DAVID BLOOM

Age relationships and depositional environments of Paleozoic strata, northern Sierra Nevada, California

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ABSTRACT

Upper Paleozoic volcanic rocks in the northern Sierra Nevada rest unconformably on the lower Paleozoic Shoo Fly Complex. Late Ordovician conodonts recovered from an exotic limestone block in Shoo Fly mélange have North American affinities; the Complex may have traveled little from its original location. Magmatism may have begun as early as Early Devonian and persisted into Early Mississippian time. The volcanic rocks constitute a longitudinal section through a relatively immature volcanic arc dominated by tholeiitic magmas. Two lithologically distinct members of the overlying Peale Formation are given formation status. The predominantly volcanogenic lower member is renamed the "Keddie Ridge Formation"; the name "Peale Formation" is retained for the upper chert member. Two new Late Mississippian–Early Pennsylvanian radiolarian localities in the Peale chert at the north end of the Paleozoic outcrop belt correlate well with a previously described assemblage at the south end and thus rule out time-transgressive deposition. Early Permian fusilinids in a chert-pebble conglomerate only 10 m upsection from an Early Pennsylvanian radiolarian locality tightly constrain a regional depositional hiatus. The Peale chert displays common soft-sediment deformation, slump structures, intraformational breccias, and abrupt termination of thick sequences along strike. Locally, the chert is intruded by tholeiitic basalt. These features suggest deposition in small, tectonically active basins, possibly in an extensional, back-arc regime. The overlying Permian sequence of arc tholeiites is truncated by Mesozoic strata in most areas but appears to grade into Triassic shale and limestone in the extreme northwest.

INTRODUCTION

In recent years, a variety of tectonic models based on regional stratigraphic and structural studies have been proposed for the Paleozoic history of the western United States, (see, for example, Churkin, 1974; D'Allura and others, 1977; Dickinson, 1977; Speed, 1979; Schweickert, 1981; Girty and Schweickert, 1984). These studies have been hampered by discontinuous exposure and lack of fossil control. A remarkably continuous belt of Paleozoic rocks is exposed in the northern Sierra Nevada between the North Fork of the American River and the Quaternary Lassen volcanic field (Fig. 1). This outcrop belt constitutes a critical link in the paleogeographic reconstruction of the western Cordillera.

Detailed geologic mapping and petrographic studies of the northern Sierra Paleozoic section during the past decade have provided new data on rock types, environments of deposition, probable magma sources, contact relationships, biostratigraphy, and biogeography. A compilation map of the northern half of the Paleozoic belt, based on work by McMath (1958), D'Allura (1977), Hannah (1980), E. M. Moores and W. S. Wise (unpub. data), and Cordell Durrell (unpub. data), is in preparation. Maps for some areas in the southern half of the section are available in Stuart-Alexander (1967), D'Allura (1977), Speed and Moores (1981), Harwood (1981), Girty (1983), and Hanson (1983). Earlier reviews of stratigraphic relations are presented in McMath (1966), D'Allura and others (1977), Durrell and D'Allura (1977), Varga and Moores (1981), Schweickert (1981), and Harwood (1983). This paper presents several new fossil localities, more detailed stratigraphic information, and petrology and geochemistry of the volcanic rocks. These data place new constraints on the tectonic history of the northern Sierra Nevada.

The stratigraphic sequence and its variations along the outcrop belt are illustrated in Figure 2. The oldest unit, the lower Paleozoic Shoo Fly Complex, includes phyllite, continentally derived quartzose sandstone, chert, and mélange. These rocks are overlain unconformably by an Upper(?) Devonian to Lower Mississippian volcanic arc sequence. Upper Mississippian to Lower Pennsylvanian ribbon chert and associated fine-grained wacke and siltstone were deposited with apparent conformity on the volcanic rocks and mark a major hiatus in volcanism. The sedimentary strata are overlain by a Late Pennsylvanian(?) to Permian basaltic to andesitic volcanic arc sequence.

All pre-Cretaceous units in the northern Sierra strike north to northwest, generally with a steep dip, as a result of the Late Jurassic Nevadan orogeny (Hannah and Verosub, 1980; Varga and Moores, 1981). Despite strong deformation and thorough recrystallization during this event, a pre-Devonian orogenic event which deformed the lower Paleozoic Shoo Fly Complex is clearly documented by fold patterns, crosscutting relationships, and local basal conglomerates (Durrell and Proctor, 1948; Varga, 1979). Truncation of all Paleozoic units by fossiliferous Triassic limestone along a profound angular unconformity provides indisputable evidence for a Late Permian–Early Triassic orogenic event (Harwood, 1983). Folding during the Nevadan orogeny was accompanied by east-directed thrusting along two major faults. The entire Paleozoic section north of Lakes basin is repeated across the Grizzly Mountain fault. The Paleozoic strata in the eastern block were thrust eastward over Jurassic rocks along the Taylorsville fault. Following the terminology of McMath (1958, 1966), the sections west and east of the Grizzly Mountain fault are referred to as the "Hough" and "Genesee Blocks," respectively.

THE SHOO FLY COMPLEX

The bulk of the Shoo Fly Complex consists of phyllite, continentally derived quartzose sandstone, and chert. The easternmost section, however, is a mélange, containing blocks of limestone, greenstone, gabbro, ultramafic rocks, and exotic sandstone slices in a matrix of serpentinite or argillaceous sandstone. The mélange occurs along the contact with upper Paleozoic volcanic rocks in both the Hough and Genesee Blocks and in a thin strip along the western margin of the Complex near Sierra City (Bond and Schweickert, 1981). Its stratigraphic relationship to the coherent sedimentary section is unknown.

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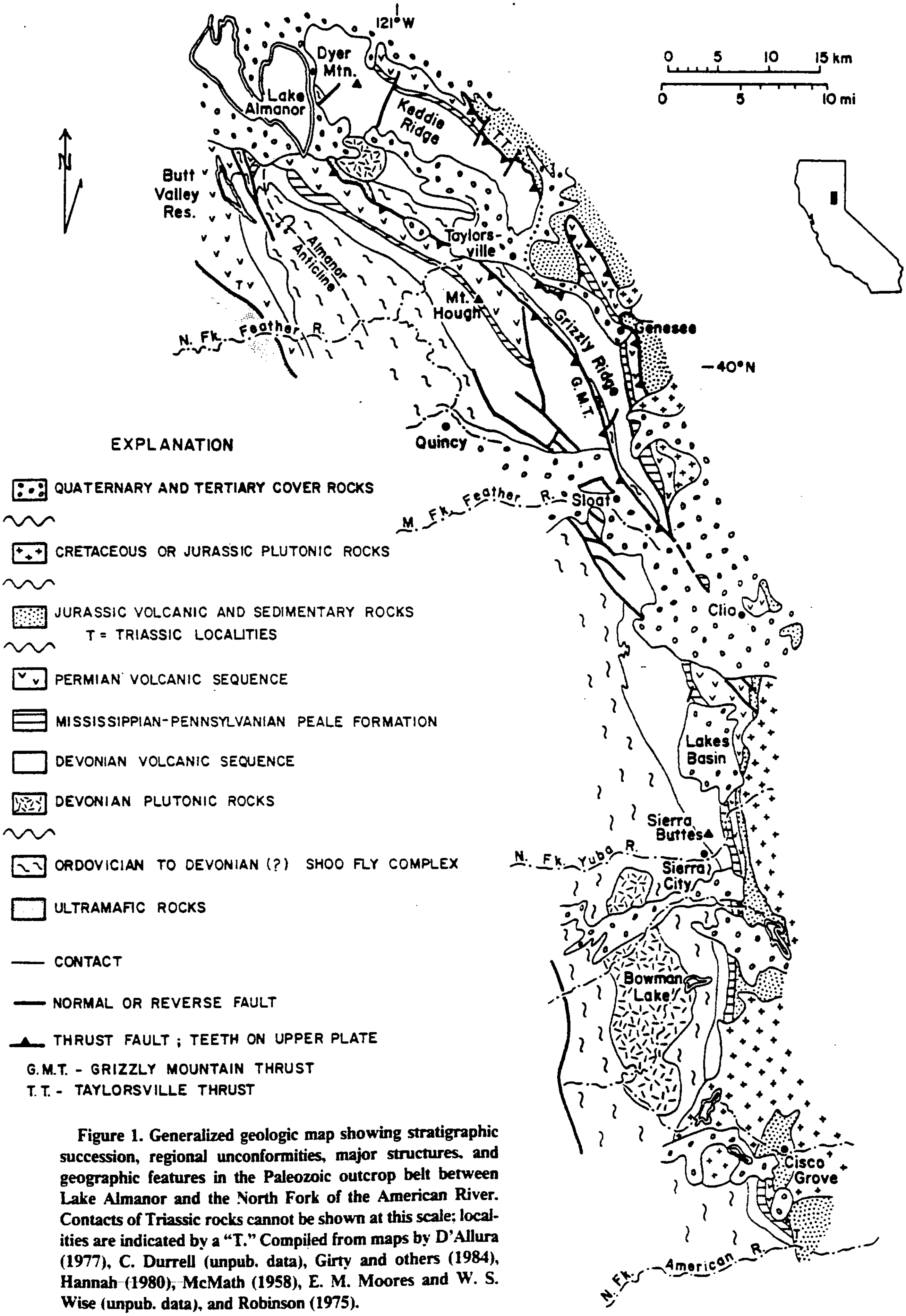

Figure 1. Generalized geologic map showing stratigraphic succession, regional unconformities, major structures, and geographic features in the Paleozoic outcrop belt between Lake Almanor and the North Fork of the American River. Contacts of Triassic rocks cannot be shown at this scale; localities are indicated by a "T." Compiled from maps by D'Allura (1977), C. Durrell (unpub. data), Girty and others (1984), Hannah (1980), McMath (1958), E. M. Moores and W. S. Wise (unpub. data), and Robinson (1975).

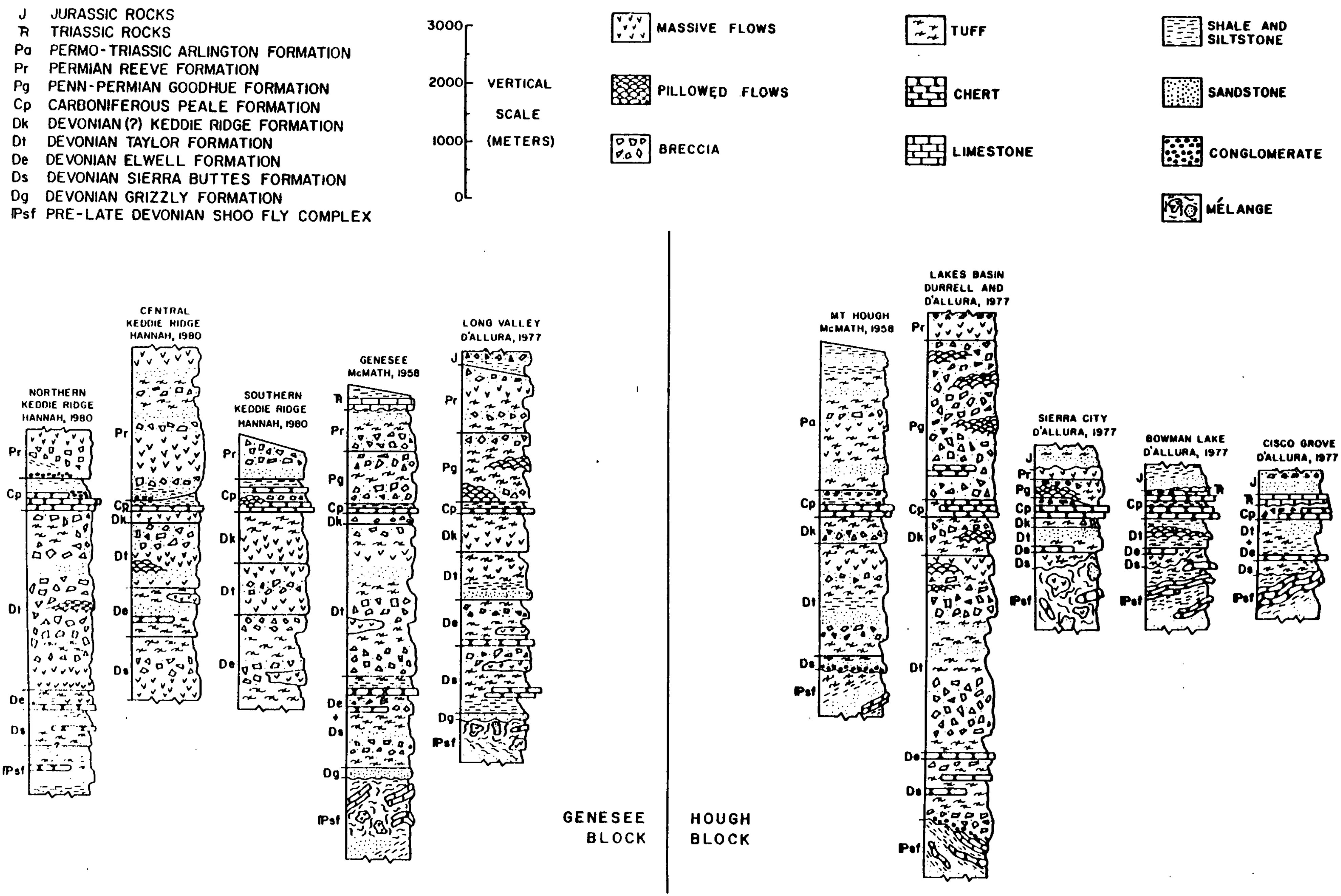

Figure 2. Comparative stratigraphic sections along the Paleozoic outcrop belt; the base of the Peale Formation was chosen as an arbitrary datum.

Age

A Late Cambrian to Devonian age for the largely unfossiliferous Shoo Fly Complex is indicated by three lines of evidence. First, a well-documented angular unconformity between the Shoo Fly Complex and the overlying Upper (?) Devonian sequence requires a pre-Late Devonian age (Durrell and Proctor, 1948; Varga and Moores, 1981). Second, fossil assemblages from the only two known localities in the complex yield Ordovician-Silurian fauna. The Montgomery Limestone (Diller, 1908), which consists of several limestone lenses in Shoo Fly mélange near the crest of Grizzly Ridge, contains Ashgillian megafossils (Boucot and Potter, 1977) and middle Maysvillian to Gamachian conodonts (A. G. Harris, 1985, written commun.). Phosphate nodules in argillaceous rocks in the Lakes basin area yield poorly preserved Ordovician to Silurian radiolaria (Varga and Moores, 1981). Third, preliminary U-Pb isotopic data from zircons retrieved from Shoo Fly tuff indicate a Silurian age (R. J. Varga and J. B. Saleeby, 1985, personal commun.). In addition, U-Pb data for detrital zircons from feldspathic sandstone blocks in Shoo Fly mélange define a linear array which intersects the concordia curve at 506 ± 22 m.y. (Girty and Wardlaw, 1984), thus requiring a maximum age of Late Cambrian to Early Ordovician.

A sample of the Montgomery Limestone collected on the flank of Mount Hough in the Montgomery Creek drainage yielded four species of conodonts: *Belodina* sp., *Drepanoistodus suberectus* (Branson and Mehl), *Panderodus gracilis* (Branson and Mehl), and *Protopanderodus insculptus* (Branson and Mehl). A. G. Harris (1985, written commun.) reported: "Three of the four species restrict the age to the Ordovician and, of these, *Protopanderodus insculptus* further restricts the age to middle Maysvillian through Gamachian. The species association is indicative of North American Midcontinent Faunas 12 and 13 (relatively warm-water biofacies) and deposition in generally warm shelfal or platformal settings." The conodonts show a Color Alteration Index (Epstein and others, 1977) of 5.5 to 6, indicating a minimum metamorphic temperature of 350 to 400 °C.

Unfortunately, all four localities yielding age information are in the easternmost part of the Shoo Fly Complex which Bond and Schweickert (1981) have interpreted as mélange. The isolated lenses of Montgomery Limestone are either exotic blocks in a tectonic mélange (D'Allura and others, 1977) or submarine slide blocks (Bond and DeVay, 1980) and therefore establish only a maximum age for this part of the Shoo Fly Complex. Girty and Wardlaw (1984) also describe the zircon-bearing sandstone as a mélange block. Although the other two localities were not interpreted by Varga (1980, 1981) as part of a mélange, it is not possible to extend the Late Cambrian–Silurian age with certainty to the entire Shoo Fly Complex. Schweickert and Snyder (1981) assumed that, because the only plausible North American source terrane for feldspathic sandstone was buried by Early Ordovician time (Suczek, 1977), the Shoo Fly sandstone is no younger than Cambrian.

Environment of Deposition

The Shoo Fly Complex is an exceedingly complicated, poorly understood suite which will undoubtedly be divided into separate units with distinct lithologies, depositional environments, and tectonic histories as work progresses. Outside the mélange zones, abundant phyllite and common ribbon chert suggest a deep-water environment. Locally abundant quartzose sandstone units, however, require an adjacent sediment source. Lithologic distributions and sedimentary structures suggest rapid deposition by gravity flows (Bond and DeVay, 1980), perhaps in a submarine fan complex (Girty and Wardlaw, 1985).

The mélange zone has been interpreted as part of an accretionary prism thrust over a passive margin sequence (the structurally lower sedimentary section in the Shoo Fly Complex) during an arc-continent collision (D'Allura and others, 1977; Bond and Schweickert, 1981). D'Allura (1977) noted that the "mélange" units in the Shoo Fly Formation of the Genesee Block do not display the characteristic penetrative deformation of subduction complexes. He proposed that the mélange is of sedimentary origin and is composed of debris shed from an advancing thrust sheet, as in the modern collisional thrust belt of New Guinea (Hamilton, 1977).

Several lines of evidence suggest that Shoo Fly deposition occurred adjacent to a continent, possibly North America. First, the shallow-water limestone olistoliths(?) contain stromatolites and oolites (Bond and DeVay, 1980), shallow-water megafossils, and shelfal or platformal conodont species with North American affinities. Boucot and Potter (1977, p. 210–211) noted that the Montgomery Limestone fauna is "similar taxonomically, biogeographically, and in benthic animal community position . . . to correlative faunas in the eastern Klamath Mountains." The conodonts, especially *Belodina*, require warm water, within 20° of the equator. Although the fauna was cosmopolitan and widespread at equatorial latitudes, a North American source for the limestone block is not excluded. This species association is common, for example, in the Ely Springs Dolomite, part of the Ashgillian carbonate platform of the western United States (A. G. Harris, 1985, personal commun.). The limestone bodies appear to be slide blocks of shallow-water origin emplaced in deep water off the continental shelf. Second, quartz sandstone units outside the mélange zone require a 2.09-b.y.-old, plutono-metamorphic source terrane (Girty and Wardlaw, 1985; Bond and DeVay, 1980) consistent with derivation from the westernmost North American craton (Farmer and DePaolo, 1983). Third, phosphatic chert, such as that in the Shoo Fly Complex, typically forms in areas of upwelling along continental margins between the 40th parallels. The present west coast of North America was one of the few areas favorably positioned for phosphate deposition in the early Paleozoic (Varga, 1982). Finally, Boucot and Potter (1977) pointed out that the Ordovician fauna in the Klamath-Sierra sequences are cosmopolitan and do not require a remote, exotic source. Early Devonian fauna in the eastern Klamaths, possibly correlative with the Sierra section, have distinctly North American affinities.

THE UPPER DEVONIAN VOLCANIC SEQUENCE

The deformed Shoo Fly Complex is overlain unconformably by an Upper(?) Devonian to Lower Mississippian sequence of arc volcanics and intercalated sedimentary rocks, including the Grizzly, Sierra Buttes, Elwell, Taylor, and newly defined Keddie Ridge Formations. Volcanic rock compositions range from Sierra Buttes felsic quartz porphyry to Taylor pyroxene andesite. At its type locality at Lakes basin, the Elwell Formation is characterized by phosphatic ribbon chert with minor intermediate volcanic rocks. To the north, however, its stratigraphic position between the Sierra Buttes and Taylor Formations is occupied by abundant dacitic to andesitic pyroclastic rocks, massive flows, and breccias. As such facies changes are expected in a complex volcanic terrane, the intermediate volcanics are included in the Elwell Formation.

The uppermost unit in the volcanic sequence consists of plagioclase- and/or quartz-phyric, oxide-rich tuff, breccia, flows, and shallow intrusions which formerly comprised the lower member of the Peale Formation. Because the two members of the Peale Formation include rocks of different ages, lithologies, and depositional environments and because they comprise discrete, mappable units over their entire outcrop area, they merit formation status. The lower member is renamed the "Keddie Ridge Formation" for the excellent exposures on the east flank of the ridge. The name "Peale Formation" is retained for the upper member because of widespread use of the name in the literature and the unique and distinctive character of the rocks.

There is no evidence for major hiatuses or angular unconformities in the Upper Devonian volcanic sequence. McMath (1958) cited interbedding of Sierra Buttes and Taylor lithologies at two locations. Hannah (1980) noted that compositional variations are gradational. D'Allura (1977) also concluded that the units are apparently conformable. Local unconformities result from paleo-relief. Although bedding and contacts are approximately parallel over long distances, upper and lower contacts of some units diverge locally by as much as 25° (more commonly, 5° to 15°), most likely reflecting paleo-relief. Slopes within modern island arcs commonly average 10° over long distances, and local relief around volcanic edifices is much greater.

Age

On the basis of rare fossil assemblages, the Elwell Formation is Late Devonian, and the Taylor and Keddie Ridge Formations are bracketed by the Elwell and the Lower Mississippian Peale Formation. Anderson and others (1974) collected two genera of Late Devonian (mid-Famennian) ammonoids from "quartzites" originally mapped in the Sierra Buttes Formation, and subsequently assigned to meta-chert of the Elwell Formation (Durrell and D'Allura, 1977). Clark (1930) collected poorly preserved stromatoporoids from a chert lens in the Sierra Buttes or Elwell Formation southwest of Long Lake in Lakes basin, dated by C. R. Stauffer as Devonian or Mississippian.

DeVay and Stanley (1979) retrieved well-preserved radiolaria from phosphate nodules in Elwell chert at Lakes basin. The fauna is dominated by *Entactiniids* with trigonal bladed spines, but also contains *Archocyrtium, Paleoscenidium,* and *Ceratoikiscum,* giving an age of Late Devonian, possibly Frasnian. Radiolaria were also obtained from phosphate nodules in a chert lens near the base of the Sierra Buttes Formation 5 km west of Greenville. The sparse spherical Spumellaria with tri-bladed spines are possibly Devonian but are not definitive (D. L. Jones and B. Murchey, 1981, written commun.). Unfortunately, no fossils are known from the Sierra Buttes or Grizzly Formations.

Two recent radiometric ages suggest that post-Shoo Fly magmatism began in the Early Devonian. Zircons from the Bowman Lake Batholith, which intrudes the deformed Shoo Fly Complex, yield a 409 ± 16 m.y. U-Pb age (Girty and others, 1984). Zircons extracted from the Wolf Creek Granite, a small biotite granite stock which intrudes Sierra Buttes rhyolite near Lake Almanor, yield an age of 380 ± 10 m.y. (J. B. Saleeby, 1985, personal commun.). This is significantly older than the Frasnian age reported for radiolaria from the Elwell Formation in the Lakes basin area.

Although the Taylor and Keddie Ridge Formations remain undated, a minimum age is indicated by Early Mississippian brachiopods (McMath, 1966) from the base of the newly restricted Peale Formation (formerly the upper member).

Origin of the Upper Devonian Volcanic Sequence

The compositions and relative abundances of flows, clastic rocks, and intrusive units within the volcanic section permit speculation on the depositional environment. Evidence discussed below suggests that the Upper Devonian volcanic sequence represents a volcanic arc constructed on transitional crust—either thinned continental crust near the transition to the oceanic regime or oceanic crust and its sedimentary cover thickened by an earlier collisional event.

The oldest volcanic rocks, the Sierra Buttes rhyodacites, are dominated by either massive and brecciated shallow plugs, dikes, and sills, or tuff and pyroclastic breccia. The mass of cross-cutting intrusive units underlying the peaks of the Sierra Buttes is clearly a vent complex (Schweickert, 1981). About 65 km north, abundant intrusive units in the thick section west of Keddie Ridge suggest another vent locality. The upper part of the Sierra Buttes section is predominantly pyroclastic rocks which grade into the less felsic Elwell Formation.

The Elwell volcanic rocks are dacitic to andesitic and are predominantly pyroclastic. Vent complexes have not been identified with certainty, but the thick section of breccia and massive flows or shallow intrusions in the Genesee Block (especially southern Keddie Ridge) is clearly much closer to a vent than the thin, chert-rich section in the Lakes basin area. The locus of the volcanoes may have shifted slightly by Elwell time, so that the present erosional surface cuts the flanks of volcanoes and intervening basins. Thick accumulations of tuff and tuff breccia observed in the Genessee Block are likely products of ash and debris flows within 5 to 10 km of a vent. Ribbon chert with sparse tuff interbeds, as observed in the Hough Block, are typical of basins removed from vents (30 to 40 km?), which receive only occasional influxes of volcanic debris.

The volcanic rocks become increasingly mafic upsection; the Taylor Formation is predominantly andesite and andesitic basalt. By far the most abundant rock type is heterolithic augite andesite breccia. In many localities, lack of internal stratification, poor sorting, matrix support of breccia clasts, and the variety of clast lithologies suggest deposition by debris flows. Because water-saturated debris slurries may travel for many kilometres, their presence does not require proximity to a vent. Thick sections that include monolithic breccia, flows, and pillow lavas, but lack intercalated sedimentary rocks, most likely represent near-vent facies. Notable breccia accumulations occupy the northern half of Keddie Ridge and the central part of the Hough Block. Tuff is more common in the northern Hough Block, and volcaniclastic turbidites dominate the southern Genesee Block; both represent more distal facies. South of Lakes basin, primary volcanic rocks are sparse (D'Allura and others, 1977). A thin sequence of pillow lava crops out near Bowman Lake; to the south, however, fine-grained turbidites become more abundant, indicating increasing distance from vents (Harwood, 1983).

This thick section of Devonian volcanic rocks represents a volcanic arc complex which formed at a convergent plate margin. Although several possible ignimbrites and sparse rounded clasts in conglomerates suggest local subaerial exposure (D'Allura and others, 1977; Schweickert, 1981), intercalation of cherts, volcaniclastic turbidites, and pillow lavas at all stratigraphic levels strongly suggests subaqueous deposition. The fossil localities in the Sierra Buttes and Elwell Formations yield marine fauna, and the Taylor Formation includes at least one bed with undated crinoid debris (McMath, 1958). Geochemical data and mineralogy indicate a nonalkaline parentage for the volcanic rocks (Hannah, 1980; Brooks and Coles, 1980). An island-arc environment is the only tectonic setting which typically contains abundant submarine pyroclastic deposits of nonalkaline, intermediate to silicic composition.

The exposed north-south segment of steeply dipping arc-volcanic rocks in the northern Sierra Nevada is probably subparallel to the original arc. More than one vent complex is recognized along strike within each formation. Because the offset between the Hough and Genesee Blocks is unknown, the original distance between vent localities is uncertain. Present distances are 50 to 65 km, comparable to or slightly less than the observed spacing of about 70 km between modern volcanoes (Marsh and Carmichael, 1974). There is little compositional variation along strike, and certainly no marked change in alkalinity or K_2O content as observed in cross sections of some modern arcs (Nielson and Stoiber, 1973; Hannah, 1980). It seems likely, therefore, that the northern Sierra strata represent a longitudinal section through an island arc. With the arc exposed in only two dimensions, any asymmetry that might indicate arc polarity cannot be observed.

THE PEALE FORMATION

The Peale Formation, as defined in this paper, is restricted to the upper member of the Peale Formation described by McMath (1966). The formation includes vari-colored ribbon chert with thin shale interbeds, fissile mudstone, and predominantly volcanogenic shale, siltstone, and sandstone. Local coarse-grained clastic units include feldspathic wacke, lithic arenite, chert pebble conglomerate, chert breccia, and heterolithic breccia. Thin lenses of highly vesicular felsic hyaloclastite occur locally in the lower part of the section. The thickness and relative abundance of rock types in the Peale Formation vary markedly along strike. Discrete sedimentary layers can seldom be followed for more than a few hundred metres; thick sequences of banded chert pinch out abruptly along strike, clearly terminated by faults in some cases. The Peale Formation appears to have been deposited in small, discontinuous, fault-controlled basins.

The contact between the Peale and underlying Keddie Ridge Formations is placed at the first appearance of rhythmically banded chert, or, in the absence of chert, at the first clastic sedimentary unit not overlain by pyroclastic rocks. The contact is gradational in some areas, and disconformable in others. Thin chert beds occur within the Keddie Ridge Formation, and pyroclastic beds are present in the Peale Formation. These relationships have been observed on Keddie Ridge (Hannah, 1980), in the Taylorsville area (McMath, 1958), and south of the 40th parallel (D'Allura, 1977).

In the central part of the northern Sierra outcrop belt, the Peale Formation is overlain by dark green, augite-rich basalt of the Goodhue Formation, and the contact between them is easily recognized. In other areas, north of Taylorsville and south of Milton Reservoir, the Goodhue basalt is absent, and the Peale is overlain by the Reeve Formation. The contact between the Peale and Reeve Formations is located at the first volcanic flows or breccia or at the dark gray, augite-rich volcanogenic turbidites clearly derived from the Reeve andesite. Coarse sand and pebbles in basal beds of the Reeve turbidite deposits are composed of plagioclase, augite, magnetite, and dark volcanic lithic fragments. These beds are distinctly different from the light colored, plagioclase-rich sandstone of the Peale Formation.

In general, the upper contact of the Peale Formation appears to be paraconformable. At Homer Lake on Keddie Ridge, for example, the contact is demonstrably depositional; shales with thin interbeds of ribbon chert give way to Reeve volcaniclastic rocks with no discordance. Intraformational conglomerates and breccias, however, suggest local erosion prior to deposition of Reeve sedimentary rocks. A significant hiatus in fossil ages between Upper Mississippian to Lower Pennsylvanian Peale chert and overlying Lower to Middle Permian clastic rocks further supports the presence of an unconformity (see discussion below). Schweickert (1981, p. 102) stated that "the Reeve Formation disconformably overlies the Peale, locally occupying channels up to 30 m deep and containing angular fragments of Peale chert."

Age

Fossils from the Peale Formation, as defined here, yield ages ranging from Early Mississippian to Early Permian. Diller (1908) first proposed an uncertain "Carboniferous" age for the Peale Formation on the basis of a collection of fusilinids. Diller's locality has not been relocated. McMath (1966) discovered an Early Mississippian brachiopod fauna near the base of the Peale Formation (as defined herein) in the Taylorsville area. The Early Mississippian age was later substantiated by a single trilobite, also collected by McMath (cited in D'Allura and others, 1977).

Harwood (1983) obtained radiolaria from Peale chert about 10 m below the top of a chert unit exposed in Big Valley Canyon, between Monumental Ridge and the North Fork of the American River. The radiolaria, including *Spongodiscaceid gen. nov.* (tetrahedral), are of Late Mississippian to Early Pennsylvanian age (Holdsworth and Jones, 1980b). Three additional radiolarian faunas have been recovered from two new localities on Keddie Ridge, and identified by D. L. Jones and B. Murchey (1981, written commun.). Two of these new radiolarian faunas were collected from a 65-m section of ribbon chert in the Peale Formation on the northeast flank of Dyer Mountain at the north end of Keddie Ridge (S½, NW¼, NW¼, sec. 31, T. 28 N., R. 9 E.). Figure 3 illustrates the lithologic units and fossil localities within this section. The first fauna, from a black radiolarian spiculite at the base of the section, contains abundant spongy Spumellariina, less common spherical Spumellariina, and "Parahagiastriid" (Holdsworth and Jones, 1980a), as well as *Spongodiscaceid gen. nov.* (tetrahedral). This latest Late Mississippian to Early Pennsylvanian fauna correlates well with the Big Valley Canyon locality 120 km to the south. The second fauna, from a red spiculitic radiolarite from the top of the section, contains "Parahagiastriid" and *Paranaella spp.* of Pennsylvanian age (Holdsworth and Jones, 1980a). The third radiolarian fauna is from gray ribbon chert about 100 m above the base of the Peale Formation at a new locality on Keddie Ridge (SE¼, SW¼, SE¼, sec. 17, T. 27 N., R. 10 E.). The chert is a radiolarian spiculite with poorly preserved radiolaria which appear to correlate with the Late Mississippian–Early Pennsylvanian fauna from Dyer Mountain and Big Valley Canyon.

Fusilinids were discovered at the new Dyer Mountain radiolarian locality in the matrix of a chert pebble conglomerate (Fig. 3). The thin lens of conglomerate crops out 10 m above the radiolarian chert sequence and is separated from it by fine-grained, green feldspathic wacke with no evidence for an intervening discontinuity. About 300 m of fine-grained siltstone and feldspathic wacke separate the conglomerate from overlying volcanic rocks of the Reeve Formation. The poorly preserved fusilinids in the conglomerate matrix are Schwagerinidae, including probable *Schwagerina*, a possible very primitive *Parafusilina*, several biserial foraminifera, and other smaller foraminifers (C. A. Ross, 1980, written commun.). According to Ross, the "age of the fusilinids is fairly certainly Early Permian and probably late Wolfcampian to middle Leonardian as seen in the West Texas standard sections." Although poor preservation precludes unequivocal correlation, the assemblage resembles the fauna of the Early Permian (Wolfcampian to Leonardian) McCloud Limestone in the eastern Klamath Mountains (Irwin, 1966). Dissolution of chert pebbles from the conglomerate yields poorly preserved radiolaria, including *Paronaella impella* (Ormiston and Land) and *Albaillella* sp. (D. L. Jones and B. Murchey, 1981, written commun.). The fauna is of Mississippian-Pennsylvanian age, probably Late Mississippian, and certainly older than the underlying black spiculite.

D'Allura (1977) described fusilinids from the matrix of a chert-bearing breccia near Bowman Lake (SE¼, NW¼, sec. 35, T. 19 N., R. 12 E.), similar to those at the Dyer Mountain locality 100 km to the north. The fauna, examined by C. A. Ross, includes *Schwagerina*, similar to *S. diversiformis*, a probable *Thompsonella*(?), and a single specimen of *triticites*. The fusilinids are probably the same age as those of the lower and middle McCloud Limestone (Wolfcampian to Leonardian).

Prior to the recent radiolaria and fusilinid discoveries on Keddie Ridge, several explanations

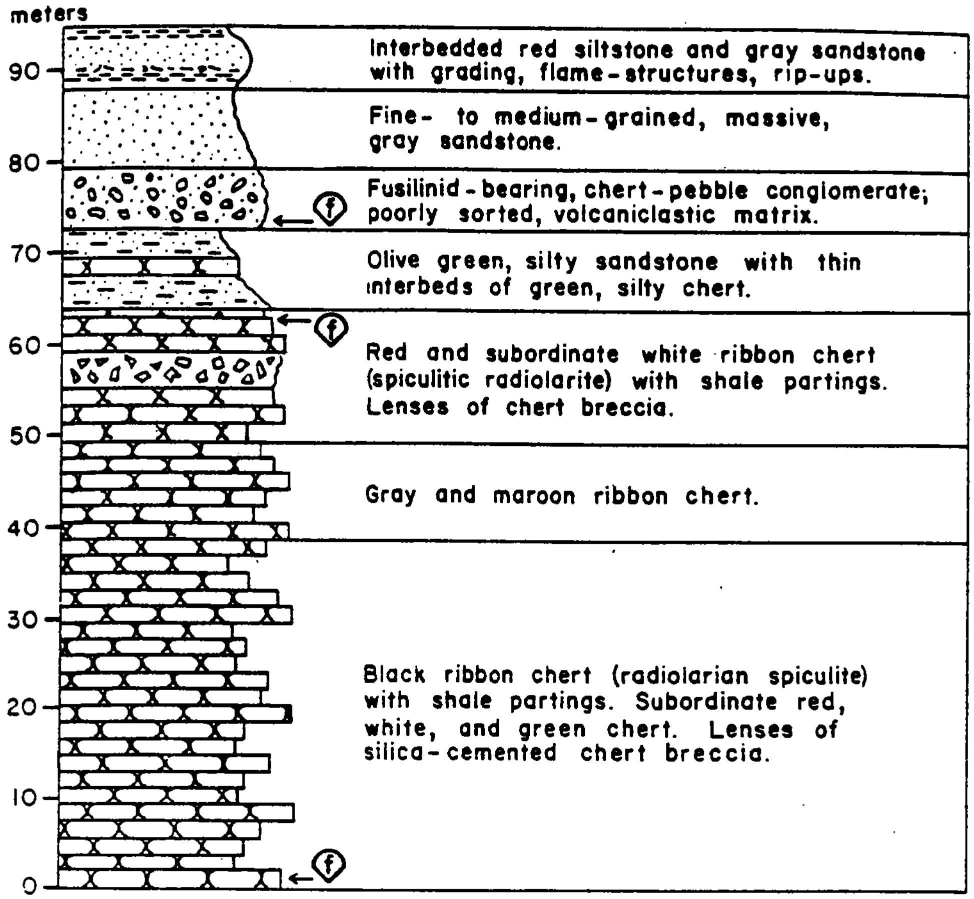

Figure 3. Measured section from the base through the lower half of the Peale Formation near Dyer Mountain. Symbol enclosing "f" indicates stratigraphic position of fossils.

of the disparate ages had been proposed. D'Allura (1977) concluded that the Peale Formation was the result of time-transgressive deposition younging toward the south, or very slow deposition accompanied by local disconformities. Schweickert (1981) helped to confirm the significance of disconformities, suggesting that the fusilinid-bearing breccia near Bowman Lake consists of fragments of Peale chert but that it was deposited at a much later time. The new fossil evidence from the Dyer Mountain locality clearly documents a major depositional hiatus over a stratigraphic interval of only 10 m. The two localities, separated by 100 km, and each made up of Late Mississippian–Early Pennsylvanian chert and Early Permian chert conglomerate/breccia, are strong evidence against time-transgressive deposition. It is reasonable to include all known Permian rocks above the depositional hiatus, whether volcanic or sedimentary, in the Permian Reeve Formation. Until consistent criteria for recognition of the hiatus in the absence of fossil control are agreed upon, however, the Reeve is restricted to the characteristic volcanogenic rocks. The period of apparent nondeposition in the Late Pennsylvanian and Early Permian indicated by the Dyer Mountain and Bowman Lake localities is occupied elsewhere by the Goodhue Formation, for which there is somewhat questionable evidence of a Late Pennsylvanian age (Durrell and D'Allura, 1977).

Environment of Deposition

Ghosts of radiolarian tests and common sponge spicules in the Peale chert suggest an organic source for the silica. All of the preserved radiolaria are sturdy spherical forms filled with quartz that is coarser grained than that of the surrounding chert; preservation of spines and more delicate forms is rare. Early filling of the spherical forms by microcrystalline quartz would aid in preservation. Large vesicles (up to 5 mm) and scoriaceous texture of sparse hyaloclastite suggest relatively shallow depths during early chert deposition. Although intercalated volcanic detritus is restricted to the lowermost part of the section, silica contribution from volcanic glass cannot be ruled out. The widespread occurrence of hematite in the chert and clastic sedimentary rocks suggests an unusually iron- and silica-rich formation water, possibly resulting from devitrification of magnetite-rich volcanic rocks of the underlying Keddie Ridge Formation in regions of high heat flow. Local mounds of massive jasper with specular hematite lining fractures are in places associated with economic manganese deposits (Trask and others, 1943) and are probably volcanic exhalatives. As there is little evidence for significant volcanic activity in the northern Sierra between the Early Mississippian and Early Permian, however, it is reasonable to assume that organic oozes and pelagic clay predominated in sediment-starved areas after input of volcanic debris ceased.

Small-scale folding observed in the Peale chert most likely resulted from slumping prior to complete lithification. Both concentric and similar folds are observed; orientations of bedding and fold axes are inconsistent and bear little relationship to contacts between the chert and adjacent units. Folding is generally restricted to isolated stratigraphic horizons, with undisturbed strata present both above and below. Detached fold noses and piled-up recumbent or nappe-like structures are common. Interbeds of monolithic, silica-cemented, intraformational chert breccia occur within folded sections. Individually, none of these criteria constitutes proof of a slump origin for the folds, but together they provide compelling evidence (Helwig, 1970).

The presence of intraformational chert breccia both within and above the bedded chert, suggests early lithification. If the breccia intercalated with the bedded chert formed by post-lithification disturbance, such as compaction or collapse resulting from volume changes, lithification could have occurred at any time. In an area on Keddie Ridge that was disturbed by injection of mafic pillow lavas, however, heterolithic chert breccia overlain by undisturbed bedded chert strongly suggests early lithification (Hannah, 1980); a thin, late-formed collapse breccia would be monolithic. Drape folds in chert beds overlying knobs of porcelaneous chert also require rapid lithification of the porcelaneous beds. Relict high heat flow from a recently extinct arc or heat associated with basaltic volcanism in a back-arc setting would speed maturation of the chert.

The following model for deposition of the Peale sedimentary rocks is proposed. Volcanism, which began with the Late(?) Devonian Sierra Buttes Formation, ceased rather abruptly in Early Mississippian time. Debris from late volcanic centers was redeposited in some areas, forming feldspathic or lithic sandstones and volcaniclastic sandy siltstone. Other areas received little volcaniclastic debris and accumulated only biogenic material and fine clay. Immediately following the termination of volcanic activity, high heat flow and hydrothermal activity locally produced metalliferous (iron and manganese) jasperoid deposits. Thermal and isostatic adjustments and probable extensional tectonism caused considerable small-scale block faulting, producing localized basins, shifting patterns of clastic deposition, and precipitating slumps and debris flows. The relatively thin chert sequence, perhaps representing 30 to 40 m.y. of geologic time, may have accumulated at rates as low as 1 mm per thousand years. Rapid diagenesis of organic-rich pelagic oozes thus could have produced lithified chert at only a few metres depth. Pauses in sedimentation, or local removal of unconsolidated sediment by slumping or scouring, could readily expose already lithified chert to erosional processes. Slow sedimentation and local erosion on an irregular topography inherited from an extinct island arc and enhanced by block-faulting continued until volcanism resumed in Late Pennsylvanian or middle Permian time.

THE PERMIAN VOLCANIC SEQUENCE

Upper Pennsylvanian and Permian volcanic rocks overlying the Peale Formation have been divided into four units: pyroxene-rich, green metabasalt of the Goodhue Formation; coarse, plagioclase-rich, gray andesite porphyry of the Reeve Formation; fine-grained tuff, volcanogenic sandstone, and shale of the Robinson Formation; and tuff, volcaniclastic rocks, shale, and limestone of the Arlington Formation, the lateral equivalent of the other three units.

As noted previously, the contact between the Peale and Goodhue Formations appears to be conformable and, in some areas, gradational. Where the Goodhue Formation is missing, north of Taylorsville and south of Milton Reservoir, there is a significant hiatus between the Peale chert and overlying volcaniclastic rocks, but there is little evidence for angular discordance.

The contact between the Goodhue and Reeve Formations is commonly concealed. McMath (1958) found no evidence for an unconformity between the two units on Grizzly Ridge. D'Allura (1977) argued that the contact is both gradational and conformable, as rock types with characteristics of both units are found near the contact. Exposures along Haypress Creek east of Sierra City show intercalation of the two rock types (Schweickert, 1984, personal commun.). On Keddie Ridge, the presence of basalt or diabase typical of the Goodhue Formation both above and below the Peale-Reeve contact indicates that pyroxene-rich basaltic lavas were not restricted to a single rock-stratigraphic unit or to a narrow time span in the Paleozoic.

McMath (1958) suggests the possibility of a local unconformity at the Reeve-Robinson contact, as Reeve-type clasts are found in the basal 30 m of the Robinson Formation. Occurrences of this sort are expected in active volcanic terranes and do not imply major pre-Robinson erosion.

Intercalation of the Peale and Arlington rock types indicates that their contact is gradational and probably conformable (McMath, 1958). Contacts within the Permian sequence are generally conformable and gradational, and local unconformities probably reflect topographic irregularities or distance from volcanic sources.

In most of the northern half of the Paleozoic outcrop belt, the Taylorsville fault truncates the Permian section. In a small area northeast of Genesee, however, a limited section of Triassic rocks, represented by the Hosselkus Limestone and Swearinger Slate, overlaps both the Reeve and Robinson Formations, apparently unconformably (McMath, 1966). The upper contact of the Arlington Formation is not exposed in the Hough Block. On the east limb of the Almanor Anticline, the Arlington Formation is cut off by the Grizzly Mountain fault or, near Lake Almanor, occupies the core of a syncline (D'Allura and others, 1977). On the west limb of the Almanor Anticline, the Arlington Formation is in fault contact with the Feather River Peridotite (Heitanen, 1973). In the southern extension of the Hough Block, the Permian section appears to be overlain unconformably by Jurassic volcanic rocks (D'Allura and others, 1977). Near the North Fork of the American River, a marked angular unconformity separates the Paleozoic section from the overlying Triassic limestone (Clark and others, 1962; Harwood, 1983).

Age

The age of the Goodhue Formation is based on a single, controversial specimen of *Helicoprion sierrensis*, which ranges from Late Pennsylvanian to Early Permian (D'Allura, 1977). The fossil is from a boulder in glacial debris included in the alluvial fan of Frazier Creek. C. Durrell examined the matrix of the Helicoprion boulder, however, and argued convincingly for its derivation from an unusual hornblende tuff at the base of the Goodhue Formation, where other indeterminate marine fossils occur (Durrell and D'Allura, 1977). The base of the Goodhue Formation in the Lakes basin area is thus apparently no older than Late Pennsylvanian.

The Reeve Formation of the Genesee Block contains several fossil localities and is clearly middle Permian in age. Three Permian(?) fossil assemblages, placed in the Robinson Formation by Diller (1908), fall in the Reeve Formation as defined by McMath (1958). In addition, McMath (1958) noted large fusilinids at several localities in Reeve calcarenite and calcareous tuff. D'Allura (1977) resampled the Little Grizzly Creek locality described by Turner (1894), which is about 100 m above the contact with the Goodhue Formation. The assemblage, particularly the brachiopod genus *Megousia*, indicates an Early Permian age, probably Leonardian or Guadalupian. Two brachiopod genera from the Little Grizzly Creek locality, *Megousia* and *Neospirifer*, have also been found near Clio, confirming the middle Permian age. Another similar assemblage, not yet fully described, occurs in the basal beds of Reeve turbidites on knobs east of Homer Lake, in the NE¼, NW¼, sec. 9, T. 27 N., R. 9 E.

The exact age of the Robinson Formation remains uncertain. Only one of the Robinson Formation localities described by Diller (1908) is contained in the more restricted Robinson Formation defined by McMath (1958). Some of the genera listed by Diller (1908) are restricted to the Permian period. The Robinson is overlain unconformably by the Upper Triassic (Norian Stage) Hosselkus Limestone. Because the contact of the Robinson with the underlying Reeve Formation is gradational, the Robinson probably does not extend into the Triassic period.

The Arlington Formation on the east limb of the Almanor Anticline, including the type locality, has not yielded any fossils. On the west limb, however, Robinson (1975) described two important fossiliferous limestone units. A bed of massive, gray oolitic limestone with abundant fossils occurs near the base of the formation. The assemblage is correlative with Zone A of the McCloud Limestone in the eastern Klamath Mountains, which is of early Wolfcampian (Early Permian) age (Wilde, 1971). A black to gray, recrystallized limestone containing pentacrinus, ammonites, belemnites, brachiopods, and *Halobia* occurs near the top of the Arlington Formation. The assemblage is of early Norian age and probably correlates with the Hosselkus Limestone in the Genesee Block (N. J. Silberling, cited by Robinson, 1975). Assuming that Robinson's correlation with the Arlington of the east limb is correct, then, the Arlington Formation spans most of the Permian and Triassic periods. The fossil evidence therefore supports (1) the correlation of the Arlington with the Permian Goodhue, Reeve, and Robinson Formations and also with the Triassic Hosselkus Limestone and Swearinger Slate (McMath, 1966) of the Genesee Block; and (2) correlation of these Permian rocks with the McCloud Limestone of the Eastern Klamath Belt (Irwin, 1977).

Origin of the Permian Volcanic Sequence

The oldest dated unit in the Permian volcanic sequence is the hornblende-bearing andesite tuff at the base of the Goodhue Formation in the Lakes basin area. These tuffs grade upward into the more typical pyroxene-rich Goodhue basalt. Although the tuff unit is as much as 1,200 m thick in the Lakes basin area (Durrell and D'Allura, 1977), it pinches out to the north and south, where the Goodhue basalt rests directly on sedimentary rocks of the Peale Formation. Near-vent facies of the basalt have been identified in the thick Goodhue sections on Grizzly Ridge and in the Lakes basin area and in the pillow lava sequence near Sierra City (D'Allura and others, 1977). In some areas, the Goodhue basalt was not deposited, and local unconformities separate Peale sedimentary rocks from overlying Reeve volcanic or volcaniclastic rocks.

The characteristic plagioclase-rich andesite porphyry of the Reeve Formation is much more extensive laterally than is the Goodhue basalt. The onset of andesitic volcanism was not synchronous everywhere; slight temporal variations in the initiation of volcanism are illustrated by the relationships between turbidite beds at the base of the Reeve Formation and a large intrusion of Reeve porphyry, both exposed near Homer Lake on Keddie Ridge (Hannah, 1980). Andesite porphyry pebbles in basal beds of the turbidites are virtually identical to the adjacent plagioclase porphyry, yet the contact is clearly intrusive. The shallow intrusive body must have been a late, but essentially identical, phase of volcanism which began slightly earlier in adjacent terranes. Nearby flows of the andesite porphyry fed debris into the basin now exposed near Homer Lake. The poorly consolidated debris was subsequently intruded by magma from the same source. This interpretation is compatible with evidence for emplacement of the porphyry into wet, poorly consolidated sediment. As the magma contacted wet sediment, explosive reactions shot fragments of partially molten rock into the soft material, producing a complex mixture of porphyry enclosed in bedded sedimentary rocks, and epidotized, deformed sedimentary inclusions in the porphyry.

Several features of the turbidite beds in the Reeve Formation indicate a proximal setting (Walker, 1967): (1) thick, coarse-grained beds; (2) irregular bedding thicknesses; (3) high sand/mud ratios; (4) amalgamated sandstones; (5) scour marks; and (6) sparse laminations and ripples. The turbidite exposures, which terminate abruptly along strike, most likely represent deep channels on the flanks of submarine volcanoes or small intra-arc basins. Because the depositional sites were local features, current-direction indicators and relative proximity of the sequences to volcanic sources are of little use in establishing the orientation of the volcanic arc on a regional scale.

The Permian volcanic sequence was erupted in an area of considerable relief, as indicated by abrupt thickness and facies changes along strike. Markedly lenticular outcrops of basin deposits indicate development of volcanic edifices and intervening basins. Diverse amygdule size and abundance further suggest variable water depths. Locally, moderate to shallow water depths are suggested by crinoids, foraminifera, and brachiopods and by oolitic limestone near the base of the Arlington Formation. No obvious subaerial deposits have been recognized; pillow lavas and turbidites are widespread, and marine invertebrates are present at several stratigraphic horizons.

The abundance of pyroclastic debris and the intermediate volcanic rocks of nonalkaline parentage clearly place the Permian volcanic sequence in an arc setting. Trace-element data suggest a relatively immature volcanic arc dominated by magmas of the low-potassium tholeiite suite (Hannah, 1980; Brooks and Coles, 1980). The Permian rocks are, in general, less siliceous, less voluminous, and less varied than are the Devonian volcanic rocks.

Termination of Permian volcanism is not well dated. Near Butt Valley Reservoir, Lower Permian pyroclastic rocks grade upward through a thick sequence of unfossiliferous black shales into Upper Triassic limestone. In the Genesee Block, the upper boundary of the Permian section occurs at an angular unconformity or is marked by the Taylorsville fault. South of Walkermine, the Taylorsville fault is not recognized, and Mesozoic rocks rest unconformably on Paleozoic units. The widespread pre–Late Triassic unconformity indicates uplift and erosion at some time in the Permo-Triassic.

THE TRIASSIC SEQUENCE

Triassic rocks have been documented in only three areas: (1) the Hosselkus Limestone and overlying Swearinger Slate north of Genesee, (2) the Norian limestone and enclosing shale at the top of the Arlington Formation near the Feather River Peridotite, and (3) the "unnamed" limestone of Harwood (1983) just north of the North Fork of the American River (see also Clark and others, 1962; McMath, 1966; D'Allura, 1977). The Late Triassic age assigned to the Hosselkus and Swearinger Formations by Hyatt (1892) has been substantiated by later studies. The presence of *Monotis subcircularis* Gabb indicates a probable late Norian age and a shallow-water environment (Westermann, 1962, cited by McMath, 1966). Similar fossil assemblages and rock types support correlation of the three northern Sierra Triassic exposures and the "Hosselkus" Limestone, Brock Shale, and Pit Formation of the Eastern Klamath Belt (Albers and Robertson, 1961; Silberling and Irwin, 1962).

At the North Fork of the American River, the unconformity between the Permian volcanic sequence and the Triassic section is profound, with angular discordances up to 90°. No unconformity has been documented between the Triassic rocks and overlying Lower Jurassic strata. If an unconformity exists, both the time elapsed and the angular discordance are slight compared to the Permo-Triassic break (Clark and others, 1962; Harwood, 1983).

DISCUSSION

The northern Sierra section represents a nearly continuous depositional sequence from lower Paleozoic through Upper Jurassic. Documented orogenic events disturbed the sequence three times: (1) mid-Paleozoic deformation of the Shoo Fly Complex; (2) the Permo-Triassic depositional hiatus and local angular unconformity between the Lower Permian and Upper Triassic strata; and (3) the Late Jurassic Nevadan orogeny, which strongly deformed the entire sequence. It is not clear whether the first two events had any connection with the Late Devonian–Early Mississippian Antler orogeny or Permo-Triassic Sonoma orogeny of the Great Basin.

A major outstanding question is whether the northern Sierra Paleozoic section formed near the margin of the North American craton or represents a far-traveled allochthonous terrane. Paleomagnetic pole positions for Permian and Devonian rocks were reset during the Nevadan orogeny but demonstrate that the section was fixed to North America by Late Jurassic time (Hannah and Verosub, 1980). Triassic fauna tie the Sierra section to the eastern Klamath section by Late Triassic time. The Early Permian fusilinid assemblage in chert-pebble conglomerate/breccia resembles the McCloud Limestone fauna of the eastern Klamaths, although unequivocal correlation is prohibited by poor preservation. The Late Ordovician Montgomery Limestone megafossils are similar to correlative faunas in the Klamaths, and its conodont assemblage is common on the North American craton. Boucot and Potter (1977) suggested that Ordovician, Devonian, and Permian faunas in the Klamath Mountains have North American affinities. The same appears to be true of the northern Sierra section; an exotic origin is not required by known fossil assemblages.

The following sequence of events, similar to that proposed by D'Allura and others (1977) and Varga and Moores (1981), is consistent with observations in the northern Sierra. The Shoo Fly sedimentary section was deposited in a continental slope-rise setting on the western margin of the North American craton. The mélange zone developed as Shoo Fly rocks were drawn into a west-dipping subduction zone. Slide blocks of fringing carbonates, oceanic basement rocks, and air- or water-transported tuffs from an approaching volcanic arc were incorporated into the uppermost part of the section. Impingement of buoyant continental material in Late Silurian–Early Devonian time caused the subduction zone to step outboard and reverse polarity. The suture prograded eastward, culminating in the emplacement of the Roberts Mountain allochthon (the classical Antler orogeny) in the latest Devonian (Roberts and others, 1958). Schweickert and Snyder (1981) propose that the pre-Devonian arc was subsequently transported northward and currently resides in the Alexander terrane of southwestern Alaska. Alternatively, remnants of the arc may be represented by Ordovician to Devonian plutonic and volcanogenic rocks in the Klamath Mountains (see, for example, Irwin. 1977). Arc volcanism resumed in the Early or Middle Devonian, depositing volcanic material on top of the deformed Shoo Fly Complex. An early phase of arc volcanism may be represented by boninites and arc tholeiites of the Copley Greenstone in the Eastern Klamaths (Lapierre and others, 1985). By Early Mississippian time. extension within the arc resulted in block faulting and volcanic quiescence in the Sierra and an oceanic basin in central Nevada (Schweickert and Snyder, 1981). If arc volcanism continued, it was well outboard of present exposures and contributed little to the northern Sierra section. Collapse of this back-arc basin or renewed westward subduction, perhaps the result of increased convergence rates in the Early Permian, may have resulted in arc volcanism in the Sierra and emplacement of the Golconda allochthon (Sonoma orogeny) in central Nevada (but see Ketner, 1984). Relatively mild deformation associated with the Sonoma event produced no penetrative foliation in the northern Sierra. Transcurrent motion in the Triassic truncated Paleozoic structural trends prior to deposition of Late Triassic limestone and Jurassic arc volcanic rocks (Schweickert, 1976).

SUMMARY

Quartzose sandstones of the lower Paleozoic Shoo Fly Complex require a 2.09-b.y.-old, plutonic-metamorphic source terrane; the North American craton is permitted. Arkose within Shoo Fly mélange requires a 506-m.y.-old volcano-plutonic source, possibly a nearby continental fragment which was subsequently transported away (Alexander Terrane?). The Montgomery Limestone fauna are characteristic of shallow-water, equatorial environments and do not require an exotic source. The phosphatic chert must have formed in areas of coastal upwelling between the 40th parallels. The Shoo Fly sedimentary rocks and mélange may have traveled little from their original location.

The Devonian volcanic sequence was deposited unconformably on the Shoo Fly Complex. Although marked paleo-relief produced local areas of erosion or nondeposition, no significant regional unconformities have been documented. The exposures constitute a longitudinal section through a relatively immature volcanic arc dominated by tholeiitic magmas. Again, fossil assemblages and phosphatic chert indicate arc development on or near the North American continent, not far from its present location. New U-Pb ages for granitoids that intrude the Shoo Fly Complex and Sierra Buttes Formation indicate onset of magmatism in the Early Devonian.

The upper and lower members of the Peale Formation are given formation status. Both are discrete, mappable units and are continuous through most of the northern Sierra Paleozoic outcrop belt. They have distinct ages, lithologies, and depositional environments. The name "Keddie Ridge Formation" is assigned to the lower member, and the name "Peale Formation" is retained for the more extensive and better-known upper member.

Two new radiolarian localities in the Peale chert on Keddie Ridge at the north end of the Paleozoic outcrop belt correlate well with a previously described locality at the south end of the belt. The radiolarian faunas constrain the age of the chert to Late Mississippian–Early Pennsylvanian and rule out time-transgressive deposition.

Four fossil assemblages in a measured section of the Peale Formation document a depositional hiatus between Early Pennsylvanian and Early Permian. Clastic rocks overlying the Peale chert, including chert breccia and chert-pebble conglomerate, are perhaps more appropriately included in the Early Permian Reeve Formation. In some areas, the depositional hiatus is occupied, in part, by the Late Pennsylvanian(?) volcanic rocks of the Goodhue Formation.

The Peale Formation contains widespread occurrences of soft-sediment deformation, slump structures, and intraformational breccia. These features, along with abrupt termination of thick sequences along strike, strongly suggest deposition in local basins, with sporadic disturbance and redeposition in a tectonically active arc system after cessation of volcanism. Local intrusion of pillow basalts into the chert indicates possible back-arc spreading.

Sedimentary rocks of the Peale Formation are succeeded by an Upper Pennsylvanian(?) to Lower Permian volcanic sequence, with no evidence for discordance. In two geographically separate areas, an angular unconformity between the Lower Permian volcanic rocks and Upper Triassic limestone is well documented. In the extreme northwest, however, no break is discerned in the shales that separate two limestone units of Early Permian and Late Triassic age, grouped, perhaps inappropriately, in the Arlington Formation.

Correlation of the northern Sierra section with contemporaneous rocks in the Klamath Mountains and the Great Basin remain tentative. New paleontologic and stratigraphic constraints, however, do not require an exotic origin for the Sierra section and provide additional links among the three terranes.

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