Stratigraphy and structure of the Schoonover sequence, northeastern Nevada: Implications for Paleozoic plate-margin tectonics

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ABSTRACT

Radiolarian biostratigraphy and detailed geologic mapping have been used to resolve the complex structure and stratigraphy of part of the Golconda allochthon in the Independence Mountains, Nevada. Here, the Schoonover sequence is latest Devonian to Early Permian in age, spanning the time interval from the emplacement of the Roberts Mountains allochthon onto the shelf in the earliest Mississippian Antler orogeny to the inception of the Sonoma orogeny. The history of the Schoonover basin is tied to that of the adjacent shelf in Nevada and provides important insights into the upper Paleozoic paleogeographic framework of the continental margin.

In the Schoonover sequence, latest Devonian (Famennian) chert overlies basaltic and andesitic greenstone and is in turn overlain by Early Mississippian (Kinderhookian) chert interbedded with tuff and volcaniclastic rocks derived from an island arc. The Kinderhookian volcaniclastic rocks grade upward, with no obvious depositional break, into siliciclastic turbidites and pebbly mudstones that contain debris derived primarily from erosion of the Antler orogenic belt, although in some beds volcanic rock fragments and greenschist-grade metasedimentary clasts are also common. The age of underlying (Kinderhookian) and interbedded and overlying (Osagian to Meramecian) chert sequences indicates that the siliciclastic turbidites are synchronous with the early deposits of the autochthonous foredeep basin of the Antler orogenic belt. The dual or composite source terranes represented by the Schoonover siliciclastic rocks place the basin between an arc and the Antler orogen on the edge of the shelf.

Meramecian-age basalt flows in the Schoonover are coeval with subsidence and basaltic volcanism in autochthonous shelf sequences in northern Nevada, suggesting that a rifting event may have occasioned the end of Antler-age compression in Nevada. The onset of limestone turbidite deposition in the Schoonover corresponds to the re-establishment of carbonate shelf conditions on the continental margin in latest Mississippian–earliest Pennsylvanian time.

The Late Devonian–earliest Mississippian part of the Schoonover depositional history has not yet been documented elsewhere in the Golconda allochthon, but Late Mississippian to Permian rocks in the Schoonover sequence are analogous to those of the Havallah sequence, suggesting deposition in the same basin.

Thrust faults in the Schoonover repeat the Late Devonian to Permian section, detaching the basinal sequence from its depositional basement. Thrust faults extend along strike for at least 10 km, but thrust plates are <1 km thick, reflecting the originally thin sequence involved in thrusting. Fold and fault data indicate that thrust plates formed and were emplaced due to northwest-southeast shortening and southeast-directed thrusting. Deformation within the allochthon postdates deposition of Early Permian strata, and the emplacement of the allochthon postdates deposition of latest Permian autochthonous strata and predates intrusion of Jurassic plutons.

The stratigraphic relations documented in the Schoonover sequence are compatible with a back-arc thrusting model for the formation of both the Roberts Mountains and Golconda allochthons, but they are more difficult to reconcile with models that interpret the allochthons as accretionary prisms developed in front of farther-traveled arcs that collided with a passive margin.

In a broader context, the stratigraphy of upper Paleozoic allochthonous rocks in Nevada records short-lived episodes of crustal shortening along the continental margin, separated by longer episodes of extensional and/or transcurrent tectonics. This data suggest that the western United States was a southwest Pacific–style active margin at least as far back as the Devonian.

INTRODUCTION AND REGIONAL GEOLOGIC SETTING

Continental-shelf sedimentation in Nevada was first interrupted by the Late Devonian–Early Mississippian Antler orogeny, when a basinal sequence of Cambrian to Late Devonian rocks was emplaced onto the edge of the continental shelf along the Roberts Mountains thrust (Roberts and others, 1958; Johnson and Pendergast, 1981; Nilsen and Stewart 1980) (Fig. 1). Erosion of the Roberts Mountains allochthon in the late Paleozoic shed sediment eastward into the Antler foredeep basin (Poole and Sandberg, 1977; Speed and Sleep, 1982; Harbaugh and Dickinson, 1981), and the allochthon itself was unconformably overlain by Late Mississippian to Permian shelf deposits (Roberts and others, 1958; Saller and Dickinson, 1982; Miller and others, 1981; Little, 1983). The old edge of the continental shelf, now covered by the Roberts Mountains allochthon and younger overlying sedimentary rocks, was again overridden by the Golconda allochthon during the latest Permian to Early Triassic Sonoma orogeny (Silberling and Roberts, 1962). The Golconda allochthon consists of an upper Paleozoic basinal sequence (the Havallah sequence) that was carried eastward or southeastward along the Golconda thrust (Fig. 1) (Roberts, 1964; Silberling and Roberts, 1962; Stewart and others, 1977; Silberling, 1973; Speed, 1979; Gabrielse and others, 1983).

The complex structure and the lack of a well-defined stratigraphic sequence within both of these allochthons make it difficult to reconstruct their prethrusting paleogeography, but the details of this paleogeography are required if the plate-margin tectonics that deformed and emplaced these rocks are to be understood. The possible causes and mechanisms for

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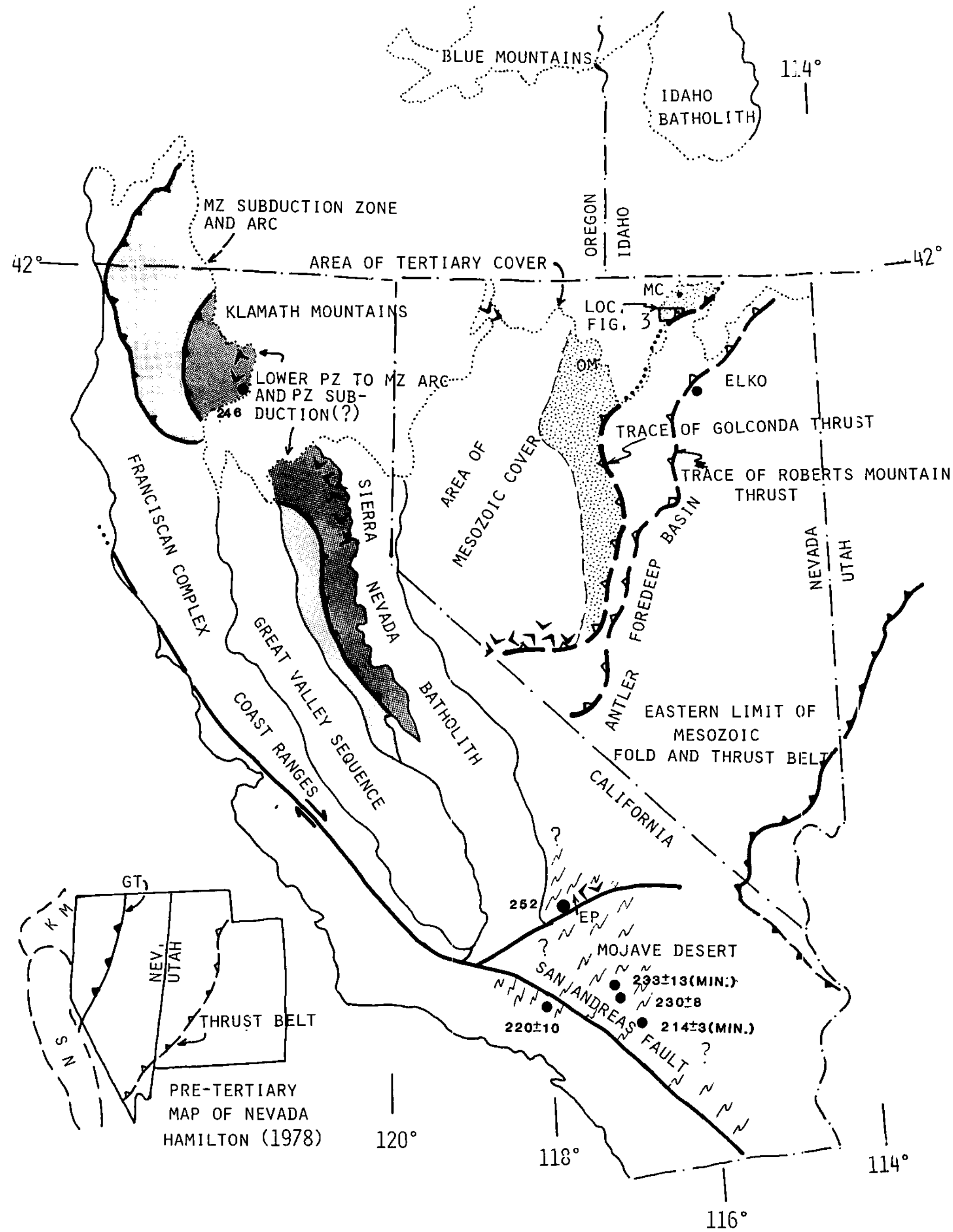

Figure 1. Index map showing locations of rock assemblages and tectonic features discussed in text, modified from King (1969). Trace of Golconda thrust and Roberts Mountains thrust is based on the eastern limit of exposures of the two allochthons. The interpretation of rock assemblages in the Klamath Mountains and northern Sierras follows that of many authors and is summarized in Burchfiel and Davis (1975). Inset emphasizes that the (now) scattered terranes discussed in text probably were much closer together in the Mesozoic and Paleozoic, and that the amount of overlap or overthrusting represented by the two allochthons in Nevada has been exaggerated by ~ 100% Tertiary extension across the Basin and Range Province (Hamilton, 1978; Hamilton and Myers, 1966). Permo-Triassic-age volcanic rocks (v's), plutons (dots with ages), and metamorphism (squiggles) compiled from Lanphere and others (1968), D'Allura and others (1977), and Jennings (1977) for the Klamaths and northern Sierras; Speed (1977b) for Nevada; and Silver (1971), Miller (1978), Cox and Morton (1980), Carr and others (1980), Miller and Sutter (1982), Cameron (1981), and Miller and Cameron (1982) for the Mojave-El Paso Mountains region. Some pluton ages represent ^{40}Ar-^{39}Ar minimum ages on hornblende (Min.). MC, Mountain City; GT, Golconda thrust; KM, Klamath Mountains; SN, Sierra Nevada; OM, Osgood Mountains; EP, El Paso Mountains.

the emplacement of the Nevada allochthons have been reviewed by Burchfiel and Davis (1972, 1975), Silberling (1973), Dickinson (1977), Speed (1978), Schweickert and Snyder (1981), Nilsen and Stewart (1980), Speed and Sleep (1982), Johnson and Pendergast (1981), Dickinson and others (1983), and Snyder and Brueckner (1983). The two models most frequently proposed are shown schematically in Figure 2 (see below). (1) The allochthons represent strata deposited between the North American continent and a west-facing island-arc system and were emplaced by thrusting during back-arc basin closure; and (2) the allochthons represent the continentward toes of large accretionary prisms developed in front of farther-traveled, east-facing arcs that collided with the continent. Model 1 implicitly acknowledges the presence of an adjacent offshore arc during the Paleozoic. This arc is thought by some to be represented by the record of intermittent Devonian through Jurassic arc volcanism in the eastern Klamath Mountains–northern Sierras (Murray and Condie, 1973; D'Allura and others, 1977; Irwin, 1981; Wright, 1982; Miller, 1983), but the geologic ties of these rock assemblages to the Nevada allochthons remain unknown, in part because of intervening younger cover (Fig. 1). The style of deformation and east-verging structures in the allochthons has most frequently been cited in support of model 2. However, the similarity in structural style and evolution of both thrust belts and subduction complexes (Lowell, 1977; Hamilton, 1979; Bally and Snelson, 1980; Suppe, 1981; Davis and others, 1983) precludes using these criteria alone to resolve the plate-tectonic setting of the allochthons.

In order to discriminate between these or other models, we need to know the exact ages, paleogeography, depositional history, and structural

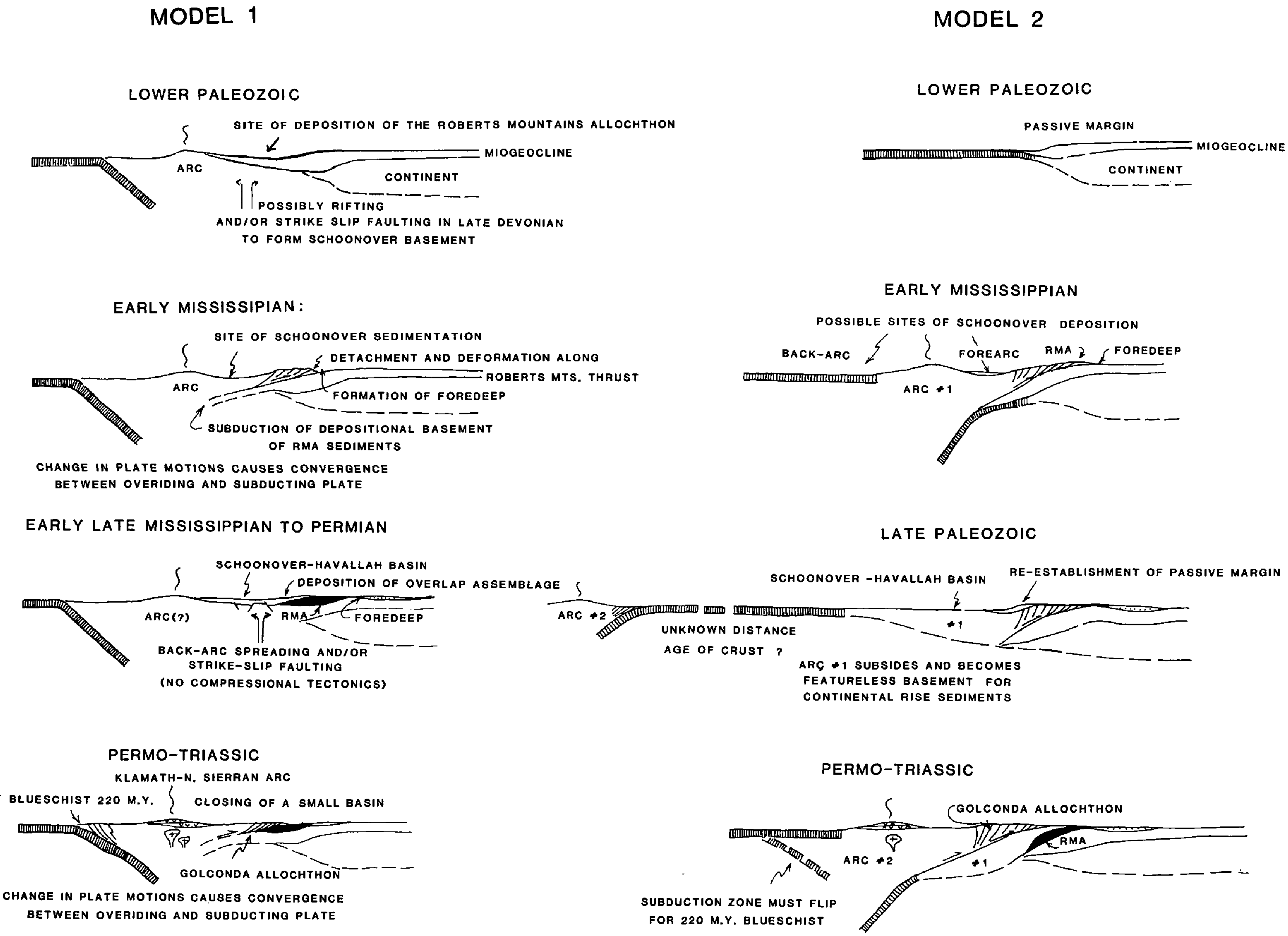

Figure 2. Most frequently proposed plate-tectonic models for the Antler and Sonoma orogenies. Model 1 in general represents that of Burchfiel and Davis (1972, 1975) and Silberling (1973), with additional possibilities reflecting data discussed in this paper. Model 2 is that of Speed (1979), Speed and Sleep (1982), Snyder and Brueckner (1983), and Dickinson and others (1983). For details, see text. RMA, Roberts Mountains allochthon. *Note:* transcurrent tectonics during any of these time spans is a possibility mentioned in the text but not generally depicted in these simplistic cross sections.

stacking order of rocks within the allochthons. If the allochthons represent long-lived subduction-zone accretionary prisms, for instance, they would be expected to exhibit a protracted deformational history and to contain offscraped sediments from extensive tracts of subducted sea floor as well as North American slope and rise deposits in their continentward toes. If the allochthons represent back-arc or marginal basin deposits, they should contain evidence suggesting proximity to both the continent and a bordering island arc and/or evidence suggesting deposition in relatively small basins.

The Antler and Sonoma orogenies thus raise important questions concerning the growth of the western United States continental margin. Did the margin grow successively oceanward by the collision of island arcs the history of which was independent of that of the North American plate? Or was western North America an active margin throughout the Paleozoic, with a fringing system of southwest Pacific–style island arcs and small oceanic basins accreted during episodes of increased plate convergence?

Radiolarian biostratigraphy and detailed mapping in the Independence Mountains, Nevada, have enabled us to unravel the stratigraphy of part of the basin that closed to form the Golconda allochthon. These new data allow valuable insight into the Paleozoic paleogeography and plate-tectonic history of the Cordilleran continental margin during both the Antler and Sonoma orogenies.

INTRODUCTION TO THE GEOLOGY OF THE NORTHERN INDEPENDENCE MOUNTAINS, NEVADA

In the Independence Mountains (Fig. 1), basinal rocks of the Roberts Mountains allochthon are thrust over lower Paleozoic autochthonous and parautochthonous strata of the Cordilleran miogeocline (Kerr, 1962; Churkin and Kay, 1967). Along the southeastern edge of the map area shown in Figure 3,[1] the Roberts Mountains allochthon is unconformably overlain by Late Mississippian conglomerate, sandstone, and shallow-water limestone (Miller and others, 1981). Both the allochthon and the autochthon subsequently were cut by high-angle faults and, following further erosion, Permian shallow-water to slope-facies strata were deposited unconformably over both lower- and upper-plate rocks of the Roberts Mountains thrust (Miller and others, 1981) (Fig. 3).

The upper Paleozoic Schoonover sequence is thrust over all of these units and is in turn unconformably overlain by late Eocene–Oligocene (Hope and Coats, 1976) volcanic rocks. Fagan (1962) first mapped and described the "Schoonover Formation" in detail and divided it into ten stratigraphic members. Fagan described small-scale folding and thrusting in the Schoonover, but without radiolarian biostratigraphy it was impossible for him to document the repetition of section by imbricate thrust faults now known to exist within the sequence. For this reason, we refer informally to these rocks as the Schoonover "sequence." Like Stewart (1980), we consider the Schoonover sequence to be part of the Golconda allochthon, because (1) it is in large part coeval with, (2) it is lithologically similar to, and (3) it has a deformational history identical to that of the Havallah sequence of the Golconda allochthon (Miller and others, 1981, 1982, and this work). The emplacement of the Schoonover allochthon occurred between latest Permian (the age of the youngest autochthonous rocks beneath the thrust) and Late Jurassic time (the age of a post-emplacement pluton to the north of the map area) (Coats and McKee, 1972; Decker, 1962). On the basis of all of the above points, it is likely that the basal Schoonover thrust is equivalent to the Golconda thrust.

[1]Figure 3 is a folded insert in this issue.

The geologic map of the Schoonover sequence in Figure 3 is based on four summers of detailed mapping coupled with the study of more than 230 radiolarian assemblages. Our understanding of Schoonover rocks has evolved slowly because of the need to understand simultaneously the complex structure and original stratigraphy of the allochthon as well as the sequence of radiolarian faunas. The discussion below first addresses the stratigraphy and paleogeography of the Schoonover basin and then describes the geometry and style of basin closure by thrust faulting. In the interest of space, details of the paleontology, sedimentary facies, and sandstone petrography of Schoonover strata are only summarized here and are presented separately (B. K. Holdsworth and others, unpub. data; Whiteford, 1984).

STRATIGRAPHY AND PALEOGEOGRAPHY OF THE SCHOONOVER ALLOCHTHON

Introduction

Thrust faults within the lower part of the Schoonover allochthon repeat a latest Devonian to earliest Permian stratigraphic succession (Fig. 3). The structure of the upper part of the allochthon, which consists of poorly exposed Pennsylvanian-Permian chert-argillite and limestone turbidites, is not as well known.

Reconstructed "stratigraphic" columns of the Schoonover are shown in Figure 4. Although many small-scale folds occur within less competent lithologies, and sections are frequently incomplete due to thrust faulting, stratigraphic contacts between lithologies can be demonstrated at many locations. Documentation of these stratigraphic contacts, together with ages of radiolarian assemblages from interbedded chert, forms the basis of our reconstructed stratigraphy.

Radiolaria collections are allocated to one of ten "Schoonover Groups" (1 to 6b), a classification according to deduced age made on the basis of the principles of Holdsworth and Jones (1980a, 1980b) that take into account relevant information obtained since 1980 (see Appendix).

Stratigraphy

The oldest chert units (DMca map unit) in the Schoonover allochthon are sometimes manganiferous, contain red jasperoid lenses, and are latest Devonian to Kinderhookian in age (Groups 1 to 2a). In many of the thrust plates, chert of this age depositionally overlies greenstone the base of which is always a thrust fault (Figs. 3, 4). Along the highest mapped thrust fault in the very northeastern part of the map area, Kinderhookian chert depositionally overlies hornblende-pyroxene andesite.

Tuffaceous sediments are interbedded with Group 2a chert, but older, underlying Group 1 chert is volcanic-free. In the lower thrust plates, thin (millimetres to centimetres in thickness) tuffaceous horizons are succeeded by thicker tuff beds and coarse volcanic breccias, of strictly Kinderhookian age (2a). In structurally higher thrust plate H, very thick beds (as much as several metres) of plagioclase and volcanic graywacke are present (Msv map unit). All Schoonover thrust plates that contain the basal portion of the stratigraphic section include these distinctive volcaniclastic horizons of Kinderhookian (Group 2a) age, except for the highest thrust plates, where they are rare to absent and are represented instead by coeval chert and possibly by andesite flows. On the basis of composition and texture, the Kinderhookian volcanogenic units are similar to sediments of known magmatic-arc provenance (Whiteford, 1984).

Interbedded with and succeeding the volcanogenic units, with no obvious depositional break, there are turbidite sequences composed of

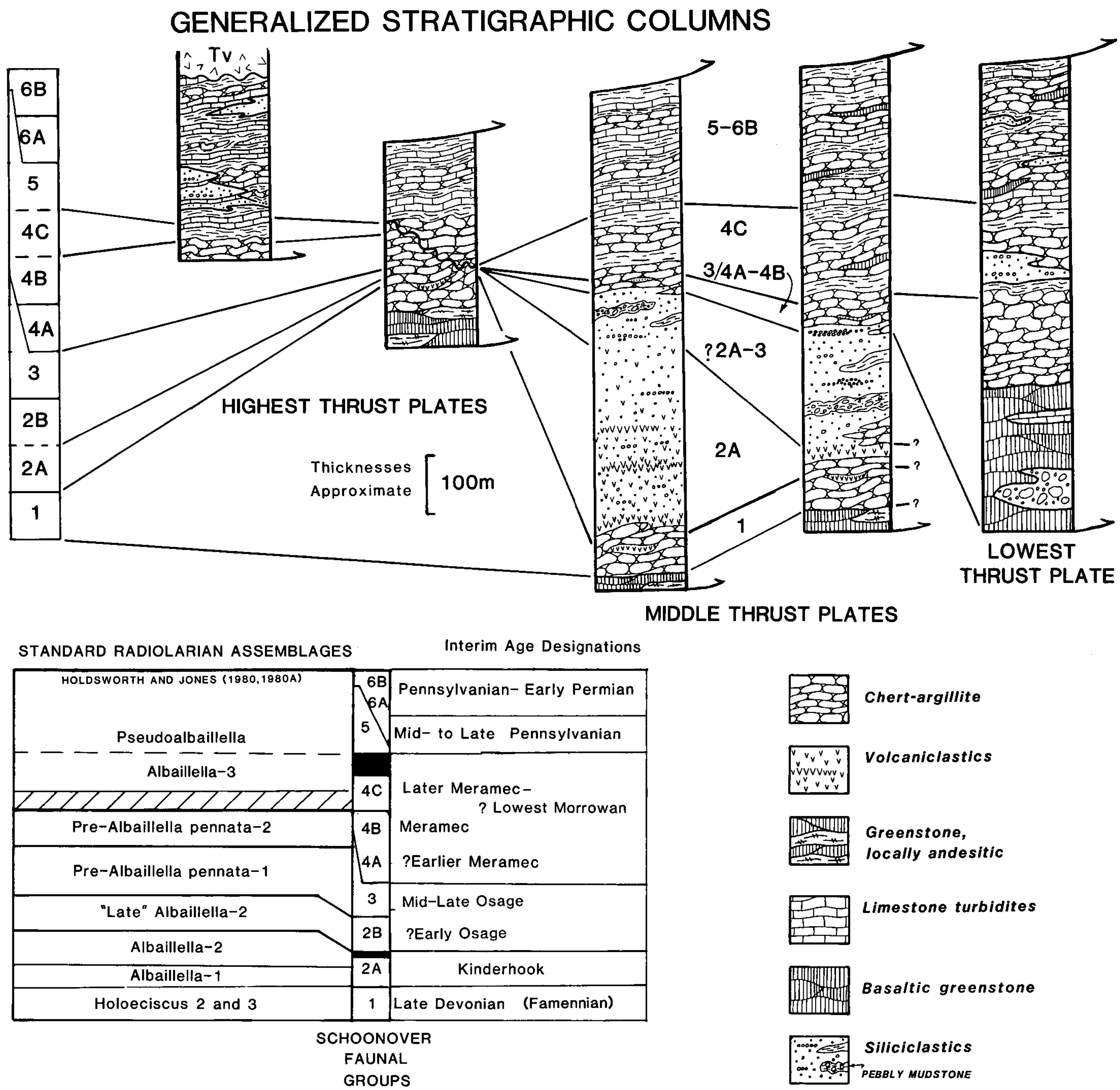

Figure 4. Generalized, schematic stratigraphic columns from the Schoonover sequence, together with ages assigned to radiolarian faunal assemblages and correlation of our faunal groups to those of Holdsworth and Jones (1980a, 1980b). Black portions of the faunal groups column represent discontinuities in the faunal record. Owing to the faulting and folding in the Schoonover, our generalized stratigraphic columns are pieced together from locally coherent portions of the section. For this reason, and on account of thickness changes due to folding in less competent lithologies, the thicknesses shown should be viewed as only crude approximations to the original thicknesses of the section.

pebbly mudstone and pebbly sandstone, conglomerate, sandstone, and shale.

No chert units occur in the lower half of this clastic section (Mss map unit), and so the precise age of the lowest units has not been established. Clastic rocks of this age are absent in some thrust plates (A′, F, and I in Fig. 3), and at these localities volcaniclastic rocks are paraconformably succeeded by distinctive green chert with Group 3 fauna and, at localities C, D, and E (Fig. 3), sparse conodont fauna of the Osagian *S. anchoralis* Zone. If Group 2a is late Kinderhookian at youngest (see Appendix), a hiatus involving the earlier Osagian may separate the volcaniclastics and mid-Osagian green chert. The exclusion of the younger siliciclastics from the successions of some thrust plates suggests the development of sea-floor highs and/or increasing channelization of turbidite units in the Schoonover basin during the Osage.

The pebbly mudstone units within the turbidite sequence contain clasts of chert and orthoquartzite as large as boulder size. The orthoquartzite clasts are petrographically indistinguishable from distinctive medium-grained, moderately well-sorted, *very well-rounded* quartzite in the Ordovician Valmy Formation of the Roberts Mountains allochthon, exposed in the Independence Mountains (Miller and Larue, 1983) and elsewhere across Nevada, a similarity first noted by Fagan (1962). Arkosic sandstone clasts that are similar to sandstone of the Cambrian Harmony Formation of the Roberts Mountains allochthon (Stewart and Suczek, 1977) are also present in the pebbly mudstone. Sandstones in the Mississippian turbidite sequence are immature sublithic arenites (*sensu* Folk, 1968; Whiteford, 1984) and contain chert, quartzite, argillite, and volcanic lithic fragments. Many argillite clasts exhibit phyllitic fabrics; in addition, polyphase deformed biotite-muscovite schist and foliated metaquartzite clasts are locally common. All gradations are seen between metamorphosed and unmetamorphosed argillite, radiolarian chert, and quartzite fragments.

The oldest chert units interbedded in the upper part of the siliciclastic turbidite sequence yield Group 3 faunas (Fig. 3, locs. I and J in thrust plate C) that, on paleontologic grounds, are Osagian to early Meramecian in age. The turbidite sequence grades up into a distinctive chert unit (Mca map unit) with Schoonover Group 3, 4a, and 4b faunas. The bulk of this clastic sequence thus is well constrained as Kinderhookian-Meramecian in age.

In the lowest thrust plate (A), Early Mississippian siliciclastic rocks are not present. Instead, a thick series of pillow basalts overlain by Meramecian chert (Schoonover Groups 4a and 4b) occurs above the basal thrust. In the southwestern part of the map area, conspicuous horizons of boulder conglomerate are present within the basalts and contain clasts of chert, limestone, and Ordovician Valmy quartzite. In higher thrust plates, rare, thin, discontinuous flows and sills occur within the Upper Mississippian to Lower Permian sequence that overlies the Lower Mississippian chert and clastic unit (Fig. 4).

Meramecian to Lower Permian sequences in the Schoonover allochthon vary somewhat between thrust plates. In general, chert and argillite are the dominant lithologies, but interbedded quartzose turbidites, chert-quartzite pebble conglomerate, and limestone turbidites are also present. The siliciclastic turbidites (Css map unit), interbedded with chert ranging from later Meramecian–Chesterian to Early Permian age (Groups 4c to 6b), are distinct from older Early Mississippian sandstones in that they are mature quartz arenites. They contain mainly chert and quartzite lithic fragments; feldspar is rare, as are metamorphic clasts. In the intermediate thrust plates, rare limestone turbidites occur within chert-argillite–rich sections. In the structurally highest part of the Schoonover, limestone turbidites of Pennsylvanian and Permian age make up ~40% of the section. Schoonover units with Group 5, 6a, and 6b faunas probably everywhere lie disconformably upon 4c or older parts of the sequence. The pre-later Pennsylvanian disconformity is most dramatic in thrust plate I, where silty chert with Group 6a fauna rests depositionally upon Famennian chert. In contrast, samples from the lowest thrust plate (A) suggest that latest Pennsylvanian–earliest Permian chert depositionally overlies latest Meramecian to Chesterian chert.

Summary and Discussion of Schoonover Stratigraphic Succession

The stratigraphic and paleontologic data outlined above suggest that the record of Late Devonian to Early Permian deposition in the Schoonover basin may contain some hiatuses. In most places, structural complexities, poor exposure, and still inadequate sampling hinder scrutiny of suspected faunal breaks, but we are confident that field observations, together with paleontologic data from key exposures described above, support our proposed stratigraphic succession and establish discontinuities or markedly condensed intervals in the successions of some thrusts. In a general way, Schoonover deposition can be viewed in terms of four distinct phases (Fig. 5).

Phase 1 began no later than latest Devonian with the extrusion of basalt and perhaps andesite. If these rocks indeed represent the depositional basement of the Schoonover sequence, one might infer a rift origin for this basin in the Late Devonian. The resulting basin accumulated a thin, commonly manganiferous latest Devonian chert sequence that was deposited under conditions of "estuarine" circulation (high biogenic productivity, CO_2-rich bottom waters) with minimal terrigenous or volcaniclastic sediment supply. Shortly thereafter, in Kinderhookian time, the basin began to receive volcaniclastic detritus. We thus infer that this basin was developed in proximity to an island arc.

Phase 2 is marked by the onset of coarse clastic turbidite deposition and a relative reduction in the proportion of volcaniclastic debris supplied to the basin. During this phase, bathymetric complexities may have developed in the basin, as some thrust sheets carry sections that do not contain Mississippian siliciclastic rocks. In these localities, a faunal hiatus may separate Group 2a and Group 3 chert beds, indicating a period of uplift, submarine erosion, or nondeposition in Kinderhookian-Osagian time that may have been coeval with the (undated) onset of siliciclastic turbidite deposition elsewhere in the basin.

Phase 3 begins in later Meramecian time with basaltic volcanism, the abrupt waning of siliciclastic turbidite deposition, a sharp increase in the maturity of sandstones, and the first appearance of significant amounts of detrital carbonate.

Phase 4 deposition is marked by an increased supply of carbonate detritus following a possibly important depositional break spanning the earlier part of the Pennsylvanian. Subsidence of the previous bathymetric high in thrust plate I occurred during this time interval. Here, a thin Devonian–Early Mississippian pelagic section is overlain by a thick sequence of Pennsylvanian-Permian limestone turbidites. Clear evidence of the type of circulation that characterized the Schoonover basin during phase 1 and possibly phase 2 is lacking, particularly during phase 4 deposition. Abundant supply and good preservation of carbonate detritus, relative frequency of conodonts, and local abundance of spongilitic chert all suggest greater enclosure and more "lagoonal"-style circulation by the Pennsylvanian.

Comparison with the Havallah Sequence and Coeval Continental-Shelf Sequences

Although limited in extent, the Schoonover sequence at present provides a longer and better-understood record of events than does any other portion of the Golconda allochthon, allowing a more complete perspective of the allochthon's paleogeographic setting and a more informed comparison of its history with that of the Nevadan portion of the continental shelf.

The most recent published contributions to Havallah sequence stratigraphy and paleontology are those of Stewart and others (1977), Murchey (1982, and *in* Miller and others, 1982), and Laule and others (1981).

So far, Schoonover phase 1 Devonian and Kinderhookian ages have not been definitely documented elsewhere in the Golconda allochthon. The Schoonover basin may, therefore, be unique in its Devonian origin

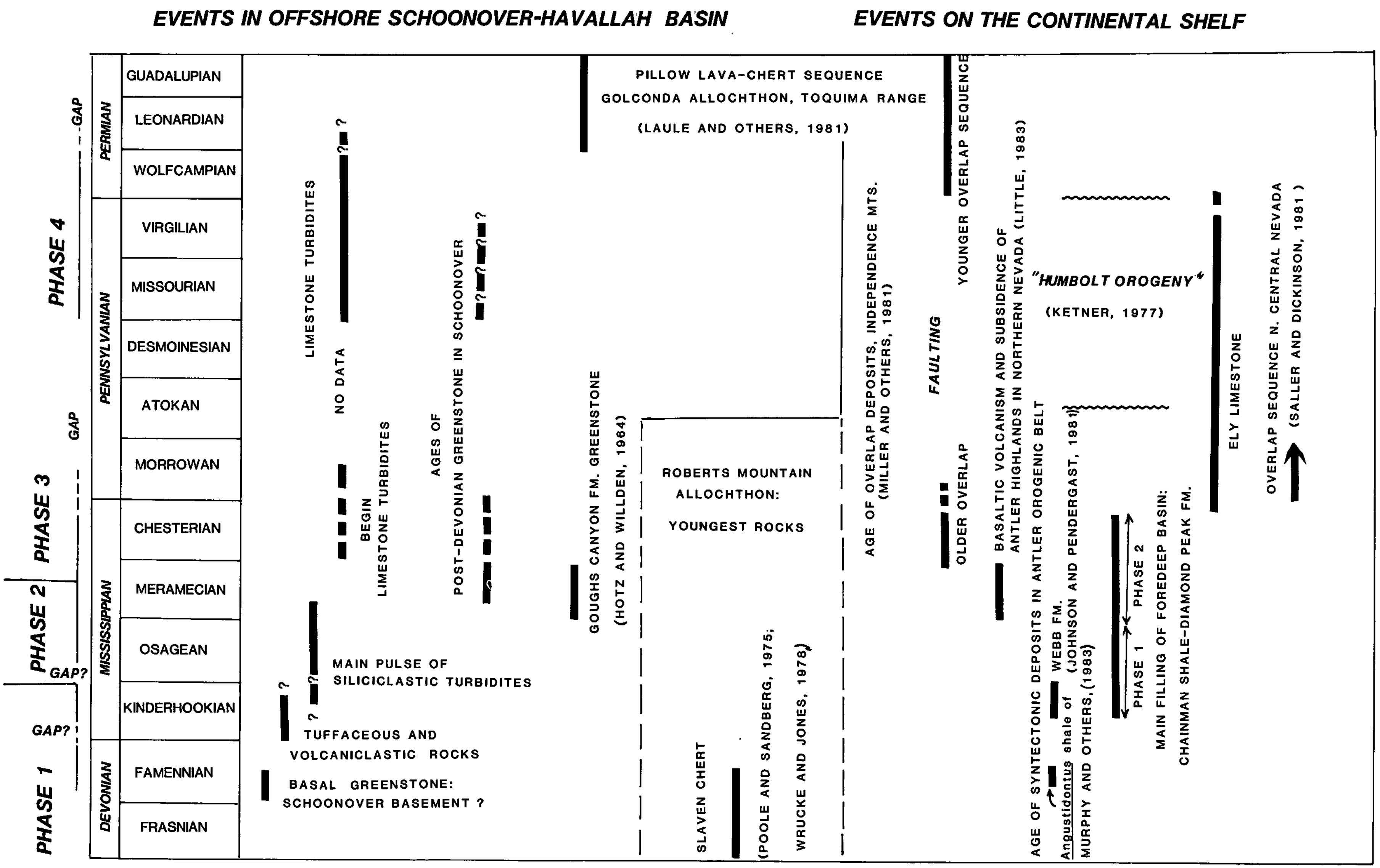

Figure 5. Timing of events in the Schoonover and Havallah basins compared to events occurring along the continental margin during the upper Paleozoic. Solid lines and "gaps" in these lines on left-hand side of diagram represent discontinuities in the faunal record. For discussion, see text.

and phase 1 history. Late Mississippian to Permian strata in the Havallah are, however, lithologically similar to coeval strata in the Schoonover. (1) Pillow lavas in the Havallah sequence are possibly the oldest rocks present but so far have been dated only as probably Late Mississippian in age (Murchey, 1982; Snyder, 1977; Hotz and Willden, 1964) and may be coeval with Meramecian-age lavas in the Schoonover. It is not certain if the fault-bounded Mississippian lavas of the Gough's Canyon Formation in the Osgood Mountains (Hotz and Willden, 1964) (Fig. 1) are part of the Golconda allochthon or autochthonous (Stewart, 1980). They contain interbedded radiolarian chert; for that reason, we have classed them as part of the allochthon (Fig. 5). Much of the depositional province that was to form the Golconda allochthon may therefore date only from this younger rifting episode, which may have also extended the Schoonover basin during phase 3. (2) The quartz-chert-bearing siliciclastics studied in the Golconda allochthon by Turner (1982) and Dickinson and others (1983) are similar to Late Mississippian and younger clastics in the Schoonover sequence (Whiteford, 1984) and, on the basis of composition, are inferred to be derived from the continental shelf. (3) Pennsylvanian-Permian limestone turbidites constitute a large part of the Golconda allochthon (Stewart and others, 1977; Murchey, 1982) and correspond both in age and lithology to limestone turbidites in the Schoonover sequence.

Late Mississippian to middle Permian strata in the central part of the Golconda allochthon (Antler Peak area and Tobin Range) are interpreted to have been deposited in a continental slope-rise environment (Miller and others, 1982; Turner, 1982; Stewart and others, 1977), in agreement with the depositional setting postulated for the Schoonover sequence (Fagan, 1962; Whiteford, 1984).

The youngest rocks in the Havallah sequence are middle Permian (Laule and others, 1981; Miller and others, 1982; Murchey, 1982), whereas those in the Schoonover are Early Permian (Fig. 5), suggesting that uplift or thrust faulting could have begun earlier in the northern part of the Golconda province. In the southern reaches of the Golconda allochthon, rifting (implied by pillow lava–radiolarian chert sequences) occurred into middle Permian times (Laule and others, 1981; Snyder and Brueckner, 1983). Pennsylvanian-Permian magmatic-arc–derived material has not been documented in Schoonover phase 4 sediments, but Permian rocks of arc affinity have been described in the southern part of the Golconda allochthon (Speed, 1977a, 1977b) suggesting the establishment of conditions similar to those that prevailed in or adjacent to the Schoonover basin during phase 1 deposition.

The Schoonover sequence has strong sedimentologic and stratigraphic ties to sequences deposited on the continental margin in Nevada, as indicated by a number of features (Fig. 5).

1. The onset of coarse siliciclastic turbidite deposition in the Schoonover in Kinderhookian time corresponds to the time of emplacement of the Roberts Mountains allochthon onto the shelf and with the beginning of Antler foredeep sedimentation farther east (Johnson and Pendergast, 1981; Harbaugh and Dickinson, 1981). Murphy and others (1984) recently described possible Famennian syntectonic deposits in the Roberts Mountains allochthon (Fig. 5). If so, deformation of the allochthon may have begun somewhat earlier than suggested by our data. With the exception of the volcanic and metamorphic detritus (discussed below), the Schoonover siliciclastics are petrographically identical to debris shed from the Roberts Mountains allochthon into the eastern foredeep as described by Harbaugh and Dickinson (1981) (Whiteford, 1984).

2. Basaltic volcanism occurred in the Schoonover basin in Meramecian time and may typify the Havallah-Schoonover basin as a whole. Autochthonous "overlap" sequences (Roberts, 1964; Roberts and Lehner, 1955) north of the Independence Mountains described first by Coats (1969) and then in detail by Little (1983) contain conglomerates overlain by basalt flows interbedded with Meramecian limestones that are in turn overlain by a deeper-water sequence of shale and turbidites. Little (1983) suggested that this sequence records rifting and foundering of the Antler highlands. Subsidence caused by a rifting-type event thus affected both the edge of the continental margin and bordering offshore basin(s) in Meramecian time (Fig. 5). The end of Antler age compression probably coincided with this extension, and sedimentation patterns in the Antler foredeep basin may also reflect this change in tectonics. Johnson and Pendergast (1981) and Dickinson and others (1983) suggested that foredeep sedimentation first occurred during a retrogradational phase of submarine slope and submarine fan deposition in a basin that remained deep into the Meramecian (Fig. 5, phase 1) followed by a progradational phase of delta-slope and delta-platform sedimentation that accumulated in gradually shoaling waters (Fig. 5, phase 2).

3. The switch from siliciclastic to predominantly limestone turbidite sedimentation in the Schoonover occurred in latest Mississippian–earliest Pennsylvanian time and is coeval with the re-establishment of carbonate conditions on the shelf after the Antler orogeny.

4. The possible Pennsylvanian hiatus and increasing supply of carbonate sediment, together with the local renewal of siliciclastic deposition during Schoonover phase 4 sedimentation, likely reflect an important faulting and tilting event along the outer edge of the continental shelf described by Ketner (1977) as the "Humboldt orogeny" (Fig. 5). Interpretation of the structures formed during this event and the stratigraphic sequences deposited during and after this event suggest that this tectonism was probably extensional in nature (Little, 1983).

These temporal and sedimentologic ties paleogeographically link the Schoonover basin (and coeval Havallah sequence) to the continental margin during the upper Paleozoic. There are, however, several enigmatic aspects to Schoonover stratigraphy and its petrology that provide further important constraints on the paleogeographic setting of this basin.

1. Latest Devonian strata in the Schoonover overlap in age with the youngest rocks in the Roberts Mountains allochthon (Fig. 5, Slaven chert). Although Schoonover sediments span the time of deformation and emplacement of the Roberts Mountains allochthon, they were not involved in Antler thrusting.

2. The petrography of Kinderhookian strata shows that contemporaneous source areas provided both recycled sedimentary rock material and volcanic and metamorphic debris to the Schoonover basin (Whiteford, 1984). Although *most* of the clastic material supplied to the Schoonover during the Early Mississippian is identical to that supplied to the foredeep, volcanic and metamorphic rocks apparently were *not* present in the eastern parts of the Antler orogenic belt that fed the foredeep (Harbaugh and Dickinson, 1981). The nature of the source terrane for some of the Schoonover Mississippian clastic rocks thus presents an interesting dilemma. Rather than view the Schoonover as having originated at a distance from both the Roberts Mountains allochthon and its foredeep (compare Snyder and Brueckner, 1983), it seems more reasonable to suggest that the Schoonover clastics may have been derived from dual source terranes that included an island arc and structurally higher, more western, or along-strike portions of the Roberts Mountains allochthon that, in addition to containing the typical Roberts Mountains lithologies, may also have contained volcanic rocks and greenschist-facies metamorphic rocks. In fact, the development of supposed Antler-age slaty cleavage has been described by Oldow (1984) in the southern reaches of the Roberts Mountains allochthon.

In summary, we interpret the stratigraphy of the Schoonover sequence to indicate an extensional or rift-related origin for this basin near the flanks of an island arc in latest Devonian time. During the Antler orogeny, the Schoonover sequence was deposited in a basinal terrane (or successor basin) that lay between the Antler orogenic belt and the arc to the west, or it lay within or along the flanks of the overriding (and hence undeformed) island-arc terrane itself (Fig. 2). In the early Late Mississippian, both the Antler orogenic highlands and offshore basin(s) were affected by extensional tectonism, as indicated by subsidence and basaltic volcanism, bringing an end to the short-lived episode of compression that resulted in the Antler orogeny. We believe that the paleogeographic constraints discussed above, together with the timing and nature of events occurring both in the offshore Schoonover basin and on the outer continental shelf, are most compatible with deposition of the Schoonover sequence in a back-arc position with respect to a west-facing arc as shown in model 1 (Fig. 2). If we accept the alternative scenario of the Antler orogeny being caused by the collision of an east-facing arc and its accretionary prism (model 2 in Fig. 2), the Schoonover-Havallah sequence would have been deposited in either the fore-arc basin or the back-arc basin of this colliding arc. If one accepts the fore-arc basin possibility, the ages of the youngest pillow-lava and chert sequences in the Roberts Mountains allochthon (the Famennian Slaven chert; Jones and others, 1979) and the oldest pillow-lava–chert sequences in the Schoonover require synchronous basaltic volcanism and possibly rifting both adjacent to the continental margin and in the fore-arc basin itself immediately prior to the collision (Fig. 2). The composition of Mississippian Schoonover clastic rocks would, in addition, require a complex mixing of detritus from the easternmost or continentward toe of the Roberts Mountains allochthon, from a greenschist-grade metamorphic terrane composed of similar rocks (unlikely to be found in the accretionary wedge) and from the volcanic arc. The back-arc basin setting of model 2 (Fig. 2) is equally difficult to envision, because debris from the continentward toe of the accretionary prism would have had to traverse the fore-arc basin and the arc massif itself, in order to be deposited in the Schoonover-Havallah basin. This latter hypothesis requires that the Antler arc be buried in the subsurface beneath the Golconda allochthon (Fig. 2), a possibility suggested by Speed and Sleep (1982). The thickest and most proximal sequences of Early Mississippian arc-derived material in the Schoonover, however, appear to occur in the higher (more oceanward) thrust sheets, which is not compatible with this hypothesis.

STRUCTURAL GEOLOGY

Map-Scale Structures

The basal Schoonover thrust places contrasting but time-equivalent deep-water rocks above shallow-water rocks (Miller and others, 1981). Beneath the thrust, autochthonous strata as young as latest Permian are in places folded but are relatively undeformed in comparison to the overlying allochthonous rocks, a characteristic feature along the Golconda thrust (MacMillan, 1972; Miller and others, 1982) (Fig. 3). The youngest strata found beneath the Schoonover thrust consist in part of turbidites that in places unconformably overlie the autochthon and are composed of detritus derived from the underlying autochthonous rocks. The turbidites contain molds of detrital brachiopods that have been dated as Late Permian (Miller and others, 1981). The stack of thin, imbricate thrust plates that compose the allochthon forms a northeast-striking, steeply (50° to 90°) northwest-dipping homocline at least 7 km thick (Fig. 3). Gentler dips are present in the uppermost part of the Schoonover. Thrust faults imbricate the Late Devonian to Permian section. Detachment of the sequence along thrust faults generally occurred beneath, within, or immediately above the Late Devonian–earliest Mississippian pelagic section and sometimes incorporates scraps of underlying basaltic to andesitic flows.

Some of the thrust faults in the Schoonover sequence extend along strike for at least 10 km, whereas other thrust-bound packets of rocks are lenticular in map view. Thrust faults commonly splay into several imbricate thrusts. Where best documented, packages of rock bound by mappable thrusts are on the order of 800 m thick or less and thus are much thinner than their lateral dimensions. The close spacing of thrust faults is likely dictated by the originally thin stratigraphic sequence (perhaps <1 km) (Fig. 4) that was involved in the thrusting.

Mesoscopic folds and faults in the Schoonover indicate southeast-directed movement along thrust faults. The steep dips throughout the map area preclude good map control for establishing minimum displacements along thrust faults. Unique lithologic-stratigraphic horizons such as the Kinderhookian (Group 2a) volcaniclastics and chert occur in each thrust plate, and thus the thrust faults do not juxtapose paleogeographically unrelated sequences.

The various lithologies in the Schoonover responded differently to deformation. Massive turbidite beds and tuff units are generally upright, indicating involvement in imbricate thrusts rather than folding. Argillite units are not well exposed but have been subjected to most of the penetrative deformation. Bedded chert crops out well and displays the greatest variety of mesoscopic structures, which we discuss in detail below. Thick chert, sandstone, tuff, and greenstone units that are interbedded with less competent strata are commonly discontinuous along strike, apparently due to boudinage. Although the style and geometry of deformation within the Schoonover vary expectably with lithology, mesoscopic structural data collected from chert units in different thrust plates are quite similar, indicating that there is no detectable difference in the strain history of different thrust-bounded packets.

Mesoscopic structural data are discussed in terms of present-day north. Tertiary volcanic rocks deposited unconformably over the Schoonover dip 20° to 50° to the northeast or northwest. Removing this tilt results in gentler dips for the Schoonover sequence, but the amount of postemplacement, pre-Tertiary tilting of the Schoonover is unknown. Basin and Range normal faults are absent, except for a down-to-the-east fault in the northeast part of the Schoonover (Fig. 3).

Mesoscopic Structural Data

Mesoscopic folds and faults indicate that the map-scale thrust faults have moved to the southeast as a result of a single progressive deformation caused by northwest-southeast shortening. Except for the direction of thrusting (southeast versus east), the details of the style and geometry of deformation in the Schoonover are identical to those described elsewhere in the Golconda allochthon (see Miller and others, 1982; MacMillan, 1972; Turner, 1982).

Deformation of the Schoonover sequence occurred under low temperature and pressure conditions. Radiolaria are well preserved, and conodont alteration color indicates maximum temperatures ranging from 90 to 150–200 °C (A. Harris, 1980, written commun.). There is no schistosity or slaty cleavage in the Schoonover; incipient axial-plane cleavage is only very rarely developed in shales within hinges of folds.

Strain is highly heterogeneous within Schoonover thrust plates, as has been described in other parts of the Golconda allochthon by Turner

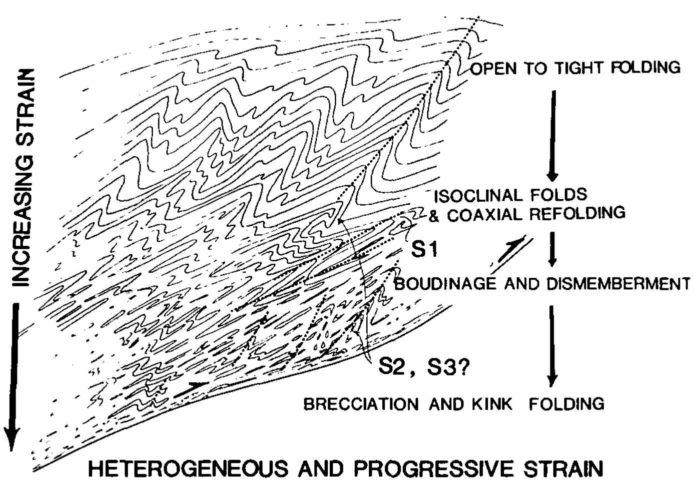

Figure 6. Schematic diagram showing the variability of mesoscopic structures as related to the amount and history of strain. Based on our observations in the Independence Mountains, Antler Peak area (Miller and others, 1982) and Tobin Range (Turner, 1982). Scale variable and dependent on lithology: metres to hundreds of metres.

(1982), Miller and others (1982), and Snyder and Brueckner (1983). Differing styles of folding and amounts of structural disruption within a particular lithologic unit generally can be explained by local variations in the strain history and percent strain during shortening and thrust faulting, as shown schematically in Figure 6.

Folds in thinly interbedded chert and shale are disharmonic, parallel, or concentric folds that are generally tight to isoclinal and commonly asymmetric. Long northwest-dipping limbs of folds are upright, and short, southeast-dipping limbs of folds are steep or dip steeply to the northwest and are overturned. Folds belong to a single generation of folding, but in a few places tight to isoclinal folds are refolded by later, but always coaxial, tight to open folds that we interpret as younger structures formed during the same deformation.

Most fold axes trend N30°E to N40°E and plunge shallowly to the northeast and southwest, forming a diffuse subhorizontal maximum (Fig. 7A). Fold axes also exhibit a diffuse girdle parallel to the average axial plane, which is oriented N30°E to N40°E and dips steeply (60° to 90°) to the northwest or southeast (Fig. 7B). The weak girdle distribution of the poles to axial planes is likely the result of coaxial refolding that has affected parts of the rock package, as shown schematically in Figure 6. Although coaxial second-generation folds are indeed present (Figs. 7A, 7B), they are very difficult to document (see discussion in Miller and others, 1982). The second-generation fold axes or pole to the girdle distribution of poles to first-generation axial planes are parallel to the mean first-generation fold axis in the Schoonover (Figs. 7A, 7B).

The northeast-southwest orientation and southeastward overturning of folds in the Schoonover indicate that they formed during (1) northwest-southeast–directed shortening, and (2) southeast-directed movement or simple shear.

The relationship of folds to small-scale faults that clearly cut the hinges of mesoscopic folds was used to calculate slip directions along these faults. The slip direction along these faults is the line within the fault plane that is normal to the intersection of the fault plane and the axial surface of the fold (Moore, 1978). Poles to these measured fault planes form a girdle showing that faults dip variably but generally strike north-northeast (Fig. 7C), parallel to the mean fold-axis orientation. The calculated slip directions shown in Figure 7D, together with the sense of slip along faults, give a direction of movement that is oriented approximately S35°E. There is good agreement between "calculated" and measured slip directions (slickensides) where both could be measured (Fig. 7E). Striations and slickensides measured along small-displacement faults of unknown sense of offset in greenstone units along the Schoonover basal thrust and within the structurally highest greenstone unit (Fig. 7F) indicate an average slip direction of S55°E to N55°W. This is close to the slip vector calculated from small-scale thrust faults in the Schoonover and indicates that the deformation within the individual thrust sheets, movement along map-scale thrust faults, and movement along the basal thrust of the Schoonover occurred during northwest-southeast–directed shortening.

Map-scale and mesoscopic-scale thrust faults in the Schoonover were not observed to be folded, but these thrust faults always cut tightly folded strata, suggesting that at least their latest movement postdated folding within individual thrust sheets. Northwest-southeast–directed shortening of the Schoonover basin thus was, at any given point in an individual thrust plate, accomplished first by folding and then by thrust faulting. The similarity in geometry and style of deformation within each thrust sheet indicates that the direction of shortening (northwest-southeast), or orientation of the external strain axes, did not change while the allochthon formed. The geometry and sequence of deformation in the Schoonover are supportive of the "bulldozer" model of thrust belt–accretionary wedge development described by Suppe (1981) and Davis and others (1983). Within the framework of this model, higher thrusts within the Schoonover were likely "frozen in" and carried piggyback on younger, more southeasterly thrusts during the formation or build-up of the allochthon (see also Seely and others, 1974; Bally and Snelson, 1980; Biddle and Seely, in press; Lowell, 1977). Although the structural style of the Golconda allochthon is perfectly compatible with the interpretation that the allochthon represents a subduction-zone accretionary wedge (Speed, 1979), we see no evidence for a protracted deformational history such as postulated by Snyder and Brueckner (1983). Schoonover deformation entirely postdated the youngest (Early Permian) deposits of the basin.

The highly deformed Schoonover sequence was then emplaced onto relatively undeformed autochthonous Permian strata in post-latest Permian and pre-Jurassic times. Slickensides and striations along faults adjacent to the basal thrust are compatible with continued southeast-directed movement of the allochthon.

NATURE AND CAUSE OF SCHOONOVER DEFORMATION: DISCUSSION

On the basis of the stratigraphic, sedimentologic, and petrologic data discussed above, the Schoonover and Havallah sequences represent a tract of slope, rise, and basinal paleogeography that lay adjacent to the continental margin during the upper Paleozoic. Beginning perhaps as early as mid-Permian (Schoonover) and continuing into Early Triassic time (southern reaches of Golconda allochthon; Speed, 1977b), this basinal terrane was telescoped by thrust faulting. Along the entire length of the allochthon, the style of deformation is very similar in that (1) thin pelagic and turbidite sequences are folded and are repeated by closely spaced thrust faults, and (2) these strata are everywhere detached from their presumably oceanic basement or substratum (MacMillan, 1972; Stewart and others, 1977; Turner, 1982; Miller and others, 1982; Snyder and Brueckner, 1983). Until we are able to accurately estimate displacement along each thrust or series of thrusts across the entire width of the Golconda allochthon, the amount of subduction (basement shortening) re-

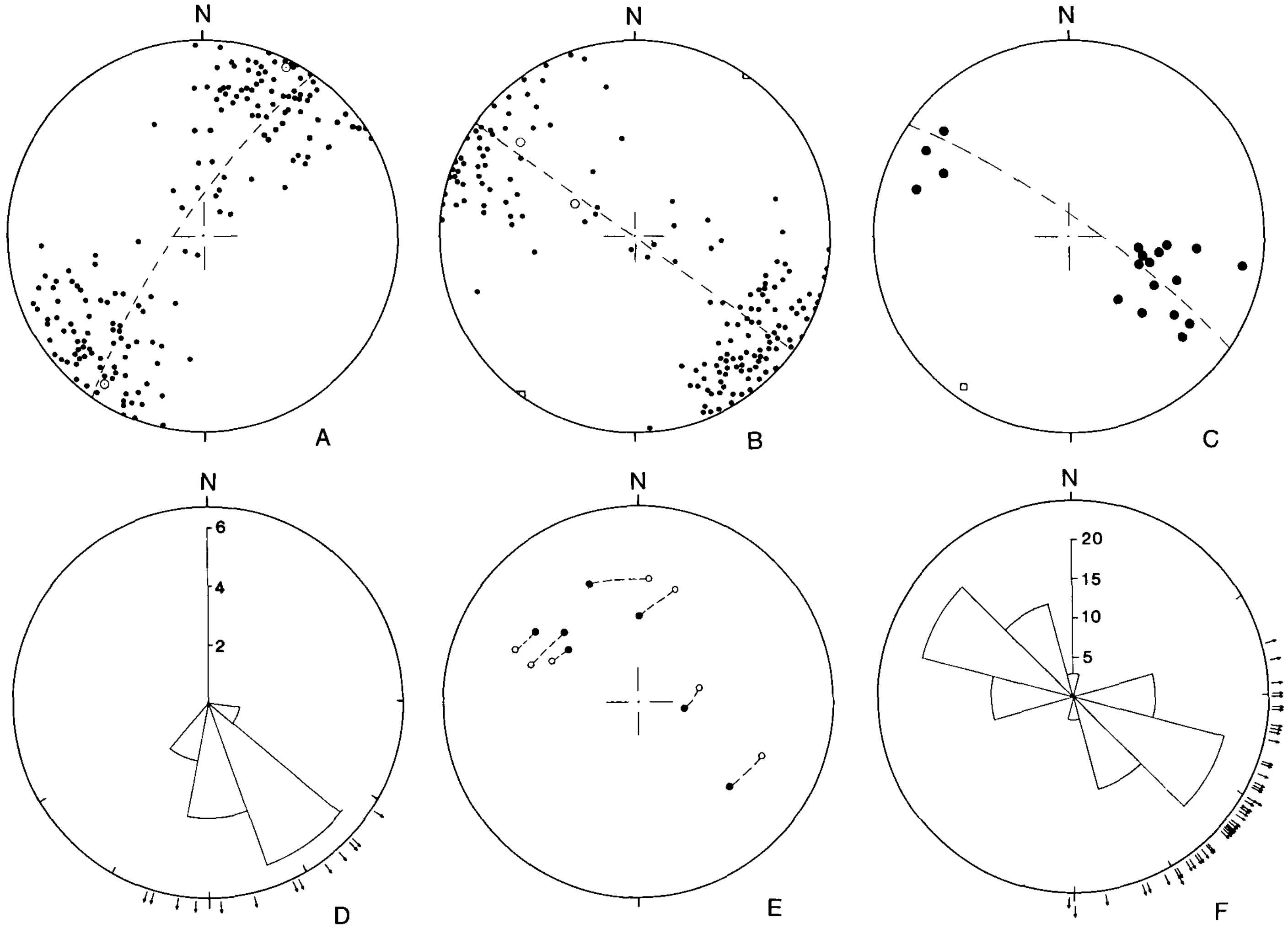

Figure 7. Structural data from the Schoonover sequence. A. Fold axes. B. Poles to axial plane. In A and B, dots are first-generation structures, and open circles represent clear-cut examples of second-generation structures. C. Poles to thrust-fault planes measured in D (dots), and pole to great circle formed by these (square). D. Rose diagram of calculated slip directions on small-scale thrust faults that cut the hinges of folds. E. Comparison of calculated slip directions (open circles) and measured striations and slickensides (dots) on seven small-scale thrust faults. F. Striations and slickensides on small-scale faults of unknown sense of offset and on bedding surfaces along basal thrust of Schoonover sequence, and along the base of higher thrust plates.

quired to produce the observed stack of imbricate thrust plates is unknown. The stratigraphic evidence from the Schoonover and Havallah sequences, however, indicates that these rocks have close faunal, lithologic, and stratigraphic ties to the continental margin and suggests that the allochthon represents a tract of ground possibly hundreds rather than thousands of kilometres in maximum width. Fragments of exotic seamounts, plateaus, or rises that occur within long-lived subduction-zone complexes (Nur and Ben Avraham, 1982) are conspicuously absent from the Golconda allochthon.

Although the structural style of the Golconda allochthon does not argue uniquely for or against the two plate-tectonic models shown in Figure 2, the contents of the allochthon and the timing of depositional events within the allochthon rule out the possibility that the allochthon represents a long-lived oceanic subduction-zone accretionary prism in front of an east-facing arc, as suggested by Snyder and Brueckner (1983) and Speed (1979).

The strongest argument in favor of eastward, not westward, subduction in Permo-Triassic times (and hence deformation of the Havallah sequence in a back-arc setting) comes from southern California. Here, the development of an Andean-type arc requires east-dipping subduction beneath the continental margin as far back as latest Permian or earliest Triassic time (C. F. Miller, 1978; E. L. Miller, 1981; Cameron, 1981; Cox and Morton, 1980; Miller and Cameron, 1982) (Fig. 1). Although the northern (marine) continuation of this arc through western Nevada and the Sierra Nevada region is by no means clear, Permo-Triassic arc and subduction-zone sequences in the Klamath Mountains and northern Sierras are logical candidates a bit farther to the north (Fig. 1). Here, Burchfiel and Davis (1972, 1975) and Wright (1982) emphasized that the unchanging locus of Permian through Jurassic arc magmatism suggests eastward subduction along this portion of the margin back into the Permian. These terranes, however, are not demonstrably tied to the continental margin in Permian times. On the other hand, the presence of volcanic debris of

Permian age in the Golconda allochthon (Speed, 1977a, 1977b, 1977c) suggests the presence of a westerly located volcanic-source terrane by this time.

CONCLUSIONS

For the first time, with the aid of radiolarian biostratigraphy, we have been able to reconstruct the original stratigraphic succession and structural evolution of part of the Golconda allochthon. The Schoonover sequence in the Independence Mountains contains a fairly continuous sedimentary record that spans the Late Devonian to Permian. Tectonic and sedimentary events recorded in the allochthonous Schoonover sequence are correlative with events in the autochthonous shelf sequences in Nevada, indicating that its history is tied to that of the continental margin throughout the upper Paleozoic. The earlier part of Schoonover deposition was coeval with the emplacement of the Roberts Mountains allochthon to the east and provides an important stratigraphic link between the Mississippian Antler orogenic belt and an adjacent offshore island arc. The timing of events and the composition of clastic rocks in the Schoonover, together with data from elsewhere in Nevada, suggest that the Antler orogeny was associated with both island-arc volcanism and greenschist-grade metamorphism. Possibly, this arc may have been "hinged" to, or intrusive into, the higher thrust plates of the Roberts Mountains allochthon along strike of the Antler orogenic belt. These data are compatible with the view that the Antler orogeny may have been related to *eastward* subduction beneath the continental margin, as suggested originally by Burchfiel and Davis (1972, 1975). Models for the Antler orogeny that invoke the collision of an east-facing arc and its accretionary prism with the continental margin and the subsequent subsidence of this arc (Speed and Sleep, 1982; Dickinson and others, 1983) are more difficult to reconcile with the new data presented in this paper. The stratigraphic succession in the Schoonover-Havallah sequence and along the continental margin indicates that Antler-age compressional tectonism was short-lived and that extensional tectonism possibly due to rifting and/or strike-slip faulting began in the early Late Mississippian. High-angle faulting, basaltic volcanism, and changes in sedimentation patterns in both autochthonous shelf sequences and the allochthonous Schoonover sequence suggest that extensional or strike-slip tectonism may well have affected the continental margin into Permian times.

The Schoonover sequence, like the rest of the Golconda allochthon, was involved in closely spaced thrust faults that detached the sedimentary fill of the basin from its depositional basement during Permian to Early Triassic time.

The new data discussed in this paper, together with regional geologic relations, are most compatible with deformation and emplacement of the Schoonover-Havallah sequence in a back-arc setting. Although the structural style of the allochthon is compatible with the interpretation that the Golconda allochthon is an oceanic subduction-zone accretionary prism in front of an east-facing arc (Speed, 1979; Snyder and Brueckner, 1983), we see no stratigraphic and sedimentologic evidence that would suggest a protracted history of deformation within the Schoonover allochthon and no evidence that strata within the allochthon were deposited far from the North American shelf.

Our more general conclusions are that rocks in the Golconda allochthon record short episodes of arc volcanism and shortening along the continental margin separated by longer episodes of extensional tectonism, perhaps related to rifting and/or strike-slip faulting, from the Devonian through the Triassic. These data suggest a modern, southwest Pacific–style, active margin history for the western United States at least as far back as Devonian times. Alternating episodes of back-arc extension, transcurrent tectonics, and shortening most likely occurred in response to changes in plate motions between a generally eastwardly subducting oceanic (paleo-Pacific) plate and the overriding North American continental plate.

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APPENDIX 1: RADIOLARIAN BIOSTRATIGRAPHY

Radiolaria collections have been allocated to ten "Schoonover Groups," 1 to 6b. The range of age represented is latest Devonian through Early Permian. The small number of Groups adopted in no way reflects the total range of variation in Schoonover faunas. A considerable range of fauna has sometimes been included under a single Group heading, notably in the cases of Groups 4a and 6b. Groups were designed to accommodate all but the sparsest of collections recovered and to provide the field geologist with the most readily comprehensible and reliable indication of the relative time significance of each collection.

The Groups bear a relatively clear-cut relationship to the Assemblages and Associations of Holdsworth and Jones (1980a, 1980b) (see Fig. 4), but it should be noted that an important change has been made to calibration of the earlier part of the *Albaillella*-2 Assemblage.

Since the start of Schoonover work in 1980, parallel investigations in Oklahoma and Europe have increased information on the pre-Pennsylvanian Radiolaria succession. In the following synopsis, references to the Woodford Shale and Sycamore Limestone of southern Oklahoma are based on B. K. Holdsworth, J. Schwartzapfel, C. Yien-Nien, and E. A. Pessagno, Jr. (unpub. data) and references to German evidence from the Rheinischen Schiefergebirges (Kieselschiefer) on B. K. Holdsworth, P. C. Jackson, and G. D. Sevastopulo (unpub. data).

Schoonover Group 1

Collections, invariably poorly preserved, are characterized by the presence of *Holoeciscus* Foreman sp.; *Haplentactinia* Foreman spp.; early, unsegmented popofskyellids and *Archocyrtium* spp. in the absence of stauraxons; *Cyrtisphaeractenium* Deflandre spp.; and *Albaillella* spp. They belong to either the *Holoeciscus*-2 or *Holoeciscus*-3 Assemblages.

The closest comparisons are with faunas of proven Famennian age from the Lower Woodford Shale of Oklahoma and from the Woodruff Formation of eastern Nevada (Holdsworth and Jones, 1980b).

A single Group 1 sample from Locality A yielded sparse conodonts. They were recognized by the late S. C. Matthews and G. D. Sevastopulo as being Late Devonian forms, not mixed with post-Devonian species (Matthews, 1982, written commun.; Sevastopulo, 1984, oral commun.).

Schoonover Group 2a

Collections are characterized by the presence of *Cyrtisphaeractenium mendax* Deflandre Group in the absence of stauraxon Radiolaria. If *Albaillella* is present, it is invariably of *Albaillella paradoxa* Deflandre Group.

C. mendax Group first appears in the *Albaillella*-1 Assemblage and faunas of this Assemblage in the Lower Woodford Shale are of Early Kinderhookian, *Siphonodella duplicata* Zone age. The entry of *A. paradoxa* Group postdates that part of the *Duplicata* Zone contained in the Lower Woodford, and *A paradoxa* s.s. is present in the Late Kinderhookian-equivalent Liegende Alaunschiefer shales, Rheinischen Schiefergebirges. In this area, the association *C. mendax* Group–*A. paradoxa*, diagnostic of the earlier *Albaillella*-2 Assemblage, appears to extend no farther than Tn2. Holdsworth and Jones (1980a, 1980b) viewed it as ranging to early Visean (?late Osagian), relying on assertions regarding the age of the association in southern France by G. Deflandre. Evidence of Engel and others (1981) seems to show that the French source horizon predates at least some part of the *Scaliognathus anchoralis* Zone (Tn3c, mid-Osagian), as is the case in Turkey (Holdsworth, 1973), and no confirmation of a range into Tn3 or higher has yet been obtained.

Group 2a thus appears to identify beds no younger than Kinderhookian, and the presence of specifically unidentifiable siphonodellids with *A. paradoxa* Group in a 2a collection from Locality B tends to confirm this. The only other known Nevadan faunas that compare with 2a are from unnamed and uncertainly dated siliceous siltstones of the southern Fish Creek Range (B. K. Holdsworth and R. K. Hose, unpub. data) cited by Ketner and Smith (1982) and viewed by them as likely correlatives of the apparently late Kinderhookian Webb Formation. Consideration of views regarding the age of Webb deposition relative to Antler orogenesis (Johnson and Pendergast, 1981; Ketner and Smith, 1982; Murphy and others, 1984) leads to the conclusion that, whatever the precise age of 2a, it is likely to identify syn–early Antler or immediately post–early Antler sediments.

Schoonover Group 2b

At Locality F, cherts contain *Albaillella* sp. cf. *Albaillella turgida* sp. nov. (B. K. Holdsworth, P. C. Jackson, and G. D. Sevastopulo, unpub. data), and the same species may be present at Localities G and H. The species with which Schoonover examples are compared occurs at a southern Irish earliest Tn3 (earliest Osagian equivalent) horizon, although the Schoonover sample from Locality F yielded a single late Kinderhookian *Siphonodella*, suggesting possible overlap in range with the younger of 2a collections.

Schoonover Group 3

Collections are characterized by the presence of *Albaillella pirum* sp. nov. Group (B. K. Holdsworth, P. C. Jackson, and G. D. Sevastopulo, unpub. data), referred to in Holdsworth and Jones (1980a, 1980b) as the "earliest well-segmented lanceolate *Albaillellas*" and taken as index of the pre-*Albaillella pennata* Holdsworth 1 Association. The Association was viewed, erroneously at it now appears, as being no older than earlier Meramecian. Group 3 collections lack *Cyrtisphaeractenium mendax* Group in their pylentonemid populations, rarely contain traces of simple stauraxons, and commonly contain slender *Albaillellas* related to *Albaillella undulata* Deflandre.

In the Rheinischen Schiefergebirges, the range of *A. pirum* Group is virtually coextensive with that of the Lydite, apparently earliest Tn3 (earliest Osagean) to at least V2a (early Meramecian). The three conodont collections obtained with Group 3 in Schoonover (Localities C, D, and E) all belong to the mid-Osagean *Anchoralis* Zone, but judging by the close juxtaposition of Groups 3 and 4a–b collections at some localities, it is highly probable that, as in Germany, the Group ranges into the Meramecian.

Schoonover Group 4a

This is a heterogeneous Group. Collections lack *A. pirum* Group and *Albaillella cartalla* Ormiston and Lane Group but may contain various morphotypes of the *A. undulata* Group with or without strongly segmented lanceolate *Albaillellas* showing incipient wings. Simple spongy-rayed stauraxons are often present. Some Schoonover collections included here compare with German upper Lydite faunas occurring within the range of *A. pirum* Group, probably within the earliest Visean (?late Osagean–earliest Meramecian).

Schoonover Group 4b

Collections are characterized by the presence of *A. cartalla* Group, almost invariably in association with simple, spongy-rayed stauraxons.

In the Rheinischen Schiefergebirges, *A. cartalla* Group enters the succession slightly above the base of the Kieselkalke at a level no older than V2a (earlier Meramecian) and persists at least to the Pla (latest Meramecian) base of the Kieselige Ubergangsschien. Won (1983) showed that a Kieselschiefer *A. cartalla*-containing fauna compares closely with that from the type horizon of the species in the Sycamore Limestone, Oklahoma. Neither the lithic horizon nor age of Won's fauna is closely specified, but it appears by reference to data from Bomighausen that its horizon is unlikely to be lower than mid-Kieselkalke equivalent, within or little below the *Paragnathodus bilineatus* Zone. The implication that the Sycamore is late Meramecian (see Holdsworth and Jones, 1980a, 1980b), not Early Mississippian (Ormiston and Lane, 1976), is strongly supported by new conodont data from the Sycamore, where *A. cartalla* Group ranges to a P1b equivalent level.

At Localities M and N, "4b" is used for faunas that lack *A. cartalla* Group but contain *Albaillella* morphotypes probably closely related to bipennate Chesterian and early Morrowan species, themselves not encountered in Schoonover.

Schoonover Group 4c

Collections are characterized by *Pseudohagiastrum*(?) *simplex* Holdsworth and Murchey (in press). This fauna is widespread in Alaska and the Cordillera, demonstrably succeeding *A. cartalla* Group levels in Alaska and containing invariably poorly preserved *Albaillella* spp. suggestive of a latest Meramecian through possibly earliest Morrowan time span.

Schoonover Groups 5, 6a, 6b

All three Groups lie within the Morrowan through Early Permian age range of the *Pseudoalbaillella* Assemblage, and no attempt has been made to achieve the more detailed resolution that may be attainable by reference to recent Japanese work.

Group 5 is characterized by presence of stauraxons with very narrow, elongate rays of hagiastrid nature, lacking spongy cortex. They arise in Group 4c time by reduction of spongy cortex in broad-rayed stauraxons—*Scharfenbergia* spp. of Won (1983)—revealing the narrow, hagiastrid-like inner ray.

Group 6a contains collections with *Paronaella triporosa* Group (Holdsworth and Murchey, in press) but in which, as in Group 5 collections, *Pseudoalbaillella* spp. are not preserved. Group 6a is probably entirely later Pennsylvanian.

Group 6b is used for all collections in which *Pseudoalbaillella* Holdsworth and Jones spp. are detectable, *Follicucullus* Ormiston and Babcock being invariably absent. Work to date on 6b collections suggests that most record a relatively narrow time span ranging from Middle or later Pennsylvanian through earliest Permian, an estimate confirmed by preliminary work on conodonts from Localities K and L (G. D. Sevastopulo, 1983, written commun.).

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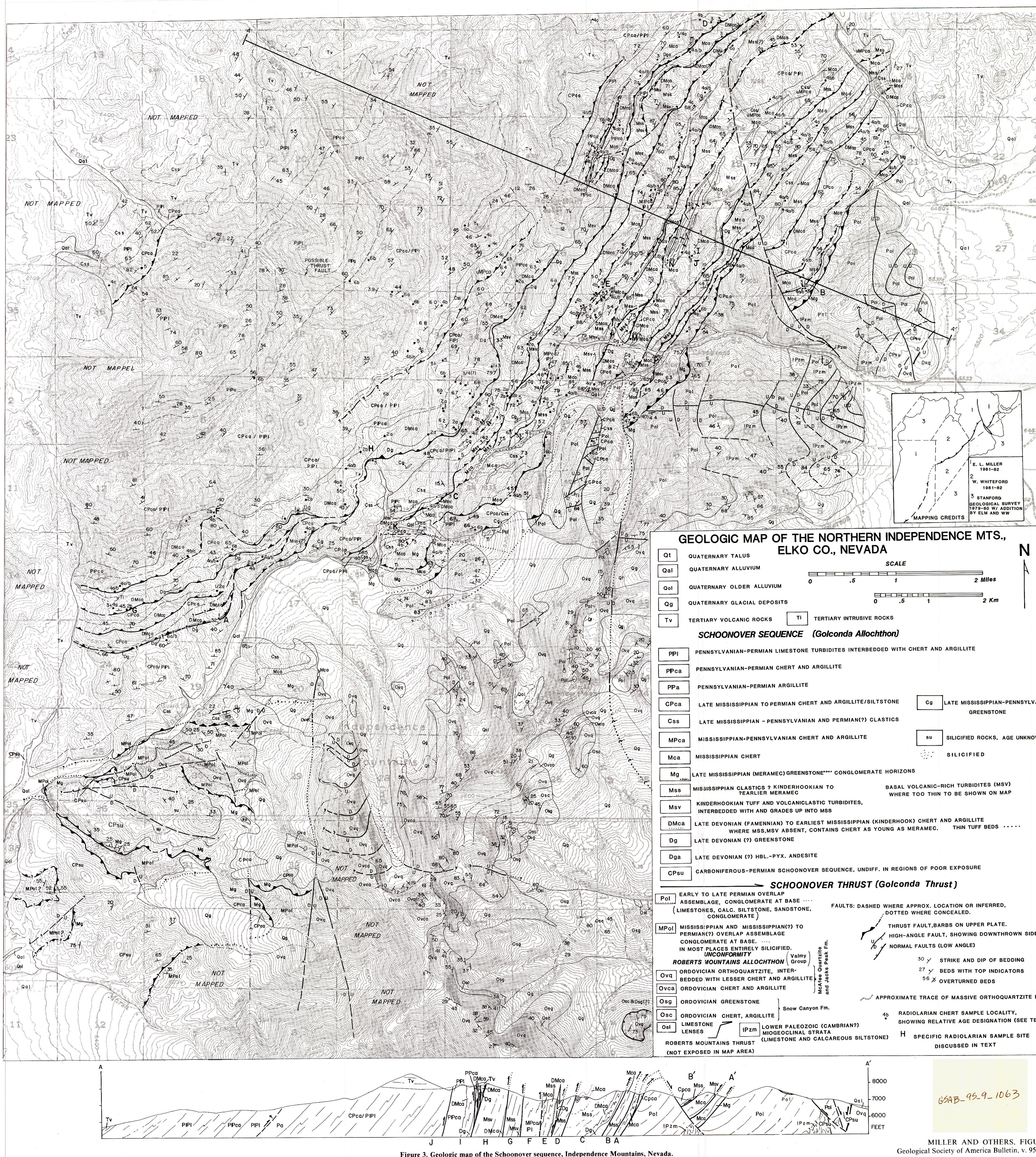

Figure 3. Geologic map of the Schoonover sequence, Independence Mountains, Nevada.