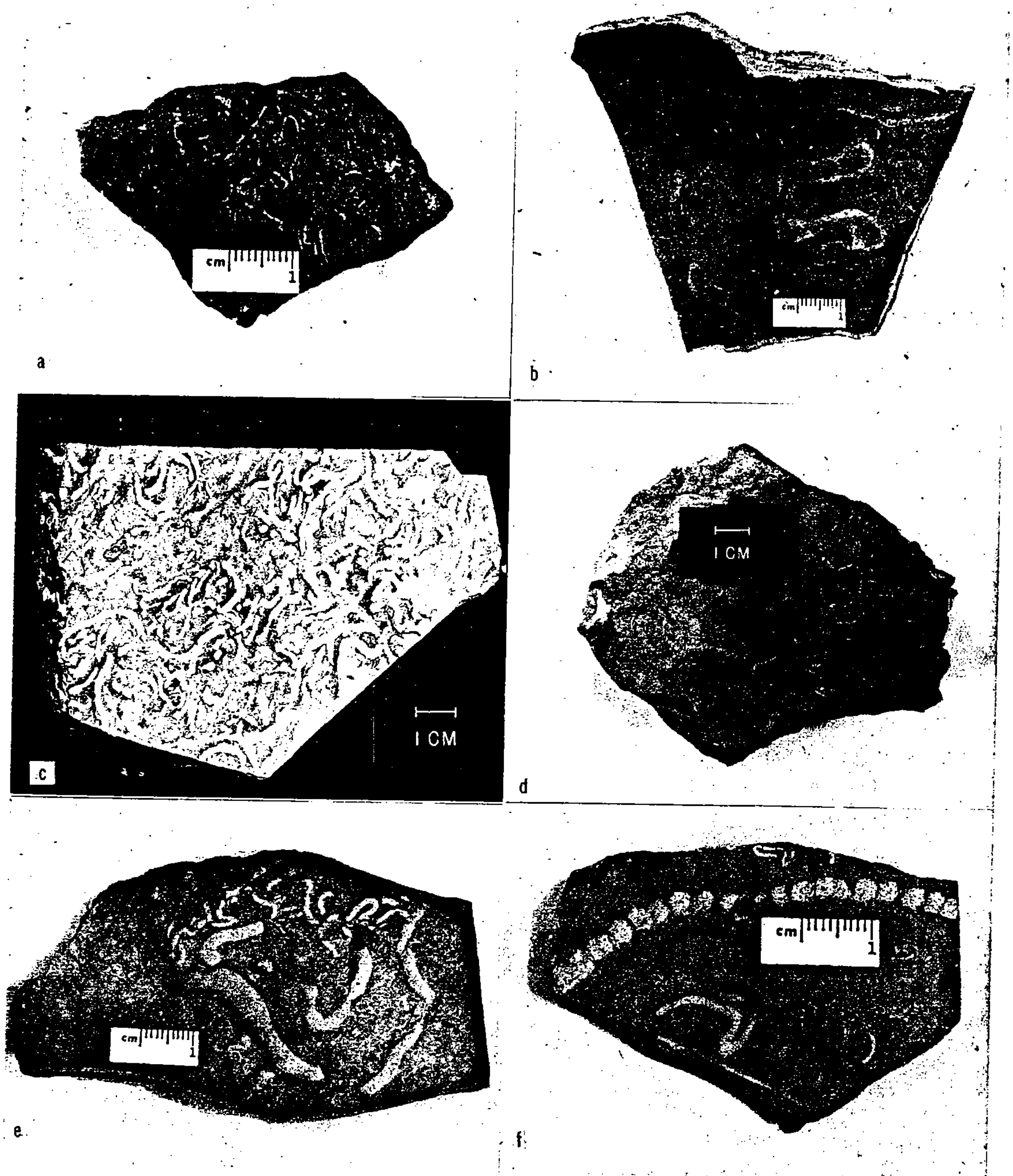


FIG. 10.—Indigenous meandering trails of *Nereites* community in hemipelagic mudstone and siltstone (division E of Bouma sequence) between sandstone turbidites. *a,* Meandering trails in Muldoon Canyon Formation, Pioneer Mountains, central Idaho. *b,* Meandering trails and small fragments of macerated plant debris in Milligen Formation of Sandberg and others (1967), Lost River Range, central Idaho. *c,* Meandering trails in Chainman Formation, Pequop Mountains, northeastern Nevada. *d,* Meandering trails in unit D of Eleana Formation, Belted Range, south-central Nevada. *e,* Narrow and wide meandering trails in Diamond Peak Formation, Diamond Mountains, central Nevada. *f,* Meandering trails and segmented trail (*Scalarituba?*) in basal beds of Scorpion Mountain Formation, Pioneer Mountains, central Idaho.

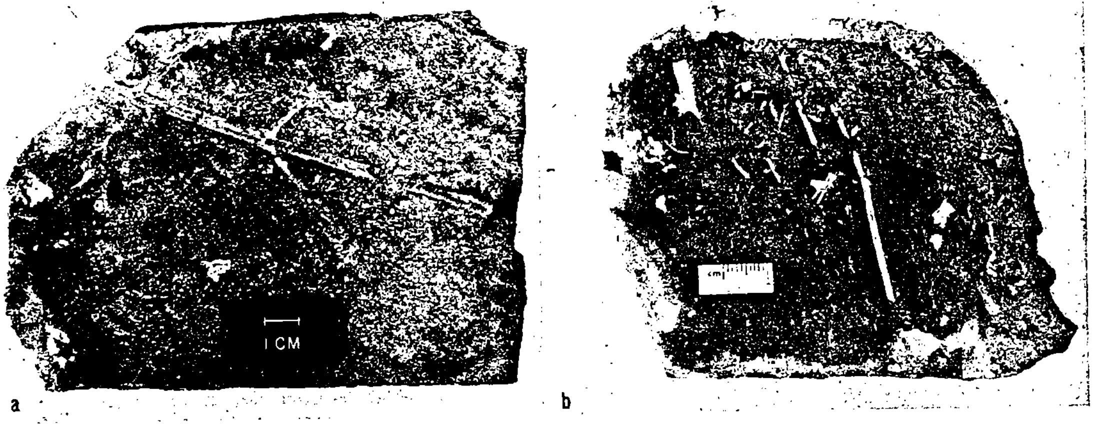


FIG. 11.—Displaced land plants in marine siltstone of Milligen Formation of Sandberg and others (1967), Lost River Range, central Idaho. *a*, Bedding surface showing relatively large stem with some branch attachments and small fragments of macerated plant debris. *b*, Bedding surface showing abraded stems with preferred orientation and macerated plant debris.

the basin slope into bathyal waters of the basin floor. Also, some turbidity currents originating near the east margin of the Antler foreland basin at the outer (west) edge of the shallow-water carbonate shelf or bank flowed westward down the basin slope into deep water of the basin floor. In both cases, the turbidity currents probably were diverted on the basin floor and flowed parallel to the basin axis, a possibility suggested by a few directional measurements on current structures in distal turbidites.

Near the end of Antler flysch deposition, clastic sediments filled the foreland trough and spread eastward across the carbonate shelf onto the cratonic platform. During this final infilling stage, shallow neritic environments above storm-wave base dominated the foreland basin and carbonate shelf areas resulting in the reworking of younger flysch and carbonate deposits. Finally, due to retarded subsidence of the foreland basin and significant decrease in volume of detritus shed from the reduced highland, widespread shallow-water carbonate deposition prevailed in the area of the former foreland trough and expanded westward onto the subdued highland.

REGIONAL DEPOSITIONAL PATTERNS

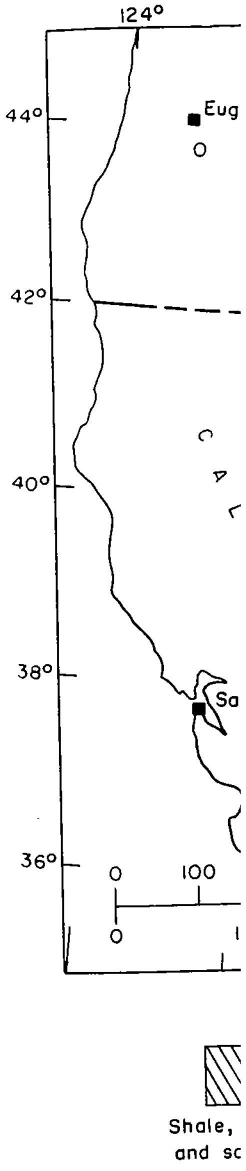
Generalized isopach and facies maps of the lower Upper Devonian, upper Upper Devonian, Lower Mississippian, and Upper Mississippian reveal important features in the evolutionary development and character of the flysch basin.

Lower Upper Devonian

The isopach and facies map of the lower Upper Devonian (fig. 12) delineates areas of thinning and thickening associated with ancestral ridges and furrows on the continental shelf that were mostly inherited from older trends. The Uinta uplift in northern Utah was a major positive area at the end of early Late Devonian time. Most of the quartz sand in the limestone and sandstone units on the inner shelf was derived from older quartzites exposed on the craton to the east, whereas the shale and siltstone deposits near the continental edge (fig. 12, open hatching) may represent fine detritus from areas of uplift along the continental margin in addition to normal continental rise sediments transported seaward from cratonic uplifts. In the southeastern part of the map the open-hatched area represents sandstone, siltstone, and shale deposits in an intracratonic basin.

Figure 13 shows an outcrop of cliff-forming Devils Gate Limestone in central Nevada that represents typical shallow-water limestone deposits on the continental shelf near the west edge of the limestone and sandy limestone area (diffuse stippling) shown on the map.

Figure 14 shows an outcrop of slope-forming Pilot Shale in northeastern Nevada that represents limy siltstone deposits in an incipient flysch basin on the shelf shown by the compact-stippled area west of the Uinta uplift (fig. 12). The basal part of the Pilot Shale in this shelf basin is laterally equivalent to the upper part of the type Devils Gate Limestone of figure 13. The lower unit of the Pilot in this shelf basin may represent extra-basinal detritus derived from both early Antler orogenic uplifts along the continental margin and local uplifts along the cratonic margin.



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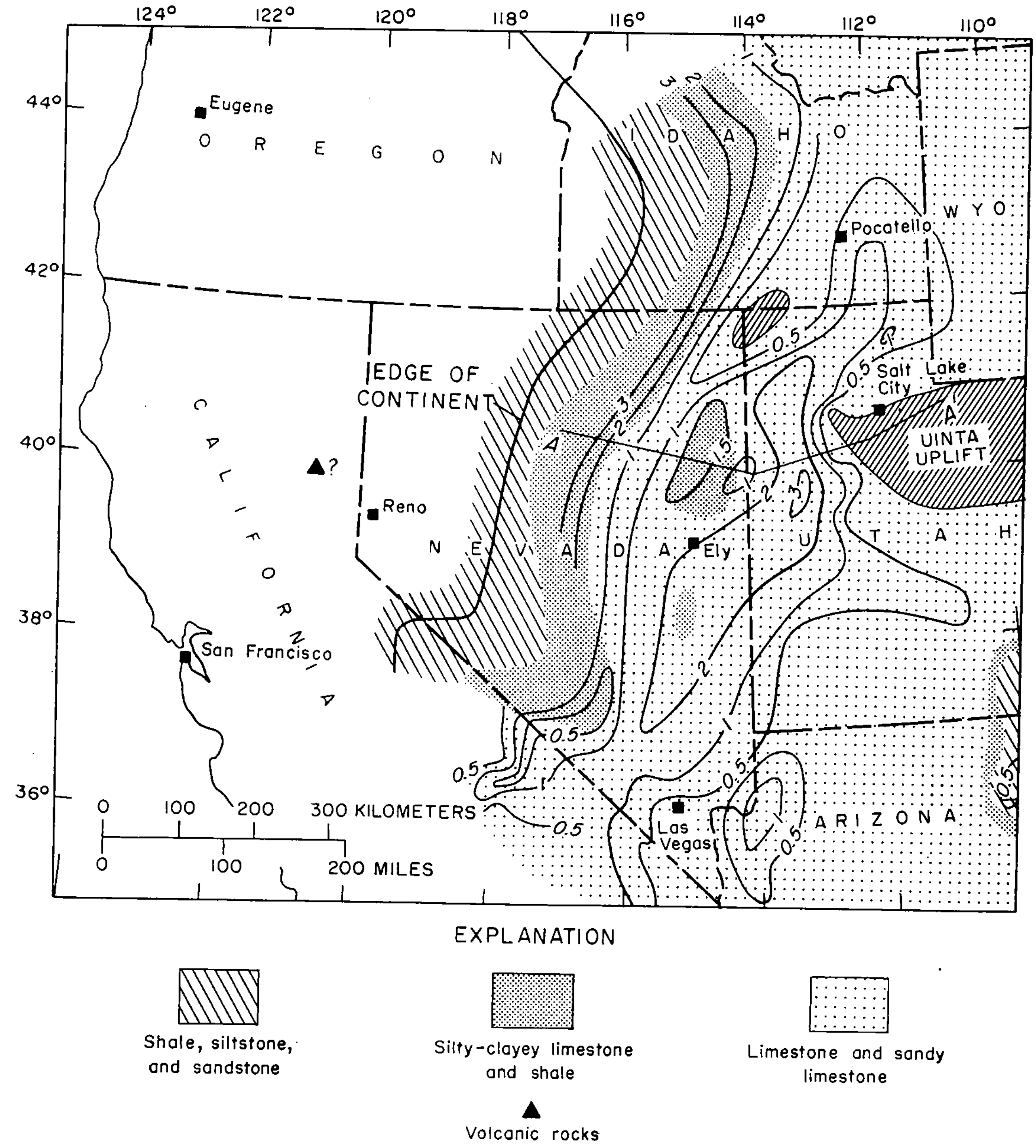


FIG. 12.—Isopach and facies map of lower Upper Devonian rocks (partly restored). Emergent areas shown by compact hatching. Isopachs in thousands of feet. Thickness and facies west of continental edge not shown owing to insufficient stratigraphic data. Cross section AA′ shown by figure 25a.

Upper Upper Devonian

The map of the upper Upper Devonian (fig. 15) reveals broad regional uplift of the shelf and platform with many emergent areas. Near the beginning of this time interval, the local but prominent Stansbury uplift (fig. 15, small area of compact hatching southwest of Salt Lake City) and its complementary subsiding basin formed at the west edge of the craton in northern Utah. The Stansbury basin adjacent to the uplift received over 450 m (1500 ft) of carbonate- and quartzite-clast conglomerate and quartzose sandstone derived from erosion of lower Paleozoic rocks in the core of the uplift

FIG. 13.—Cliff-forming thin-bedded Devils Gate Limestone at Devils Gate, central Nevada, represents shallow-water limestone deposits typical of outer carbonate shelf.

(Rigby, 1958; Stokes and Arnold, 1958). Figure 16 shows an outcrop of one of the carbonate-clast conglomerate units in the Stansbury Mountains. The Stansbury uplift and adjacent high area in northwestern Utah divided the previously continuous shelf basin into two parts, outlined by 500-foot isopach lines in figure 15 (compare figs. 12 and 15).

Figure 17 shows an outcrop of Pilot Shale in the southern of the two basins near the Nevada-Utah State line. The ledge shown in the center of the picture is a sandy limestone turbidite unit that is conglomeratic and contains flute casts, displaced shallow-marine fossils, and slump folds. The limy siltstones above and below the ledge are late Late Devonian in age, and like similar limy siltstones in the early Late Devonian part of the Pilot may represent extra-basinal detritus derived from uplifted areas both east and west of the shelf basins. Thin sandstone and limestone turbidite beds are common in the lower unit of the Pilot Shale within the shelf basins.

A major hiatus has been recognized between the lower and middle units of the Pilot Shale in the eastern Great Basin (Sandberg and Poole, 1970). This widespread hiatus records an interruption in deposition on the upper Upper Devonian continental shelf in the western United States (fig. 2) that is believed to reflect regional warping concomitant with emplacement of the Roberts Mountains Allochthon. Emplacement of the allochthon onto the outer continental shelf greatly restricted the shelf seas east of the orogenic highland, and created widespread euxinic and hypersaline conditions that resulted in some euxinic and evaporitic deposits in latest Devonian time.

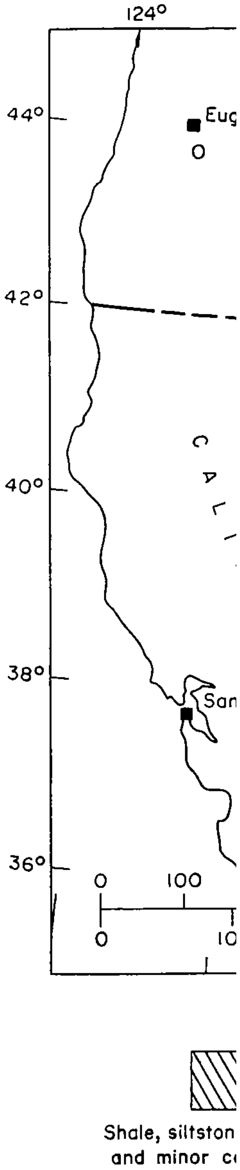
Figure 18 shows an outcrop of strongly deformed upper Upper Devonian radiolarian oceanic chert and argillite of the Slaven Chert that occurs in the Roberts Mountains Allochthon in central Nevada. The major source of chert, argillite, and quartzite detritus deposited in the Antler foreland basin included chert and argillite of the Devonian Slaven Chert and type Milligen Formation, chert, argillite, and quartzite of the Ordovician Valmy, Vinini, Phi Kappa, and related formations, and several Cambrian formations exposed in the Antler orogenic highland.

In southwestern Nevada and adjacent California the open-hatched area on figure 15 is a fine-grained flysch sequence probably derived from uplifts along the continental edge. In the northeastern part of the map the open-hatched area represents evaporitic deposits.

Lower Mississippian

The Lower Mississippian map (fig. 19) shows a well-developed flysch trough directly east of the Antler orogenic highland or Roberts Mountains Allochthon. East of the exogeosynclinal flysch trough or foreland trough carbonate sand, silt, and mud deposits, all of the shallow-water type, covered the shelf and platform including many former emergent areas. The eastern margin of the allochthon was overlapped by Lower Mississippian detrital sediments. Sedimentological data on Lower Mississippian deposits west of the Antler highland indicate a marginal

FIG. 14.—Slope-forming lower unit of Pilot Shale (Dpl) in Red Hills, northeastern Nevada, represents shaly limy siltstone deposits in an incipient basin on the carbonate shelf. Guilmette Limestone (Dg) ledges in lower foreground; Joana Limestone (Mj) cliff in upper right.



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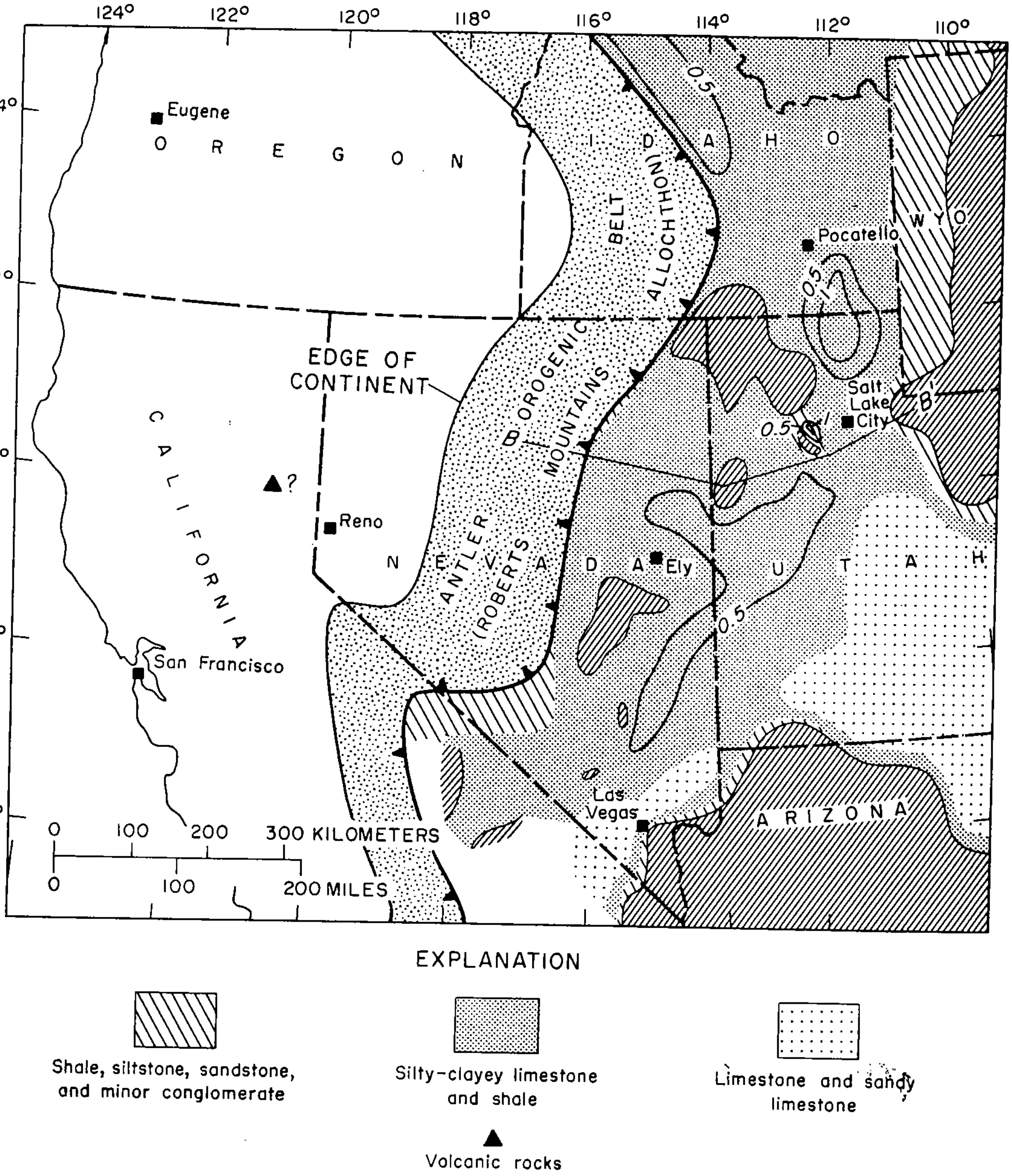


FIG. 15.—Isopach and facies map of upper Upper Devonian rocks (partly restored). Emergent areas shown by compact hatching. Isopachs in thousands of feet. Thickness and facies west of continental edge not shown owing to insufficient stratigraphic data. Roberts Mountains Allochthon emplaced near end of late Late Devonian time. Cross section BB′ shown by figure 25b.

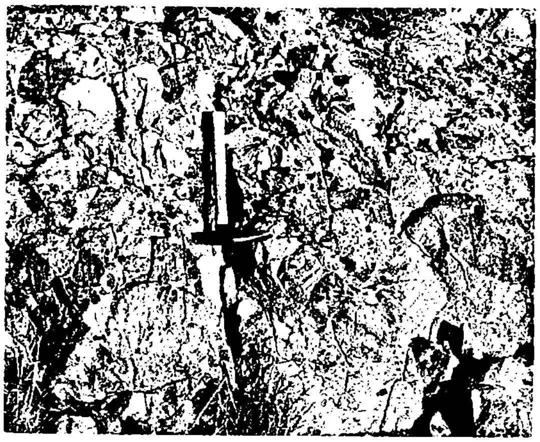


FIG. 16.—Upper Upper Devonian carbonate-clast conglomerate in Stansbury Formation, Stansbury Mountains, northwestern Utah, represents coarse detritus from local Stansbury uplift at outer edge of cratonic platform.

ocean basin environment that included some volcanism. Note the proto-Oquirrh basin outlined by the 1,000-foot isopach in north-central Utah, south of Salt Lake City (fig. 19).

Figure 20 shows an outcrop of slope-forming Lower Mississippian Milligen Formation of Sandberg and others (1967) in central Idaho that represents fine-grained flysch deposits east of the trough axis.

Figure 21 shows a typical cliffy outcrop of Lower Mississippian Joana Limestone in westernmost Utah that represents relatively pure limestone sediments deposited on the carbonate shelf between the subsiding foreland trough on the west and the stable cratonic platform on the east. The Lower Mississippian upper unit of the Pilot Shale consists of thin-bedded sandy and silty limestone and limy siltstone, which in many areas represent a depositional setting similar to that of the Upper Devonian lower unit of the Pilot. The upper unit of the Pilot is believed to contain a significant amount of detritus derived from the Antler orogenic highland.

Upper Mississippian

The Upper Mississippian map (fig. 22) shows the full development of the flysch basin east of the Antler orogenic highland. Locally very thick deposits of chert and quartzite gravels in the foreland basin indicate major uplift of the Antler mountainous terrane to the west in Late Mississippian time. The compact-stippled narrow band on the shelf (fig. 22) represents the change from dominantly limestone deposits on the east to dominantly fine-grained detrital sediments of the siliceous flysch on the west. By very late Mississippian time, the westerly derived clastic sediments filled the foreland trough and spread eastward across the limestone shelf onto the cratonic platform.

Several volcanic-rich Upper Mississippian deposits have been recognized in north-central Nevada and in northern California (fig. 22). Possibly, Mississippian formations in Nevada that contain submarine lava flows are allochthonous and were thrust eastward across the Antler orogenic belt in post-Mississippian time.

Figure 23 pictures an outcrop in north-central

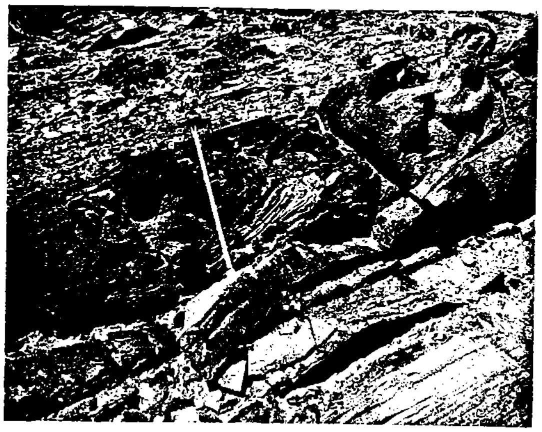


FIG. 17.—Sandy limestone turbidite (ledge 1 m thick in center of picture) that is conglomeratic and contains flute casts, displaced shallow-marine fossils, and slump folds within lower unit of the Pilot Shale in Confusion Range, Utah, near Nevada State line. Note large slump fold behind tape.

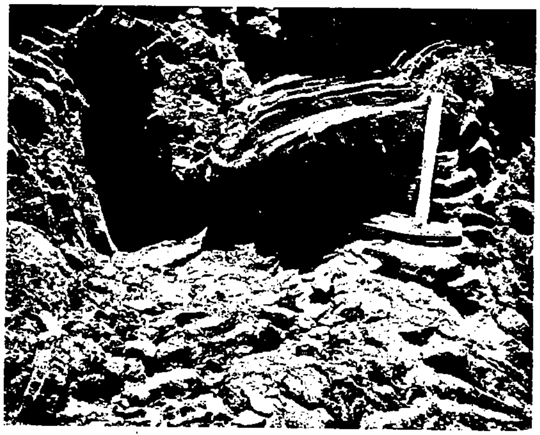
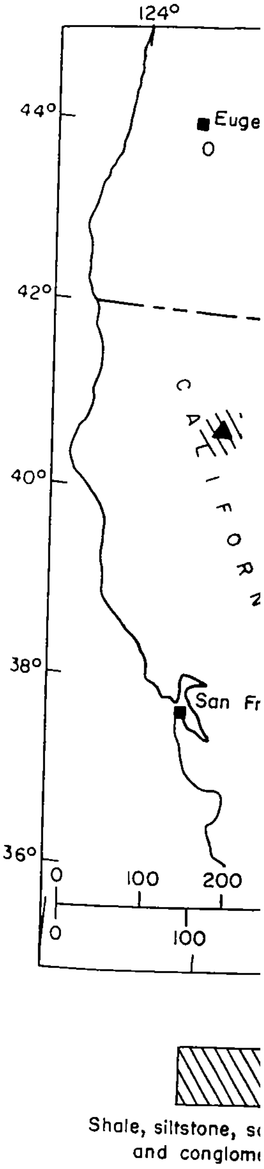


FIG. 18.—Strongly deformed upper Upper Devonian radiolarian oceanic chert and mudstone of Slaven Chert in Roberts Mountains Allochthon, Toquima Range, central Nevada.



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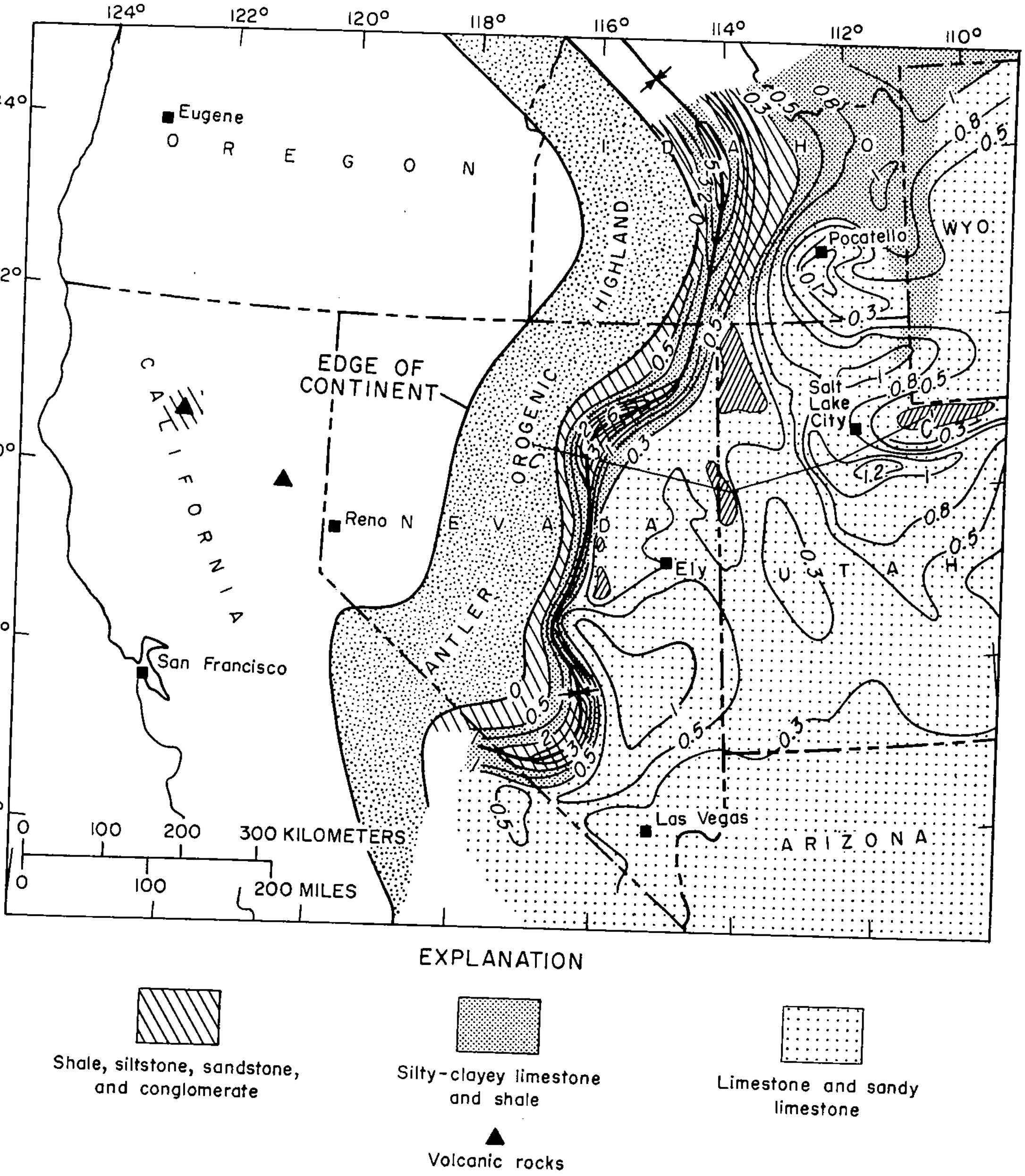


FIG. 19.—Isopach and facies map of Lower Mississippian rocks (partly restored). Emergent areas shown by compact hatching. Isopachs in thousands of feet. Thickness and facies west of continental edge not shown owing to insufficient stratigraphic data. Cross section CC′ shown by figure 25c.

FIG. 20.—Slope-forming argillite, siltite, and minor quartzite of Lower Mississippian Milligen Formation (Mm) of Sandberg and others (1967) in Lost River Range, central Idaho, represents fine-grained flysch in eastern part of foreland trough. Milligen underlain by shaly limestone of upper Upper Devonian Three Forks Formation (Dt) which directly overlies the prominent limestone cliffs of lower Upper Devonian part of the Jefferson Formation (Dj) of carbonate shelf. Milligen overlain by Upper Mississippian slope-forming and cliffy limestone units in upper right (Middle Canyon Formation, Mmc, and Scott Peak Formation, Msp). Photograph by C. A. Sandberg.

Nevada showing nearly vertical conglomerate beds of a part of the Upper Mississippian Diamond Peak Formation that are overlain with angular unconformity by steeply dipping limestones of the Pennsylvanian and Permian Strathearn Formation of Dott (1955). This Upper Mississippian conglomerate sequence was deposited along the west margin of the Antler foreland trough adjacent to the Antler highland, and is believed to represent mostly submarine upper fan deposits. The angular unconformity seen in figure 23 records medial Pennsylvanian uplift and erosion along the east margin of the Antler highland.

Figure 24 shows an outcrop of slope-forming Upper Mississippian Indian Springs Formation of Webster and Lane (1967) in southeastern Nevada that may contain a significant amount of reworked flysch sediments transported eastward across the carbonate shelf onto the platform margin which, in this picture, is represented by the underlying Upper Mississippian Battleship Wash Formation of Langenheim and Langenheim (1965). The upper contact of the Indian Springs Formation shown in figure 24 is placed at the base of a limestone-pebble conglomerate bed about 14 m (46 ft) above the upper contact selected by Webster and Lane (1967). The conglomerate bed apparently marks a regional unconformity correlative with the major unconformity at the top of the formation described by Gordon and Poole (1968)in southwestern Nevada. No turbidites have been recognized in the Indian Springs Formation in southern Nevada. Numerous *in situ* rhizomorph compressions of *Stigmaria* (Pfefferkorn, 1972) penetrate the top surface of the Battleship Wash Formation at Arrow Canyon. The occurrence of *Stigmaria,* which presumably is a rhizomorph of *Lepidodendron* and similar lycopods, indicates estuarine environmental conditions in this area in late Late Mississippian time.

ORIGIN OF ANTLER FORELAND BASIN

The four cross sections in figure 25 were constructed on an east-west line extending from north-central Nevada to north-central Utah across geosynclinal isopach and facies trends (figs. 12, 15, 19, 22). This upward chronological sequence of sections reveals several significant regional tectonic features. Major east-directed horizontal forces in the upper crust apparently caused eastward translation of axes of ridges and basins on the continental shelf during Mississippian time as depicted by the slanted dashed arrows in figure 25c and d. Figures 19, 22, and 25c-d indicate eastward expansion and translation of the Antler foreland basin, which received thick sediment accumulation, and its east-bordering complementary arch that received

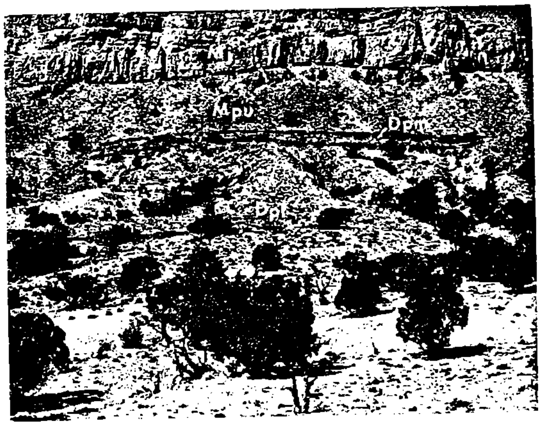
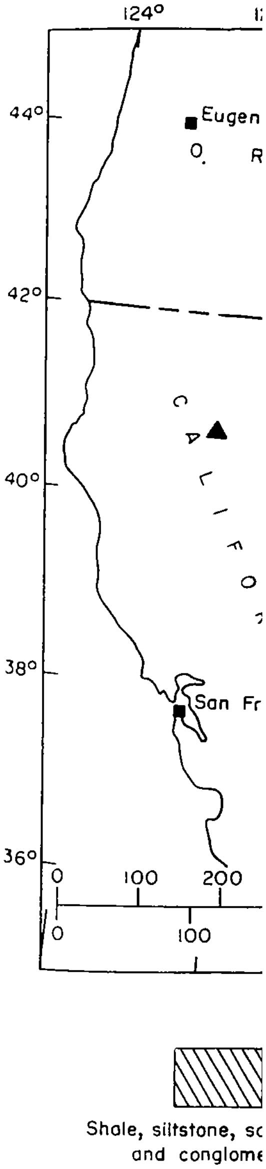


FIG. 21.—Cliff-forming Lower Mississippian Joana Limestone (Mj) in Burbank Hills, westernmost Utah, represents relatively pure shallow-water dominantly bioclastic limestone deposits of carbonate shelf. Slope-forming unit between base of Joana cliff and the prominent dark sandstone ledge in middle of slope is Lower Mississippian upper unit of the Pilot Shale (Mpu). Sandstone ledge represents most of middle unit of Pilot (Dpm) and underlying slope-forming siltstones and limestones represent lower unit of Pilot (Dpl).



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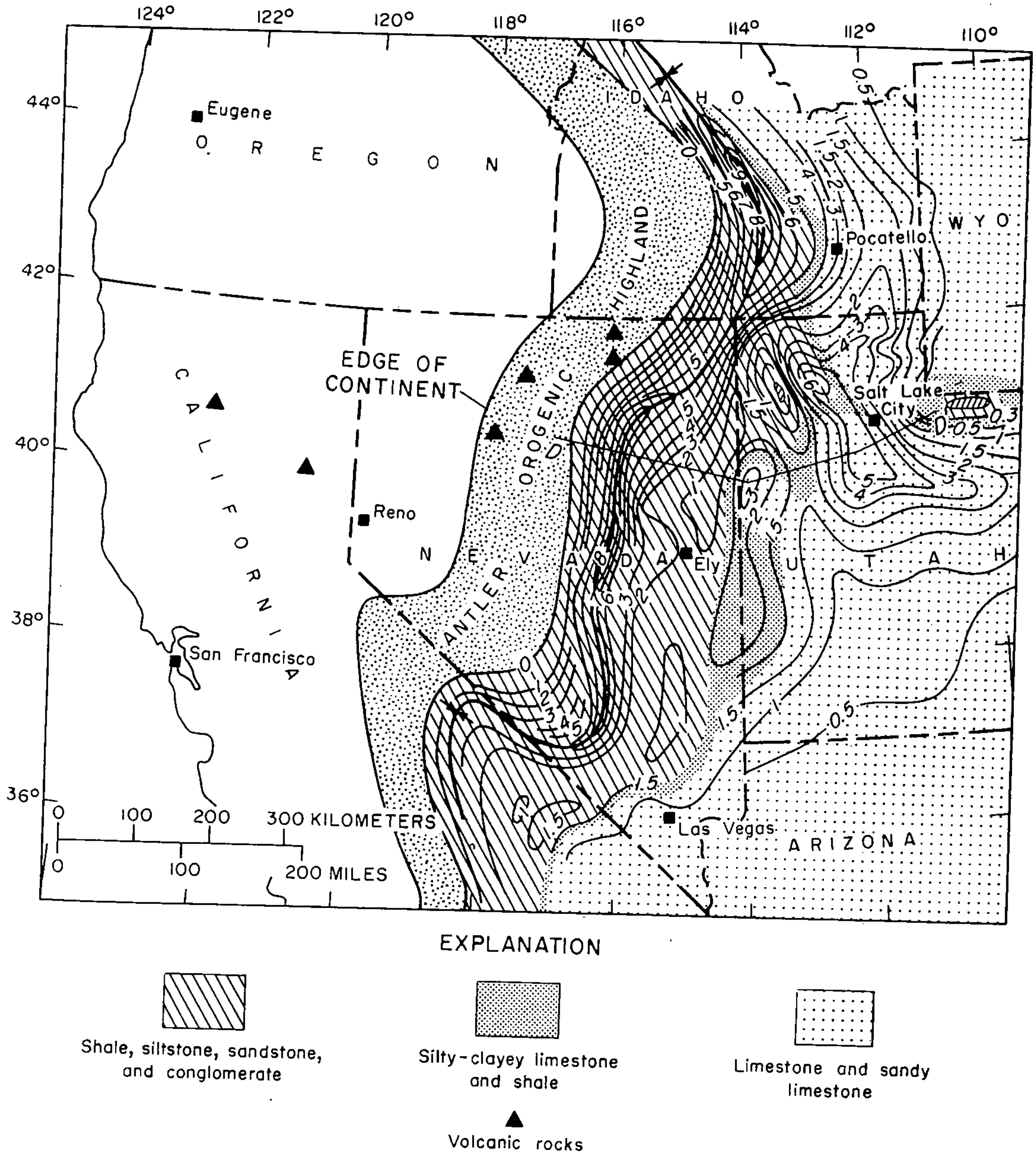

FIG. 22.—Isopach and facies map of Upper Mississippian rocks (partly restored). Emergent areas shown by compact hatching. Isopachs in thousands of feet. Thickness and facies west of continental edge not shown owing to insufficient stratigraphic data. Cross section DD′ shown by figure 25d.

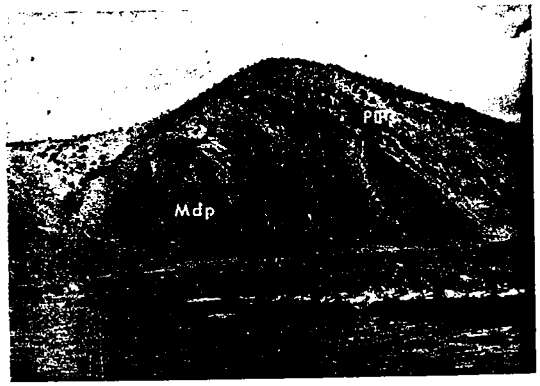

FIG. 23.—Nearly vertical conglomerate beds of Upper Mississippian part of Diamond Peak Formation (Mdp) overlain with angular unconformity by steeply dipping limestones of Pennsylvanian and Permian Strathearn Formation (PIPs) in west Carlin Canyon, north-central Nevada—Upper Mississippian conglomerate represents coarse-grained flysch deposited along west margin of Antler foreland trough adjacent to the Antler highland.

thin sediment accumulation. Most likely, continental margin deformation during the Antler Orogeny warped the continental crust under the shelf and initiated sites destined for subsequent major subsidence and uplift; continued orogenic compressive stress that was directed continentward resulted in a general eastward shift in sites of thick sedimentation (fig. 25c-d) during the Carboniferous.

Plate-Tectonic Model

The geological evolution of western United States can be explained by plate-tectonic models even though many features remain obscure. Paleozoic paleogeography of the United States Cordillera seems compatible with the suggestion of Burchfiel and Davis (1972) that an offshore island arc complex above an east-dipping subduction zone was separated from the continental edge by a small ocean basin. Figure 26 shows a hypothetical and generalized plate-tectonic model which may help explain the origin of the Antler foreland basin and its flysch deposits. Thickness trends and facies patterns indicate a relatively stable Atlantic-type continental margin from late Precambrian to Early Devonian time (fig. 26a; also see Stewart and Poole, this volume).

Figure 26b shows Antler orogenic deformation and subsequent overthrust or obduction of Devonian and older oceanic sedimentary and mafic volcanic rocks from the inner arc or marginal ocean basin onto the outer continental shelf. Major deformation of the eugeosynclinal rocks occurred along the continental margin during early Antler orogenic activity, and this strong deformation is believed to predate emplacement of the Roberts Mountains Allochthon. Small slices of serpentinized ultramafic rocks are tectonically interleaved with oceanic crustal and sedimentary rocks of the allochthon (Poole and Desborough, 1973). Poole and Desborough (1973) considered these serpentinites to be fragments of early Paleozoic or late Precambrian upper mantle that were detached at the eastern Pacific margin along active subduction or obduction zones during middle Paleozoic lithospheric plate convergence. The east-directed overthrusting may have been related to compressive stress transmitted continentward from the underthrusting oceanic plate which resulted in partial closure of the marginal ocean basin (Burchfiel and Davis, 1972). This compressive stress may have warped the continental crust under the shelf and initiated development of the structural exogeosynclinal trough or foreland basin directly east of the Antler orogenic belt.

Although the model of figure 26 gives a good first-order fit with the geologic data available in the United States Cordillera, it may be somewhat oversimplified. Nevertheless, it seems evident from regional patterns of paleogeography and paleotectonics that the origin of the Upper Devonian and Mississippian foreland trough and flysch deposits in the western United States is related to the interaction of oceanic and continental plates along the Paleozoic continental margin.

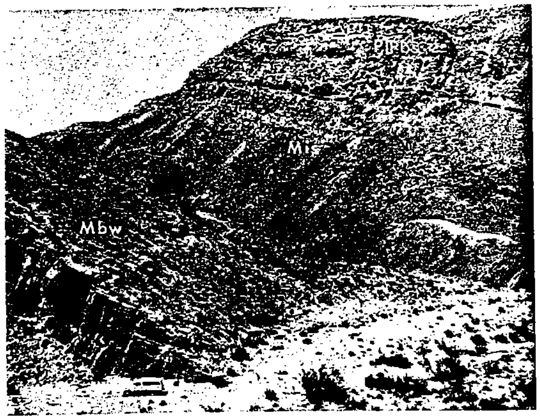

FIG. 24.—Slope-forming Upper Mississippian Indian Springs Formation (Mis) at Arrow Canyon, southeastern Nevada, represents flysch sediments transported eastward across carbonate shelf onto the platform margin which is represented by underlying limestone cliff of the Upper Mississippian Battleship Wash Formation (Mbw) behind truck. Limestone cliff above Indian Springs Formation is basal part of Bird Spring Formation of Pennsylvanian and Permian age (PIPbs).

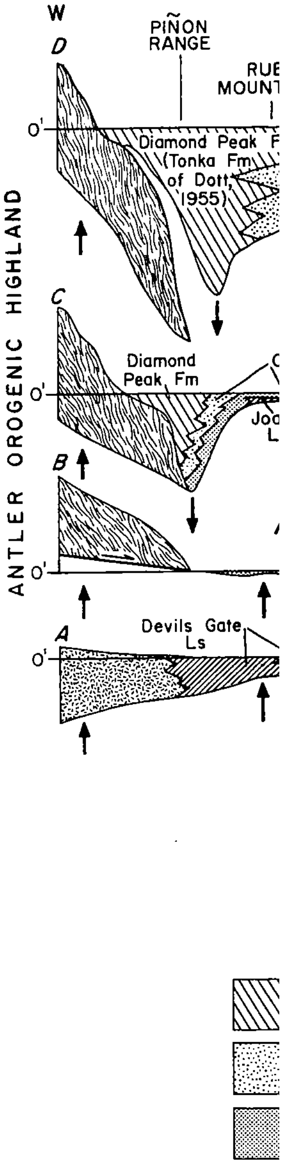

FIG. 25.—Cross sections
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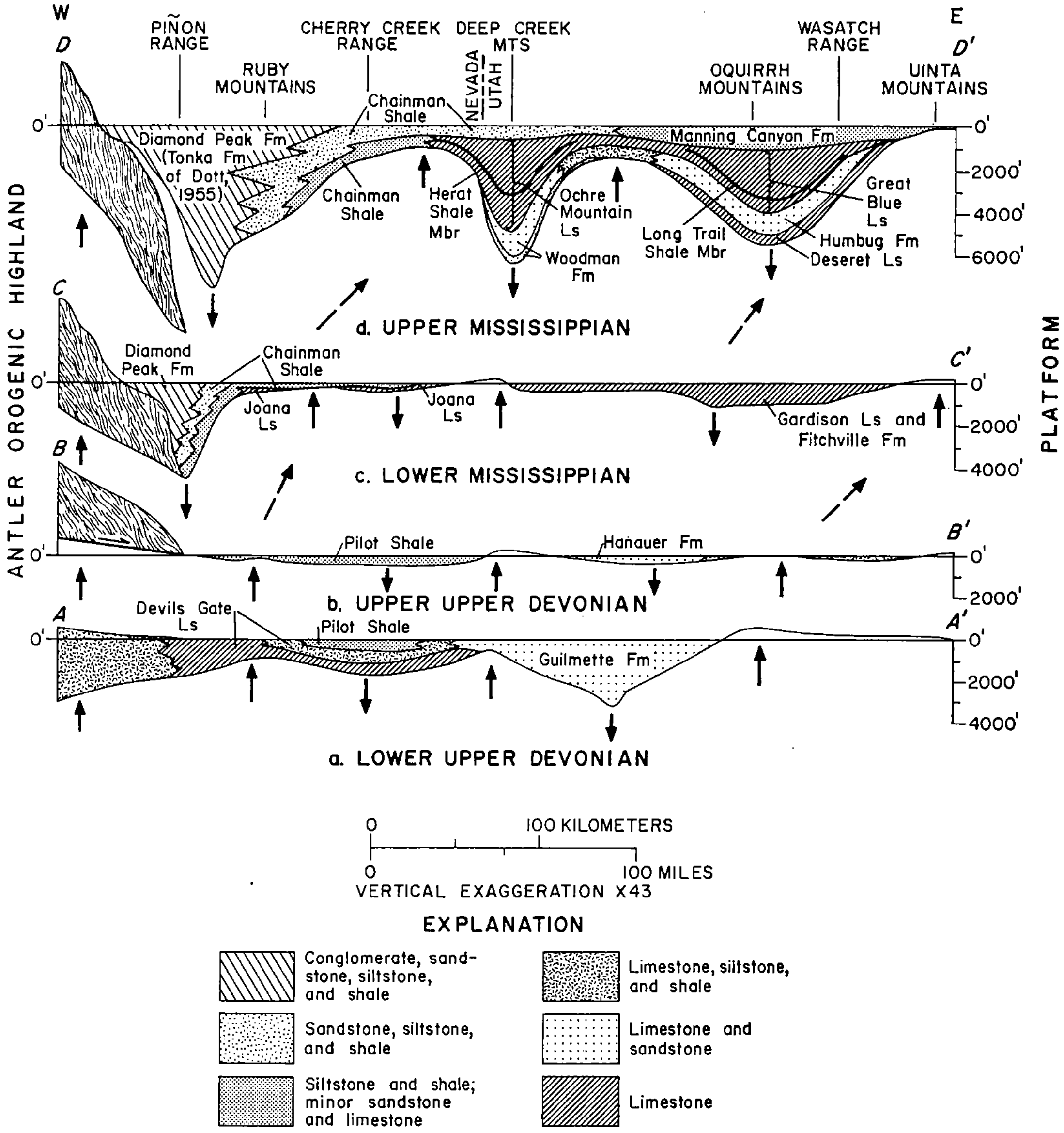
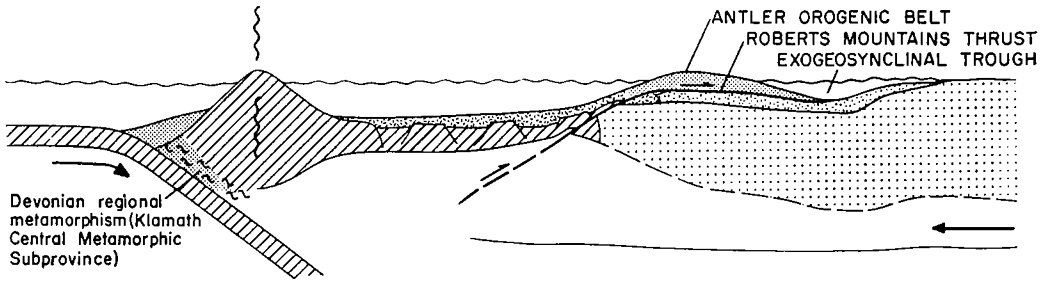
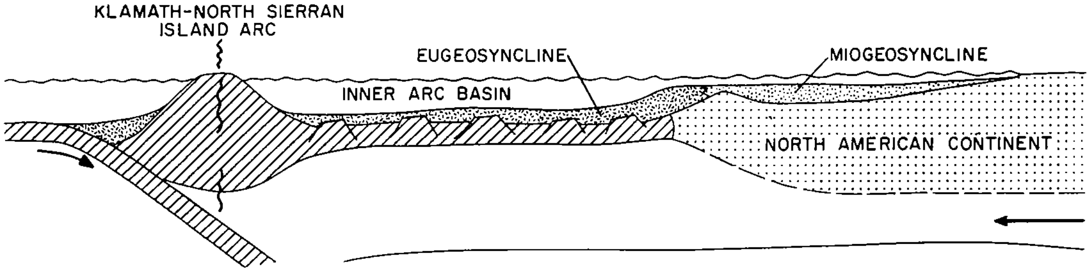


FIG. 25.—Cross sections from north-central Nevada to north-central Utah showing development of structural and depositional features on the continental shelf during the Antler Orogeny. Roberts Mountains Allochthon on left side of sections B, C, and D is depicted by compact wavy lines.



b. MIDDLE DEVONIAN–EARLY MISSISSIPPIAN



a. LATE PRECAMBRIAN–EARLY DEVONIAN

FIG. 26.—Hypothetical and generalized sketch showing relationship between early Paleozoic island arc and the North American continent based on the hypothesis of an east-dipping subduction zone (modified from Burchfiel and Davis, 1972). Continental crust in diffuse stippling; oceanic crust in hatching; upper mantle below crust is unpatterned; strongly deformed transitional and eugeosynclinal rocks in Antler orogenic belt shown by compact stippling; metamorphism in subduction zone shown as short squiggly lines. *a,* Relatively stable continental margin. *b,* Antler orogenic deformation and emplacement of Roberts Mountains Allochthon from the inner arc basin.

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