Revista Mexicana de Ciencias Geológicas, volumen 16, numero 1,
1999, p. 35-62.
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Sociedad Geológica Mexicana, México, D.F.

NEOPROTEROZOIC(?) TO PENNSYLVANIAN INNER-SHELF, MIOGEOCLINAL STRATA IN SIERRA AGUA VERDE, SONORA, MEXICO

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ABSTRACT

Sierra Agua Verde contains one of the most complete and best exposed sections known of inner-shelf miogeoclinal strata in Sonora, Mexico. Over 3,700 m of Neoproterozoic(?), Cambrian, Lower Ordovician, Upper Devonian, Mississippian, and Lower and Middle Pennsylvanian strata are exposed. The lowest exposures are several hundred meters of quartzite, siltstone, and dolostone of Early Cambrian and possibly Neoproterozoic in age. A major structural break separates these strata from a nearly 600-m-thick, but incomplete succession of Middle(?) and Upper Cambrian carbonate strata. A 137-m-thick unit of Upper Cambrian siltstone overlies the Cambrian carbonate unit. Conformably above these strata are two Lower Ordovician carbonate units that have a total thickness of almost 900 m. The Lower Ordovician strata are unconformably overlain, with a angularity of 10 degrees, by a 342-m-thick succession of carbonate, quartzite, and sandstone of Late Devonian (Frasnian and Famennian) age. These Upper Devonian rocks are overlain by a cliff-forming carbonate unit of Late Devonian (Famennian) and Mississippian (Kinderhookian, Osagean, Meramecian, and Chesterian) age. This unit is about 868 m thick and forms the crest of the range. The thickness of Upper Devonian strata in this unit is about 85 m and that of the Mississippian strata is about 783 m. The highest unit exposed in the range comprises ledge- and slope-forming carbonate strata of Early and Middle Pennsylvanian (Morrowan and Atokan) age. The Pennsylvanian strata measured are 688 m thick, but the top is not exposed.

The strata in Sierra Agua Verde resemble some of the inner-shelf strata of the Cordilleran miogeocline exposed in eastern California and southern Nevada. Sierra Agua Verde may represent an essentially undisrupted continuation of these shelf rocks from California, or part of a structural block that has been displaced left laterally from California by about 600 km of offset along the hypothetical Mesozoic, or perhaps late Paleozoic, Mojave-Sonora megashear of Silver and Anderson (1974).

Keywords: Neoproterozoic, Pennsylvanian, Miogeoclinal Strata, Sierra Agua Verde, Sonora, Mexico.

RESUMEN

La Sierra Agua Verde contiene una de las secciones más completas y mejor expuesta de rocas miogeoclinales de plataforma interna en Sonora, México. Más de 3,700 m de estratos del Neoproterozoico (?), Cámbrico, Ordovícico Inferior, Devónico Superior, Misisípico y Pensilvánico medio e inferior están expuestos. La parte inferior de la sección comprende varios cientos de metros de cuarcitas, limolita y dolomita de edad Cámbrico Temprano y posiblemente Neoproterozoico. Una interrupción estructural mayor separa a estos estratos de una secuencia incompleta de casi 600 m de rocas carbonatadas del Cámbrico Medio (?) y Superior. Una unidad del Cámbrico Superior, representada por 137 m de limolita sobreyace a las rocas carbonatadas cámbricas. Cubriendo concordantemente a estas capas se presentan dos unidades carbo-natadas del Ordovícico Inferior, con un espesor total de aproximadamente 900 m y que a su vez son cubiertas discordantemente, con un ángulo de 10 grados, por 342 m de una secuencia constituida por rocas carbo-natadas, cuarcitas y areniscas del Devónico Tardío (Frasniano y Famenniano). Estas rocas del Devónico Superior están sobreyacidas por una unidad carbonatada, que forma escarpes, del Devónico Tardío (Famenniano) y Misisipico (Kinderhookiano, Osageano, Merameciano y Chesteriano). Esta unidad tiene un espesor aproximado de 868 m y forma la cuesta de la sierra. El espesor de las capas del Devónico Superior en esta unidad es de casi 85 m y el de las capas misisípicas de cerca de 783 m. La unidad más alta que aflora en la sierra comprende salientes a laderas y corresponde con estratos carbonatados de edad pensilvánica temprana y media (Morrowano y Atokano). Las capas pensilvánicas medidas tienen un espesor de 688 m, aunque la cima no aflora.

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Los estratos en la Sierra Agua Verde son semejantes a algunos de los estratos de plataforma interna de miogeoclinal Cordillerano que afloran en el oriente de California y el sur de Nevada. La Sierra Agua Verde puede representar esencialmente una continuación no interrumpida de estas rocas de plataforma desde California, o parte de un bloque estructural que ha sido desplazado lateralmente hacia la izquierda desde California sobre una distancia de 600 km a lo largo de la hipotética megacizalla de Mojave-Sonora (Silver y Anderson, 1974) durante el Mesozoico, o quizás Paleozoico tardío.

Palabras clave: Neoproterozoico, Pensilv[anico, Estratos de miogeoclinal, Sierra Agua Verde, Sonora, México.

INTRODUCTION

Sierra Agua Verde, which lies about 110 km east of Hermosillo, Sonora, (Figurel), contains one of the most complete and well exposed sections of Neoproterozoic(?) to Pennsylvanian rocks known in Sonora. The presence of Paleozoic rocks in the range was apparently first recognized in the 1970's by Françoise Peiffer-Rangin (written communication, 1988) who found fossiliferous Mississippian rocks at two places. In 1982 and 1983, we studied the range and recognized Cambrian, Lower Ordovician, Upper Devonian, lower and upper Mississippian, and early Pennsylvanian strata (Stewart and others, 1984, 1988). Minjarez-Sosa and others (1993) and Ochoa-Granillo and Sosa-León (1993) subsequently studied the area and described Ordovician, Devonian, Mississippian, Pennsylvanian, and Permian strata. The Permian rocks described by these geologists are apparently in a part of Sierra Agua Verde outside of the area of our study. Some results of our studies were previously reported (Stewart and others, 1984; 1988; Repetski and others, 1985; Poole and others, 1995). Gehrels and others (1995) determined the ages of detrital zircons from the Proveedora Quartzite of Early Cambrian age and from a sandstone of Late Devonian age in the section we describe here.

Sierra Agua Verde is a relatively high range that has elevations ranging from about 500 m near the base to 1,700 m near the crest (Figure 2). The most complete exposure of Paleozoic rocks is 5 to 8 km north of a dirt road that crosses the range between Villa Pesquería (Matape) and San José de Batuc (Batuquito). Best access to the lower part of the section on the west side of the range is by a dirt road entering the range 7.5 km north-northeast of Villa Pesquería and continuing northeastward to near Cerro El Pollo within Sierra Agua Verde (Figure 3). In 1982 and 1983, this road was easily passable with a 4-wheel-drive vehicle, but during a 1992 visit to the area the road was in poor condition and only passable with extreme difficulty. Access to the upper part of the section on the east side of the range in 1983 was by a road along the west side of the range to La Noria de Varela, then east across the northern part of the range to Agua Caliente (El Rancho Agua Caliente), and finally south within the range to an area east of Cerro Santiago (Figure 3). The present status of the road south of Agua Caliente is unknown.

Our work consisted of geologic mapping, measurement of a composite stratigraphic section, and chronostratigraphic studies based on identification of conodonts, foraminifers, algae, *incertae sedis*, and corals (Tables 3 and 4). Field mapping was by J.H. Stewart and F.G. Poole; measurement of the stratigraphic section was by J.H. Stewart, A.K. Armstrong, F.G. Poole, A.G. Harris, B.R. Wardlaw, and J.M. Morales-Ramírez. Conodont identifications are by A.G. Harris, J.E. Repetski, and B.R. Wardlaw; foraminifers, algae, and *incertae sedis* identifications are by B.L. Mamet; and coral identifications are by W.J. Sando and W.A. Oliver, Jr. In addition, A.R. Palmer identified Early Cambrian trilobites and Late Cambrian acrotretid brachiopods. A.K. Armstong studied the petrography of the carbonate rocks. This report summarizes the results of these studies.

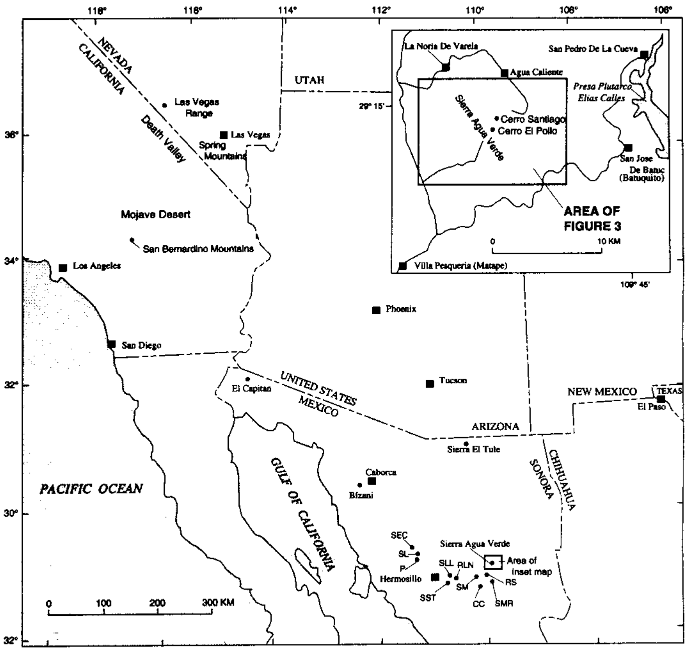


Figure 1. Index map showing location of Sierra Verde and other localities in Sonora, Mexico, and adjacent parts of the United States. Symbols: CC, Cerro Cobachi; P, Placeritas; RLN, Rancho Las Norias; RS, Rancho Sobechi; SEC, Sierra El Carnero; SL, Sierra López; SLL, Sierra Los Leyva; SM, Sierra Mazatán; SMR, Sierra Martínez; SST, Sierra Santa Teresa.

STRATIGRAPHY

The main part of Sierra Agua Verde consists of a relatively unfaulted east-dipping succession of Neoproterozoic (?) to Pennsylvanian strata (Figures 3, 4). However, west of this

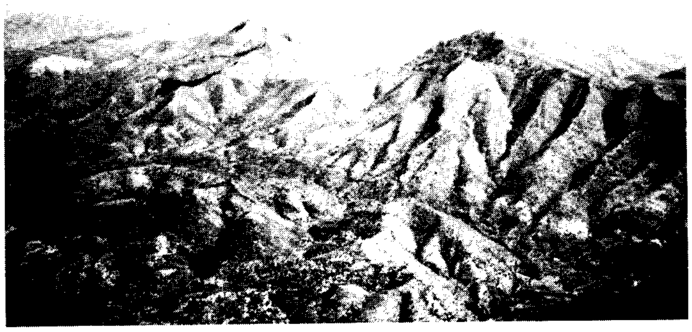


Figure 2. Low altitude oblique aerial photograph of Sierra Verde, looking north. Highest part of range is underlain by Upper Devonian and Mississipian carbonate rocks; valley-forming unit in middle ground directly west of the main part of the range is Cambrian siltstone unit.

relatively unfaulted section, are several high-angle normal faults and low-angle thrust faults that disrupt the Cambrian strata and preclude the measurement of a complete section of these rocks. Below the zone of structural disruption, Upper Proterozoic (?) and Lower Cambrian strata are recognized, and above this disrupted zone Middle (?) and Upper Cambrian, Lower Ordovician, Upper Devonian, Mississippian, and lower and middle Pennsylvanian strata are recognized. A few patches of undated and unassigned Paleozoic (?) rocks are present in thrust slices in the western part of the range (Figure 3). A generalized stratigraphic column of the Neoproterozoic (?) to Pennsylvanian strata is shown in Figure 4; detailed stratigraphic sections in Figures 5 to 8. Conodont zones in Ordovician, Devonian, and Mississippian rocks in Sierra Agua Verde are shown in Figure 9; biostratigraphic summary of conodonts from Sierra Agua Verde in Table 1, of foraminifers, algae, and *incertae sedis* in Table 2; and of Devonian and Mississippian corals and stromatoporoids in Table 3.

NEOPROTEROZOIC (?) AND LOWER CAMBRIAN QUARTZITE, SILTSTONE, AND DOLOSTONE UNIT (MAP UNIT ZꞒNq)

The Neoproterozoic (?) and Lower Cambrian quartzite, siltstone, and dolostone unit (map unit ꞒNq) crops out in the western part of Sierra Agua Verde (Figure 3). The unit is structurally complicated, poorly exposed, and lacks distinctive marker beds. For these reasons, a stratigraphic succession or thickness, except for the top 80 m, was not determined. The total thickness is probably several hundred meters and the base is not exposed (Figure 4). The strata consist of yellow-gray, medium-gray, pale-red, and light-greenish-gray micaceous siltstone and phyllitic siltstone; minor amounts of yellow-gray very fine grained to fine-grained quartzite, yellow-brown fine- to coarse-grained quartzite and pebble conglomerate; and limestone and dolostone. Some conglomerate layers contain clasts as large as 8 mm.

Approximately the upper 80 m of the Neoproterozoic (?) and Lower Cambrian unit is exposed in apparent stratigraphic continuity below the Proveedora Quartzite where it was measured on the west side of the range (Figures 3, 4). These 80 m of strata consist of very pale orange, very fine to fine-grained evenly laminated quartzite; very-pale-orange and medium-gray micaceous, laminated siltstone; and medium-light-gray and light-brown, locally oolitic dolostone. These strata contain the brachiopod *Obolella* and the Early Cambrian trilobite *Nevadella* (A.R. Palmer, written communication, 1982).

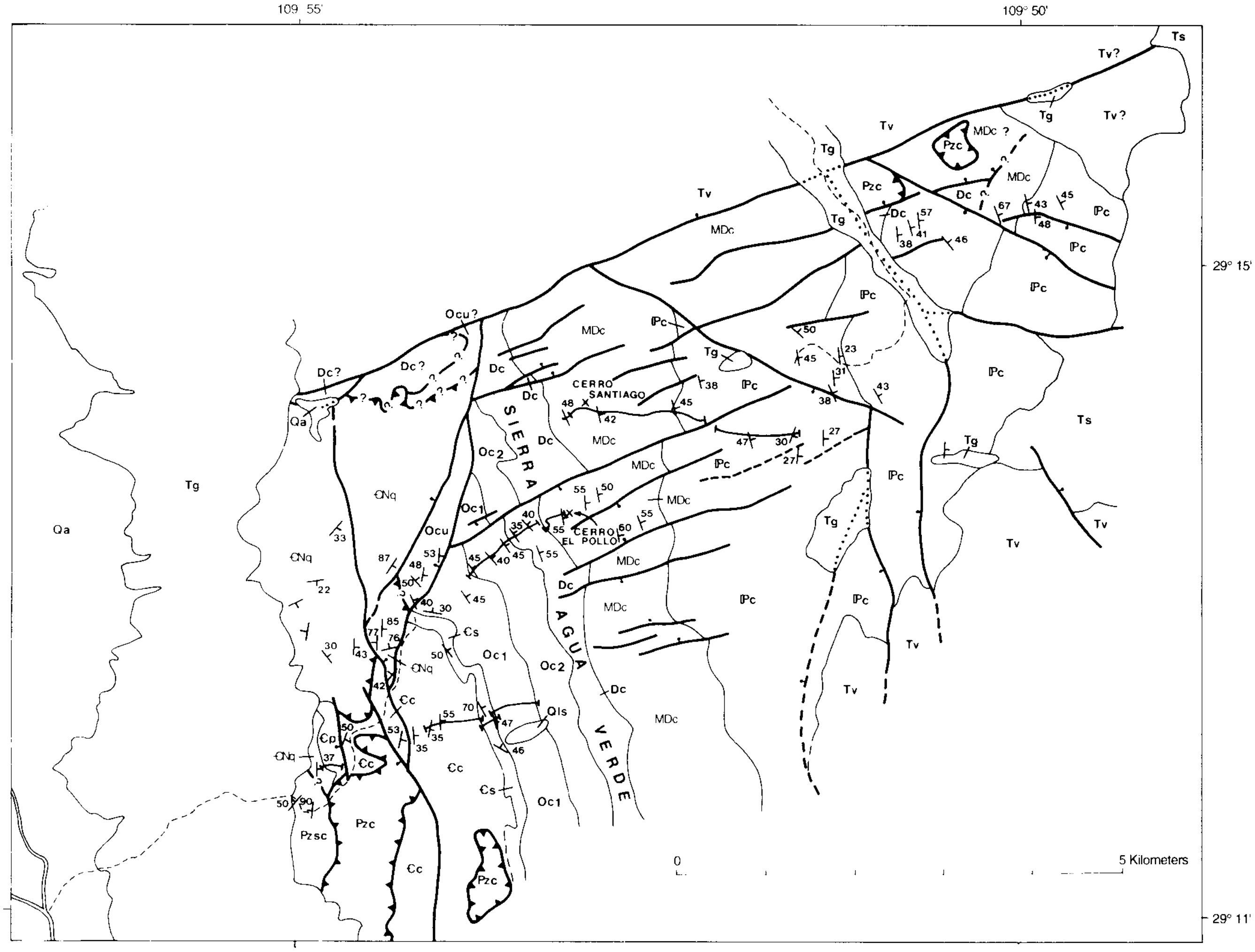
LOWER CAMBRIAN PROVEEDORA QUARTZITE (MAP UNIT Ꞓp)

The Proveedora Quartzite (Figure 5, subunits 2-4) crops out in a relatively small area in the western part of Sierra Agua Verde (Figure 3). The Proveedora Quartzite was named by Cooper and others (1952) in the Caborca region, 280 km northwest of Sierra Agua Verde, and has been extended to Sierra Agua Verde on the basis of similar lithology and the presence of trilobites, either in the formation or in adjacent units, that indicate an Early Cambrian age in both areas (Stewart and others, 1984). The Proveedora in Sierra Agua Verde is 120 m thick (Figure 5) and consists mostly of pinkish-gray, fine- to coarse-grained quartzite that forms cliffs and resistant outcrops. The upper part of the formation locally contains granule conglomerate (subunit 4). *Skolithos* (vertical burrows) is present locally in the quartzite. The Early Cambrian trilobite *Olenellus gilberti* (A.R. Palmer, written communication, 1982) is present in siltstone in the upper part of the Proveedora Quartzite 450 m north of the measured section.

MIDDLE (?) AND UPPER CAMBRIAN CARBONATE UNIT (MAP UNIT Ꞓc)

The Middle (?) and Upper Cambrian carbonate unit crops out in the western part of Sierra Agua Verde. The unit is separated from Lower Cambrian rocks by a major structural zone that precludes measurement of a complete section of Cambrian strata. Incomplete exposures of Middle (?) and Upper Cambrian rocks are 742 m thick (Figure 5, subunits 5-11) and consist of lime mudstone, dolomitic lime mudstone, and recrystallized limestone commonly containing metamorphic sericite. The carbonate rocks are thin to thick bedded, commonly with wavy or knobby bedding; laminated bedding is common. One channel filled with sedimentary breccia was noted. Vertical or irregular burrows are locally abundant. The Middle (?) and Upper Cambrian carbonate unit forms low ridges and valleys in the lower, western part of Sierra Agua Verde.

The Middle (?) and Late Cambrian age of the unit is based on apparent conformity with dated Upper Cambrian strata above, and with the known presence of a thick Middle and Upper Cambrian carbonate succession elsewhere in Sonora (Cooper and others, 1952; Stewart and others, 1990). No identifiable fossils were found.



EXPLANATION

Qa, Quaternary alluvial deposits
Qls, Quaternary landslide deposits
Tg, Tertiary gravel deposits
Ts, Tertiary sandstone, siltstone, and conglomerate
Tv, Tertiary volcanic rocks
Pzc, Undated (Paleozoic?) limestone
Pzsc, Undated (Paleozoic?) siltstone and limestone
ℙc, Pennsylvanian ledge- and slope-forming carbonate unit
MDc, Upper Devonian and Mississippian cliff-forming carbonate unit
Dc, Upper Devonian carbonate and siliciclastic unit
Oc2, Lower Ordovician carbonate unit 2
Oc1, Lower Ordovician carbonate unit 1
Ocu, Undivided Lower Ordovician carbonate units 1 and 2
Ꞓs, Upper Cambrian siltstone unit
Ꞓc, Middle(?) and Upper Cambrian carbonate unit
Ꞓp, Lower Cambrian Proveedora Quartzite
ꞒNq, Neoproterozoic(?) and Lower Cambrian quartzite, siltstone, and dolostone unit

Contact

Thrust fault. Sawteeth on upper plate Dashed where inferred. Queried where uncertain

High-angle fault. Bar and ball on downthrown side. Dashed where inferred

55 Strike and dip of strata

Line of measured section

Dirt road

Jeep trail

Figure 3. Geologic map os part of Sierra Agua Verde, showing distribution of Neoproterozoic (?) and Paleozoic strata and location of measured sections.

UPPER CAMBRIAN SILTSTONE UNIT (MAP UNIT Ꞓs)

The Upper Cambrian siltstone unit is 137 m thick (Figure 5, subunits 12 and 13). It forms a conspicuous strike valley in the western part of Sierra Agua Verde (Figures 2, 3) and consists of evenly laminated and platy siltstone and a few 1- to 3-cm-thick layers of interstratified laminated lime mudstone. Linguloid and acrotretid brachiopods (*Angulotreta*) and hexactinellid sponge spicules (A.R. Palmer, written communication, 1982) are present in the unit 400 m south of the measured section. *Angulotreta* is a guide fossil to the Upper Cambrian, and is characteristic of outer-shelf strata in Nevada (A.R. Palmer, written communication, 1982).

LOWER ORDOVICIAN CARBONATE UNIT 1 (MAP UNIT Oc1)

Lower Ordovician carbonate unit 1 is 493 m thick (Figure 6, subunits 14 to 16) and forms the lower, steep, west-

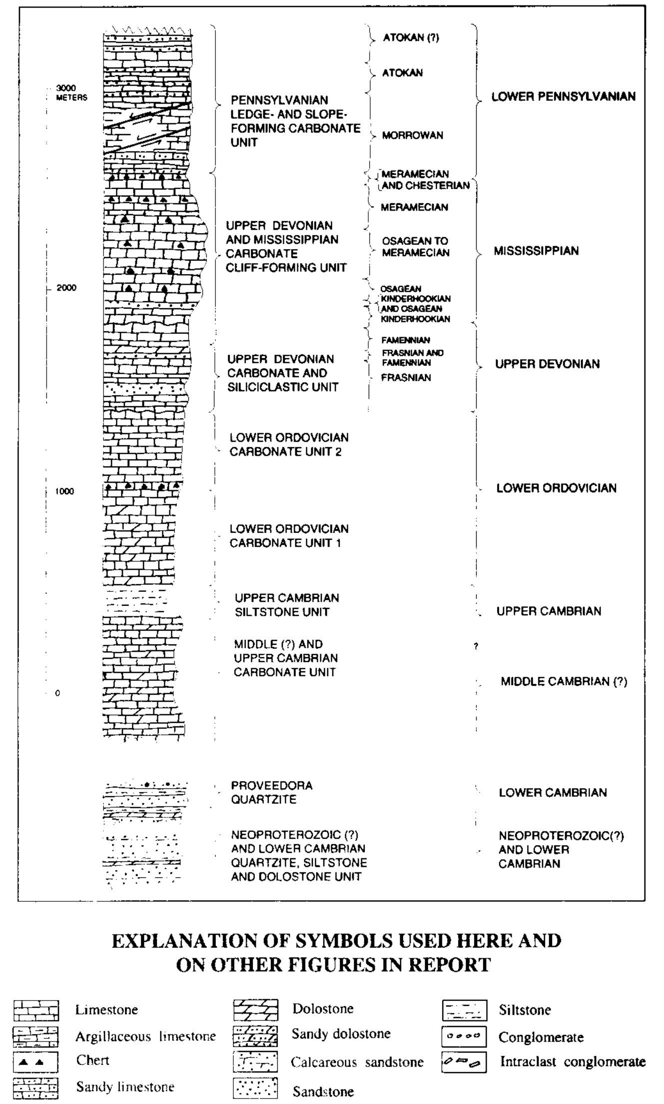


Figure 4. Generalized stratigraphic column of Neoproterozoic, Cambrian, Devonian, Mississipian, and Pennsylvanian strata in Sierra Agua Verde.

ern part of Sierra Agua Verde (Figures 2, 3). It consists of dolomitic lime mudstone, recrystallized limestone, and common intraformational conglomerate. Metamorphic sericite is common. The strata are laminated to very thin bedded, commonly with wavy or crepelike structures. Biogenic tubes and burrows are common in some parts of the unit. Conodonts from the lower part of the unit (Table 1) are early Early Ordovician in age (*C. lindstromi* Zone to *R. manitouensis* Zone, Figures 6, 7); conodonts from the upper 0.5 m of the unit are early middle Early Ordovician in age ("low-diversity interval" or *M. dianae* Zone).

The contact of Lower Ordovician carbonate unit 1 with Lower Ordovician carbonate unit 2 is subtle. It is placed at the color change from very light-colored rocks below (yellowish-gray, in part) to light-gray rocks above. The overlying rocks form a more massive ledgy interval than the underlying units. The basal unit (subunit 17, Figure 6) of Lower Ordovician carbonate unit 2 forms a fairly conspicuous ledge.

LOWER ORDOVICIAN CARBONATE UNIT 2 (MAP UNIT Oc2)

Lower Ordovician carbonate unit 2 is 405 m thick (Figure 6, subunits 17 and 18) and forms a steep slope in the lower, steep, western part of Sierra Agua Verde (Figures 2, 3). The unit is composed of lime mudstone, recrystallized limestone, and about 4 percent chert. Sparse oolitic grainstone is present in the basal 112 m of subunit 18. A thin bed of intraformational conglomerate was noted in the lower part of the unit. Stratification is indistinct, but generally laminated to thin bedded. Sericitic metamorphic minerals are common. Conodonts (Table 1) from the lower part of the unit are middle Early Ordovician in age (*M. dianae* Zone) and from the upper 14.5 m are latest Early Ordovician in age (*R. andinus* Zone) (Figure 7).

The contact of Lower Ordovician carbonate unit 2 with the Upper Devonian carbonate and siliciclastic unit is a major unconformity with an angular discordance of about 10 degrees. A distinctive ledge-forming fossiliferous packstone about 0.8 m thick lies directly above the contact.

UPPER DEVONIAN CARBONATE AND SILICICLASTIC UNIT (MAP UNIT Dc)

The Upper Devonian carbonate and siliciclastic unit is 342.8 m thick (Figure 8, subunits 19 to 31). The siliciclastic strata consist of sandstone, quartzite, and minor amounts of siltstone. The sandstone and quartzite are fine to coarse grained, moderately to well sorted, commonly calcareous, and composed of subrounded quartz. The quartzite and sandstone of subunit 21 (Figure 8) contain common grains of potassium feldspar in addition to quartz. The sandstone and quartzite are laminated and contain sparse thin sets of low-angle cross-strata. The highest subunits (30 and 31) are composed of silicic siltstone and very fine grained quartzite interstratified with limy, very fine grained sandstone and sparse lime mudstone. Carbonate strata in the unit consist of lime mudstone and minor amounts of packstone, dolomitic limestone, and dolostone. The lime mudstone and packstone are characterized by sparse to abundant fossil detritus as well as corals, gastropods, brachiopods, foraminifers, and stromatoporoids. Bioturbation is locally conspicuous. Dolostone with algal laminae is present in the upper part of the unit.

Conodonts from the lower 68 m of this unit (subunits 19 to 23) indicate a *Pa. transitans* Zone to *Pa. punctata* Zone (early Frasnian) age (Table 1). Higher strata contain conodonts of middle to late Frasnian (early Late Devonian), late Frasnian, and Famennian (late Late Devonian) age.

Reworked corals from subunit 19 (basal 0.8 m of unit) are of probably Middle Devonian age. Corals from subunit 25 are Middle or Late Devonian in age (Figure 8; Table 3). The stromatoporoid *Amphipora* also was recognized in dark-gray dolostone beds in subunit 25.

Subunit 30 of the Upper Devonian carbonate and siliciclastic unit forms a distinctive brown-weathering slope that is

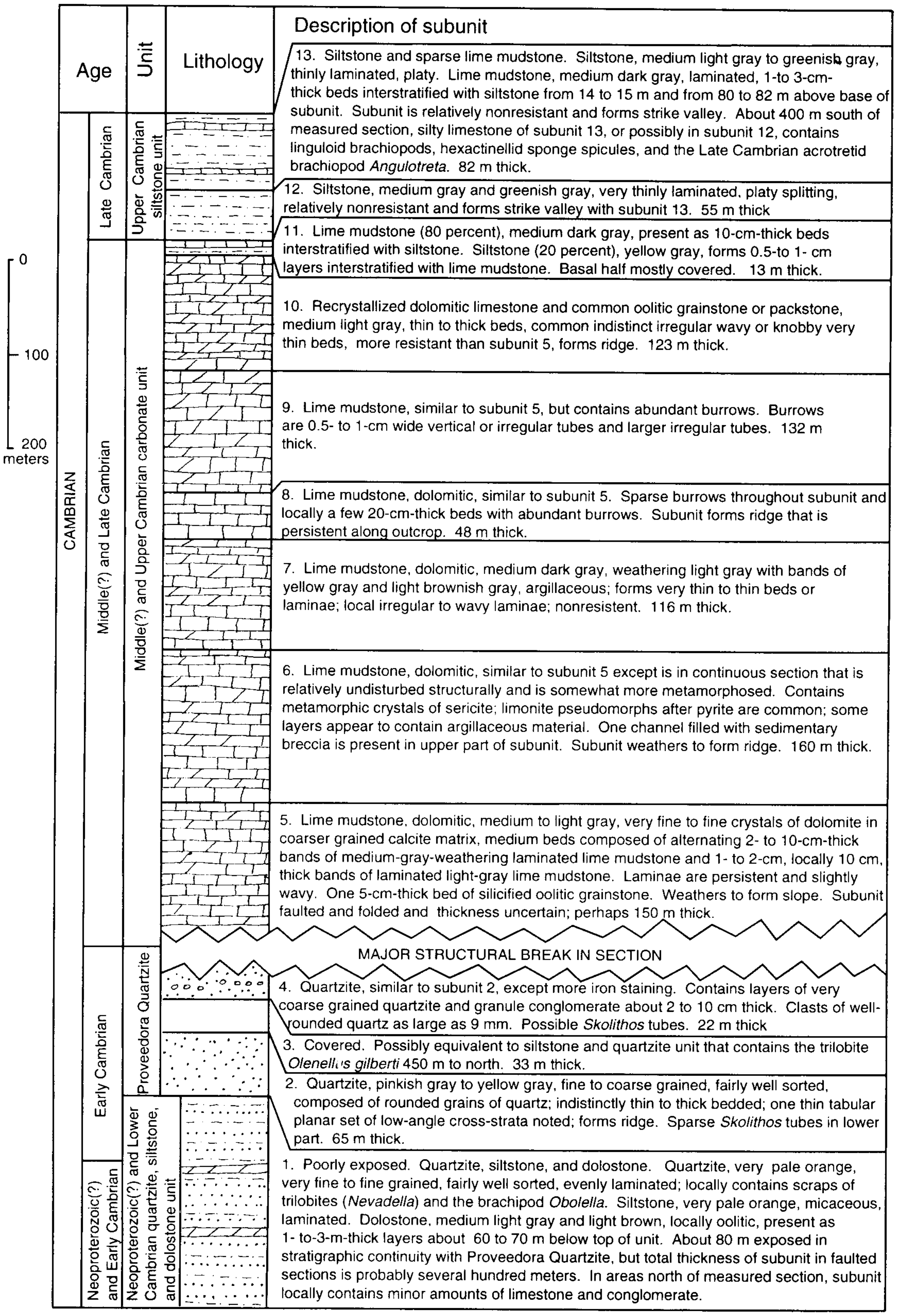


Figure 5. Lithologic column and description of Neoproterozoic (?) and Cambrian quartzite, siltstone, and dolostone unit; Lower Cambrian Proveedora Quartzite; Middle (?) and Upper Cambrian carbonate unit; and Upper Cambrian siltstone unit in Sierra Agua Verde.

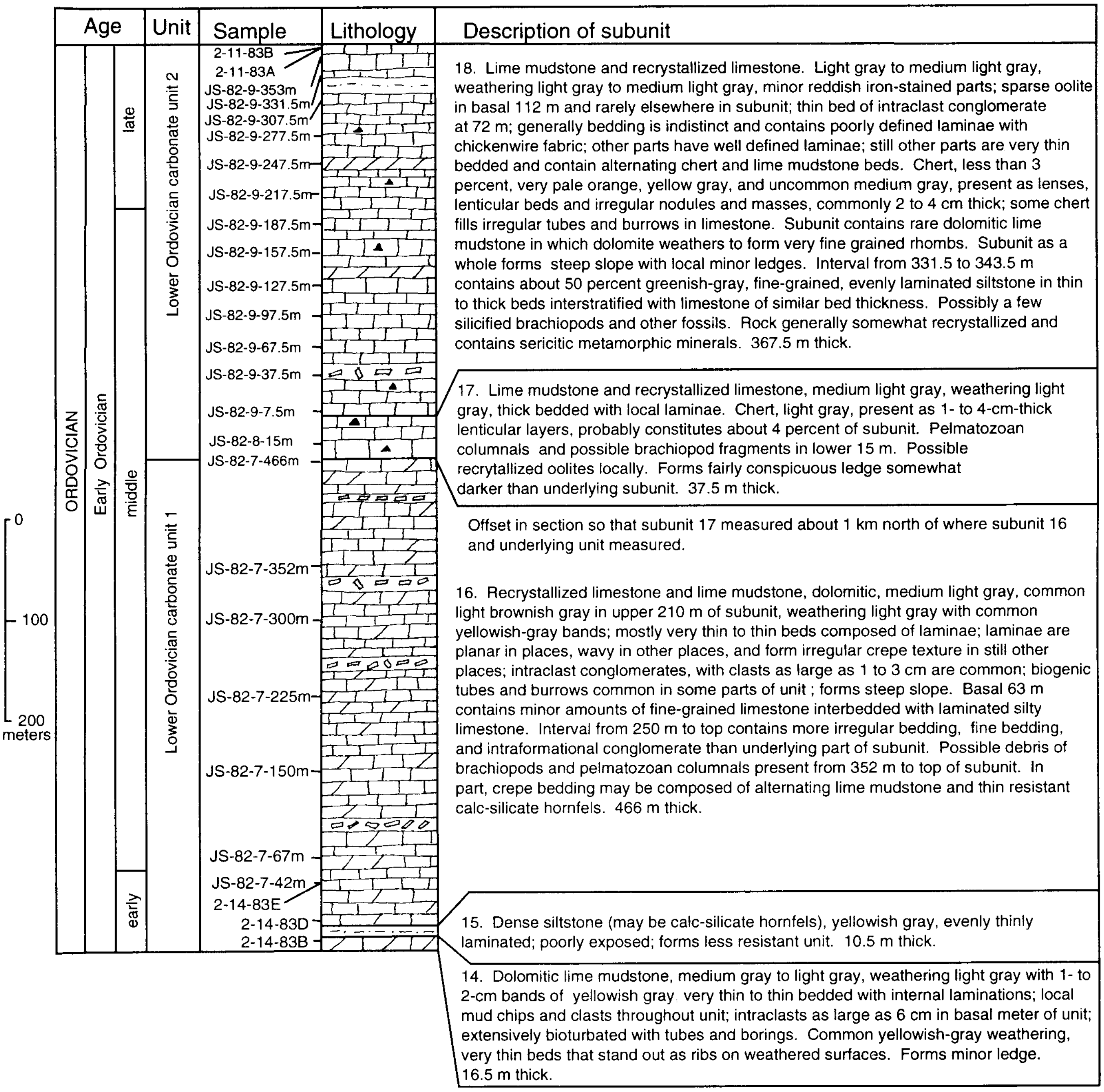


Figure 6. Lithologic column and description of Lower Ordovician carbonate units 1 and 2 in Sierra Agua Verde.

useful in mapping the contact between it and the overlying Upper Devonian and Mississippian cliff-forming carbonate unit.

UPPER DEVONIAN AND MISSISSIPPIAN CLIFF-FORMING CARBONATE UNIT (MAP UNIT MDc)

The Upper Devonian and Mississippian cliff-forming carbonate unit is 867.6 m thick (Figure 9, subunits 32 to 47). It forms the high crest and flanking parts of Sierra Agua Verde (Figures 2, 3) and is composed primarily of lime mudstone, packstone, and wackestone, all of which are commonly dolomitic. Small amounts of chert characterize much of the unit. The resistant character of subunit 41, which forms the highest part of the range in most areas, is due to the greater abundance of chert than other parts of unit MDc. The 32.9-m-thick subunit 38 is distinctive; it is composed of fine- to coarse-grained, limy sandstone. The thickness of Upper Devonian strata in this unit is about 85 m and the thickness of Mississippian strata is about 783 m.

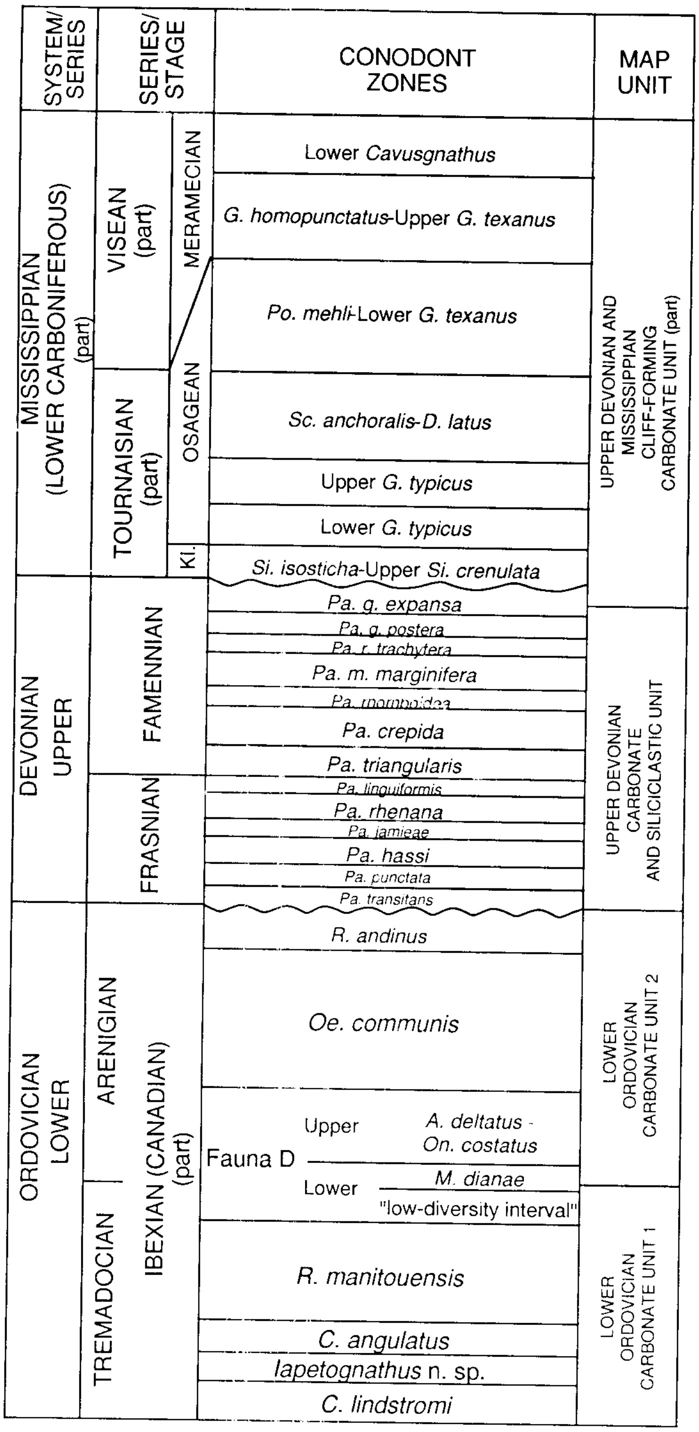


Figure 7. Conodont zones for Ordovician, Devonian, And Mississipian rocks in Sierra Agua Verde. Kl = Kinderhookian.

Conodonts (Table 1) indicate the lowermost part of the Upper Devonian and Mississippian cliff-forming carbonate unit is late Famennian (latest Late Devonian). Higher strata are late Kinderhookian (early Early Mississippian), late Kinderhookian and Osagean (late Early Mississippian), Osagean (late Early Mississippian), middle Osagean to earliest Meramecian (late Early Mississippian), latest Osagean or earliest Meramecian (latest Early Mississippian), and early Meramecian and late Meramecian (early Late Mississippian) in age. Corals (Table 3) collected from subunit 47 indicate a Late Mississippian or Early Pennsylvanian age. Based on the absence of five conodont zones (see conodont zonation in Johnson and others, 1991, and Poole and Sandberg 1991), we interpret the contact between subunits 35 and 36 as an unconformity which seems to coincide with the Devonian-Mississippian systemic boundary.

The contact between the Upper Devonian and Mississippian cliff-forming carbonate unit and the overlying Pennsylvanian ledge-and-slope-forming carbonate unit is placed at the change from generally massive-weathering lime mudstone below to the more distinctly bedded, interstratified limestone, silty limestone, and sandstone above. An unconformity at this contact is suggested by the thinness of Chesterian rocks below the contact; these Chesterian strata may be as thin as 45 m (Table 2). The contact is easily seen on aerial photographs as a change from massive units below to ledge-and-slope-forming units above.

*PENNSYLVANIAN LEDGE-AND SLOPE-FORMING CARBONATE UNIT (MAP UNIT **Pc**)*

The Pennsylvanian ledge-and-slope-forming carbonate unit is at least 688 m thick (Figure 9, subunit 48) in the incomplete section we measured. The strata in the measured section are cut by faults recognized at 76 to 85 m, 104 m, and 206 m above the base of the unit. The unit consists of packstone and wackestone with minor grainstone, lime mudstone, and argillaceous lime mudstone. The unit is also characterized by sparse to common layers of packstone or wackestone containing quartz silt to fine sand and fine-to medium-grained sandstone. These rock types are interstratified in prominent 2- to 12-m-thick sets that give the unit a banded appearance. The strata contain common bioclasts or in-place pelmatozoan, bryozoan, brachiopods, corals, gastropods, foraminifers, fusulinids, algae, ostracodes, or mollusks. The unit is unconformably overlain by Tertiary volcanic rocks (Figure 3).

Studies of foraminifers indicate that the Pennsylvanian ledge-and slope-forming carbonate unit is of Morrowan age in the basal 397 m, Atokan from 431 to 492 m above the base of the unit, and Atokan(?) at 674 m above the base of the unit (Table 2). The topmost part of the measured section is characterized by *Chaetetes*, a regionally important index fossil in the Pennsylvanian (Table 3).

REGIONAL CORRELATIONS

The oldest units exposed in Sierra Agua Verde are the Neoproterozoic(?) and Lower Cambrian quartzite, siltstone, and dolostone unit and the overlying Lower Cambrian Proveedora Quartzite. Rocks of these ages are widespread in Sonora and in eastern California and Nevada. Regionally,

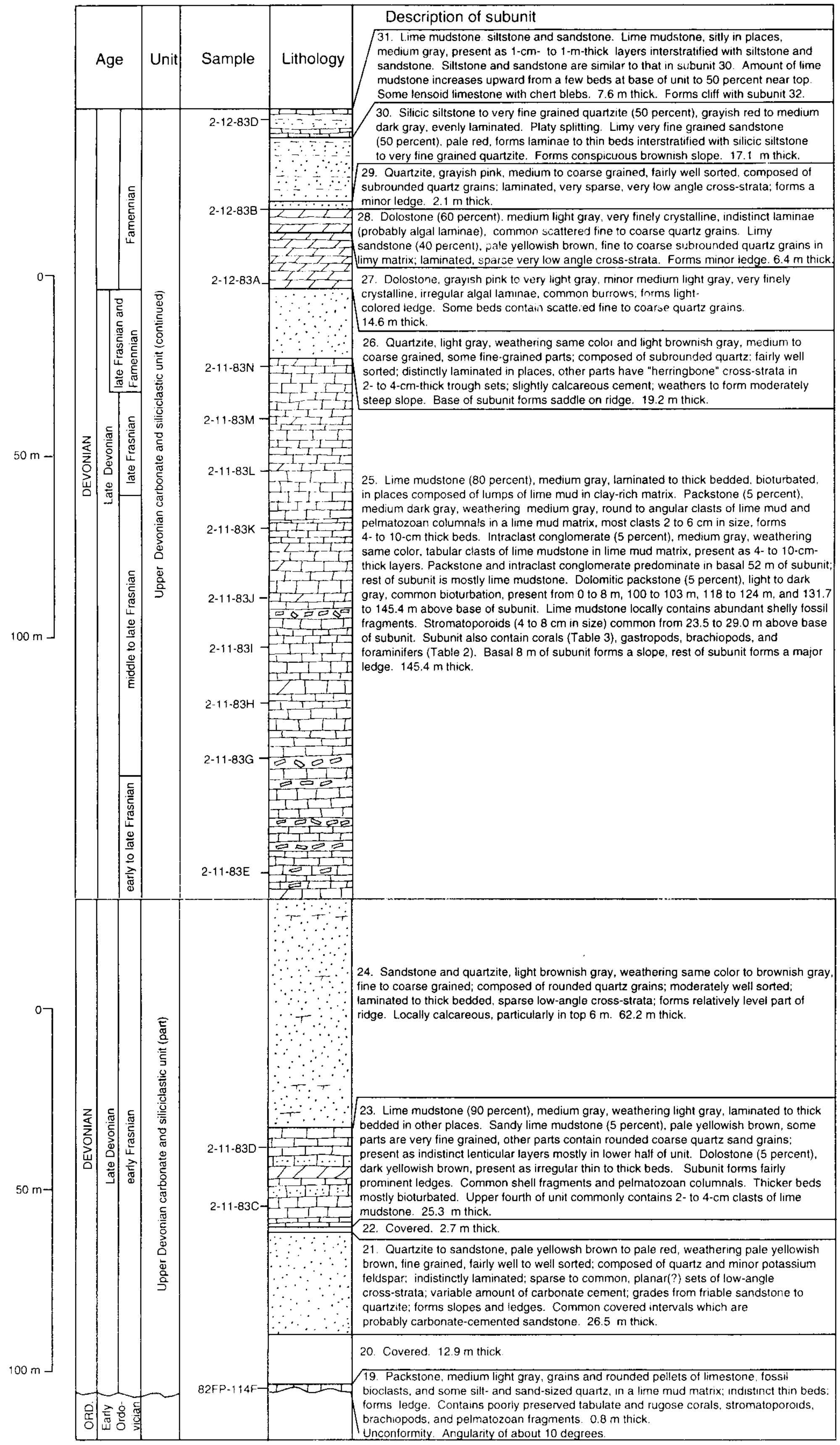


Figure 8. Lithologic column and description of Upper Devonian carbonate and siliciclastic unit in Sierra Agua Verde. Note different scale from Figures 5 and 6—Continued.

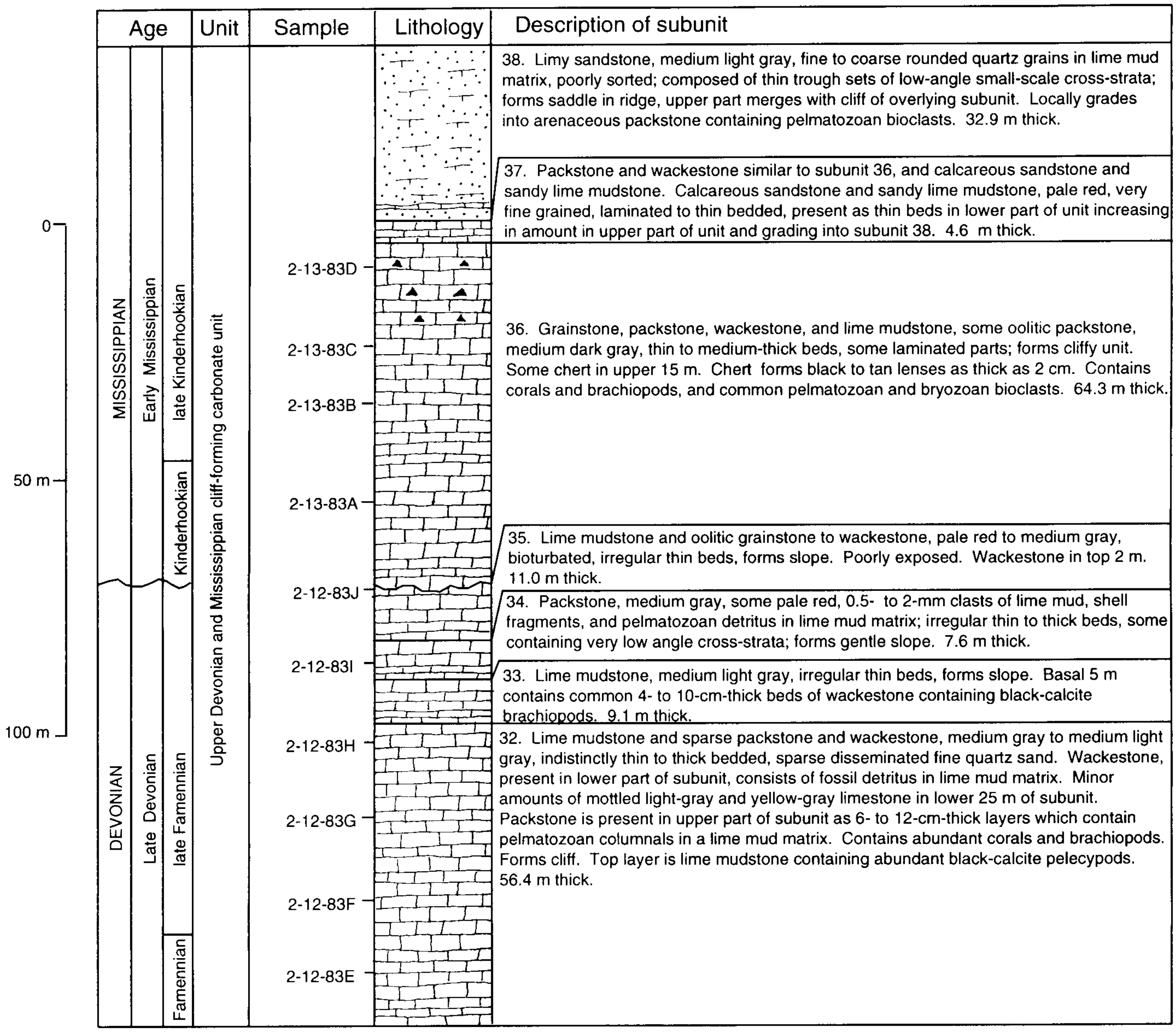


Figure 9 (part 1 of 5). Lithologic column and description of Upper Devonian and Mississippian cliff-forming carbonate unit in Sierra Agua Verde. Note scale is same as figure 7, but different from Figures 5 and 6.

rocks of Neoproterozoic and Early Cambrian age are as thick as 3,300 m in the Caborca area (Figure 1) where they rest on Precambrian crystalline basement rocks. In contrast, strata of Neoproterozoic and Early Cambrian age are absent in northern Sonora (González-León, 1986) and southern Arizona, New Mexico, and west Texas where the relatively thin Bolsa Quartzite, or correlative rocks, of Middle and Late Cambrian age rests unconformably on Precambrian crystalline basement rocks (Hayes, 1975). The Proveedora Quartzite is an important regional unit composed of pure quartz arenite and characterized by *Skolithos* (vertical borings) in the lower part. In addition to outcrops in Sierra Agua Verde, the Proveedora Quartzite crops out near Hermosillo (Morales-Montaño and Cota-Reyna, 1990; Morales-Montaño and others, 1990), in Sierra López, 50 km northeast of Hermosillo (Stewart and others, 1990), and in the Caborca region (Cooper and others, 1952, Stewart and others, 1984). The correlative Zabriskie Quartzite is widespread in eastern California and southern Nevada (Figure 10). Correlation of the Proveedora Quartzite and Zabriskie Quartzite is based on similar lithology and age (based on trilobites) of these units in Sonora, California, and Nevada. The Zabriskie Quartzite is characteristic of the Cordilleran miogeocline of eastern California and southern Nevada, and the presence of the correlative Proveedora Quartzite in Sonora is indicative of a continuation of this belt.

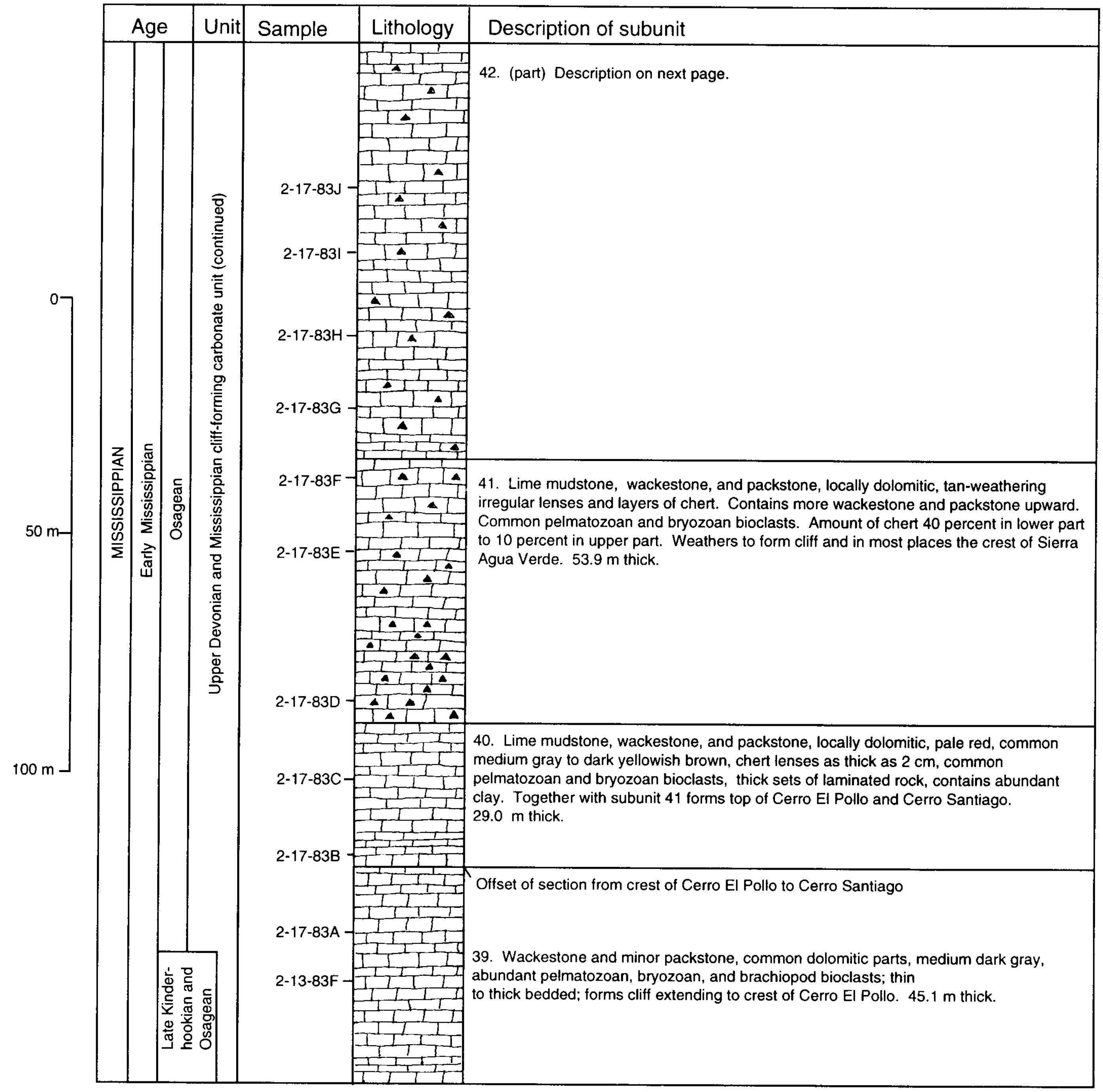


Figure 9 (part 2 of 5). Lithologic column and description of Upper Devonian and Mississippian cliff-forming carbonate unit in Sierra Agua Verde. Note scale is same as figure 7, but different from Figures 5 and 6.

Strata of Middle(?) and Late Cambrian age in Sierra Agua Verde consist of a carbonate unit overlain by a siltstone unit. The carbonate unit in an incomplete section is over 600 m thick. Lithologically, this unit is comparable to partial sections of Middle and Upper Cambrian or, in part, Middle and Upper Cambrian, carbonate strata exposed near Sierra López (Stewart and others, 1990) and in the Caborca region (Cooper and others, 1952). Northwest of the Caborca region, the closest outcrops of thick Middle and Upper Cambrian carbonate rocks are in the San Bernardino Mountains and Mojave Desert region of California (Brown, 1991) where they are part of the Cordilleran miogeocline. In northern Sonora, southeastern Arizona, and southwestern New Mexico, Middle and Upper Cambrian rocks consist of the Bolsa Quartzite and the overlying Abrigo Formation. The Bolsa and Abrigo are part of the relatively thin cratonal platform succession unlike the thick miogeoclinal succession in Sierra Agua Verde.

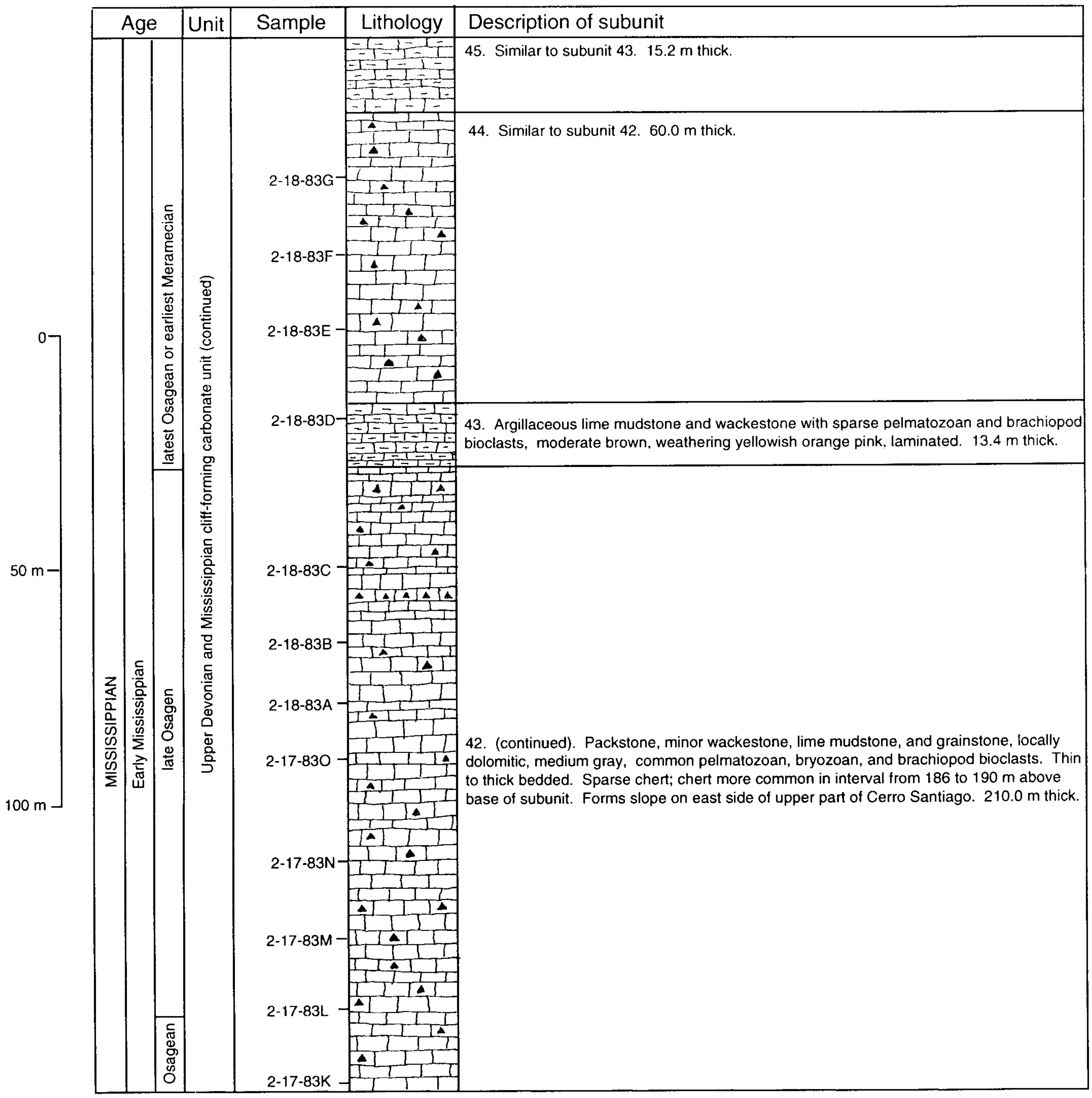


Figure 9 (part 3 of 5). Lithologic column and description of Upper Devonian and Mississippian cliff-forming carbonate unit in Sierra Agua Verde. Note scale is same as figure 7, but different from Figures 5 and 6.

The 82-m-thick Upper Cambrian siltstone unit in Sierra Agua Verde was originally considered by Stewart and others (1984) to be correlative with the Dunderberg Shale, a prominent Upper Cambrian unit in eastern California and southern Nevada. This correlation was based on lithologic similarity and on the presence of acrotetid brachiopods characteristic of the lower part of the Dunderberg (A.R. Palmer, written communication, 1982). Although this correlation may be valid, it now is considered questionable (Stewart and others, 1984) because the Dunderberg Shale in eastern California and southern Nevada is overlain by a thick Upper Cambrian carbonate unit, the Nopah Formation, whereas the siltstone unit in Sierra Agua Verde is overlain by Lower Ordovician strata. In addition, the acrotetid brachiopods could range upward in age to nearly Early Ordovician. As suggested by Stewart and others (1990), the siltstone unit may be correlative in Sonora with unit 4 of

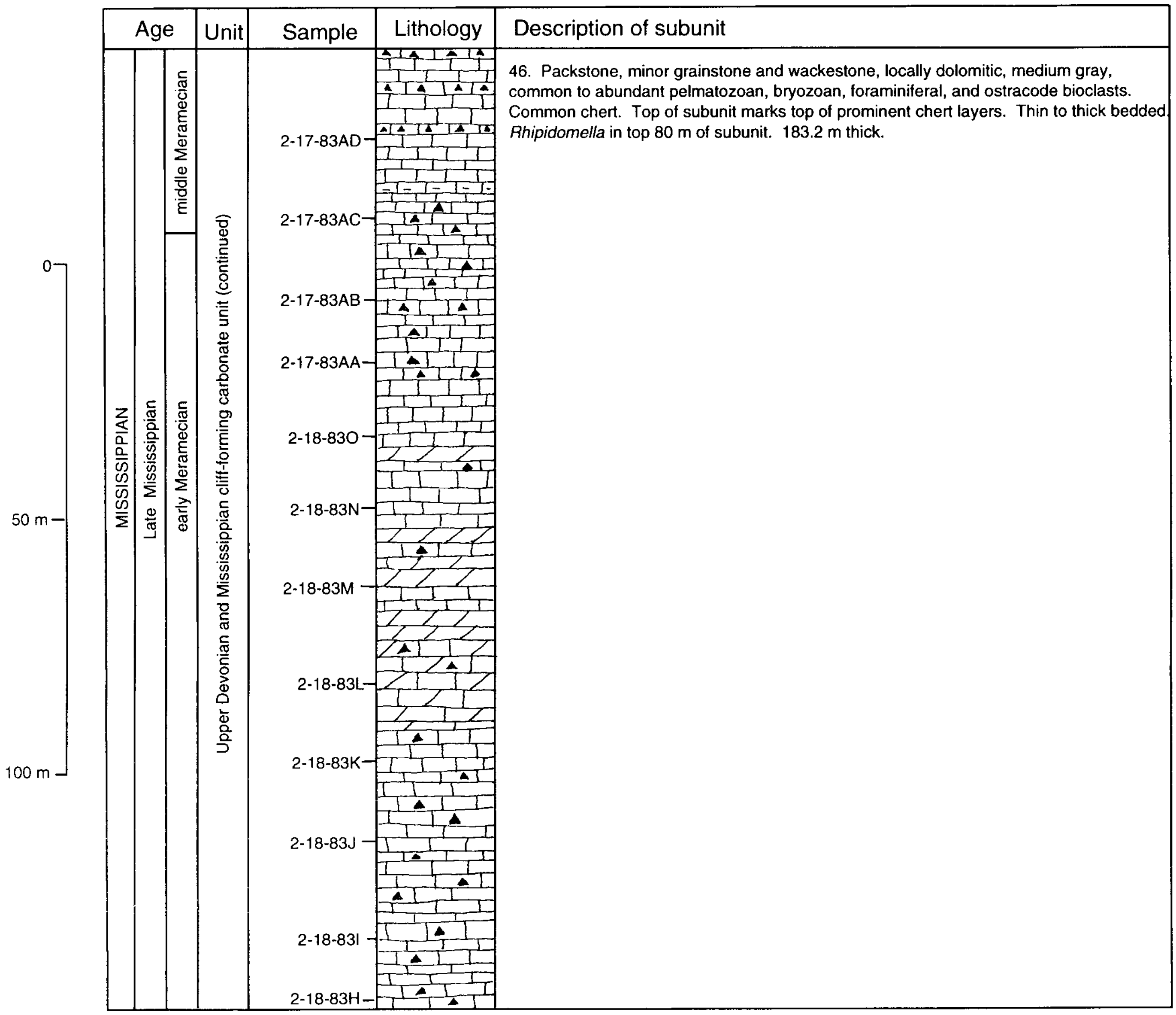


Figure 9 (part 4 of 5). Lithologic column and description of Upper Devonian and Mississippian cliff-forming carbonate unit in Sierra Agua Verde. Note scale is same as figure 7, but different from Figures 5 and 6.

Stewart and others (1990) in the Sierra López area. This unit 4 is 510 m thick and consists of thin-bedded limestone and shale and minor amounts of chert and dolomite. This unit contains phyllocarid crustaceans (commonly referred to as "*Caryocaris*") that are either latest Cambrian or earliest Ordovician in age.

Lower Ordovician rocks conformably overlie Cambrian rocks in Sierra Agua Verde and consist of about 900 m of lime mudstone and intraformational conglomerate. Poole and others (1995) have reviewed the distribution, lithologic character, and correlation of Ordovician rocks in Sonora. They consider that the Ordovician rocks in Sierra Agua Verde are inner shelf deposits and represent a more cratonward paleogeographic position than more complete Ordovician sections at Rancho Las Norias, Sierra Martínez, Cerro Cobachi, and Sierra López that lie west or south of Sierra Agua Verde (Figure 1). They also note similarities of Ordovician rocks in central Sonora to individual units in Utah, southern Nevada, eastern California, southwestern and south-central New Mexico, west Texas, and the State of Chihuahua. If the correlation, as described above, of Neoproterozoic (?) and Cambrian rocks in Sierra Agua Verde with those in the San Bernardino Mountains and the western Mojave Desert region has merit, then the Ordovician strata in Sierra Agua Verde might be expected to correlate with strata in the San Bernardino Mountains and western Mojave Desert region. At present, however, no Ordovician shelf strata have been definitely identified in the San Bernardino Mountains or the western Mojave Desert region. Perhaps such

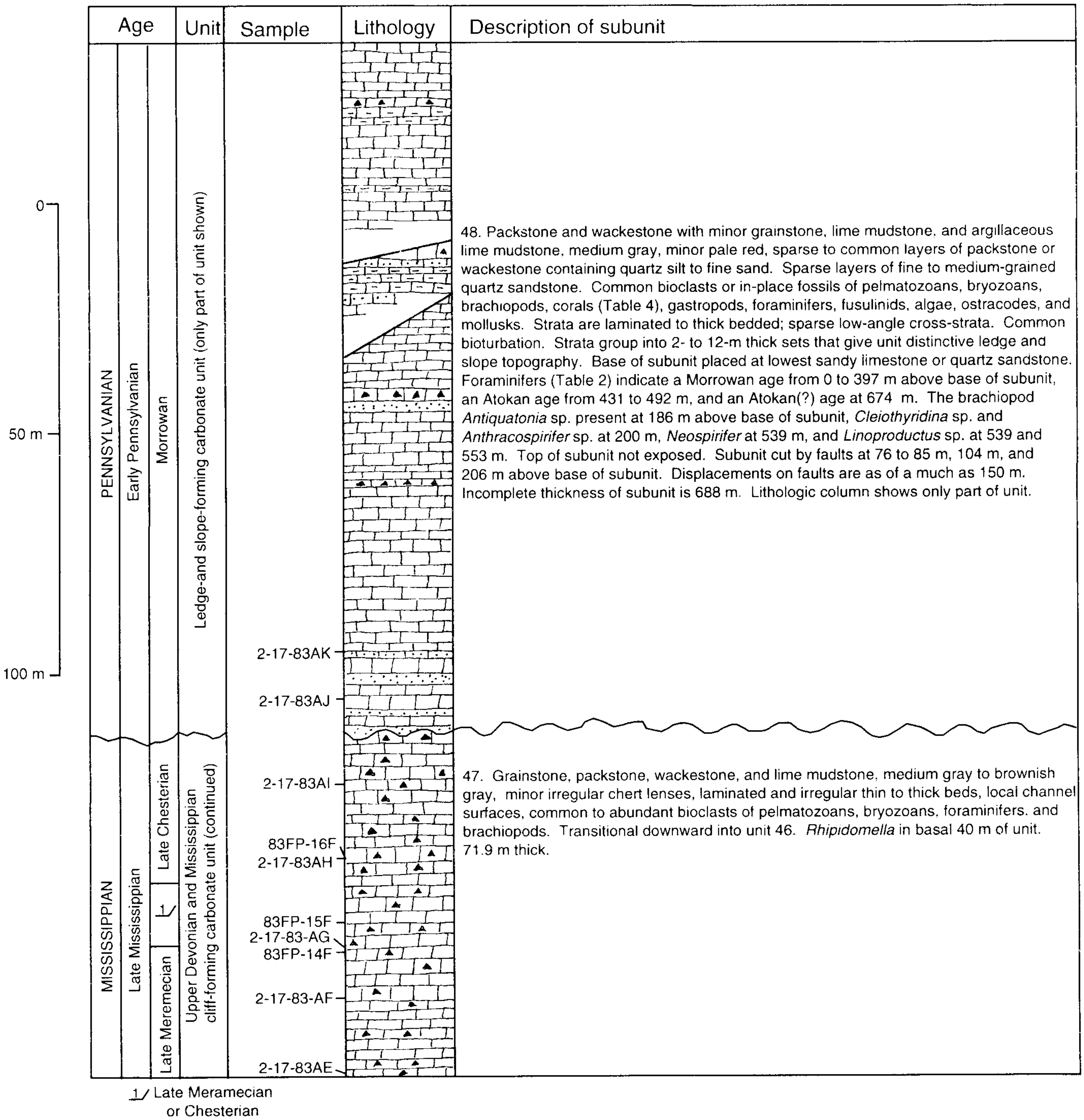


Figure 9 (part 5 of 5). Lithologic column and description of Upper Devonian and Mississippian cliff-forming carbonate unit in Sierra Agua Verde. Note scale is same as figure 7, but different from Figures 5 and 6.

strata could exist in the structurally complex and metamorphosed rocks in these regions, or these regions were relatively inland on the shelf compared to Sierra Agua Verde and Ordovician strata have been removed by pre-Devonian erosion.

The pre-Upper Devonian unconformity in Sierra Agua Verde is an important regional stratigraphic feature in Sonora as well as in other areas of the western and southwestern United States. In Sonora, Middle and Upper Ordovician strata are truncated northeastward below Devonian rocks at this unconformity, so that at Sierra Agua Verde Upper Devonian strata rest directly on Lower Ordovician strata (Poole and others, 1995). A similar unconformity is characteristic of Paleozoic cratonal platform strata in southeastern Arizona, southwestern New Mexico (Hills and Kottlowski, 1983) and in

Table 1. Biostratigraphic summary of conodonts in the Sierra Agua Verde, Sonora, Mexico. Stratigraphic position of conodont collections is shown in Figures 6, 8, and 9. Relative abundance of species: A, abundant (>20 specimens); C, common (5-19 specimens); R, rare (<5 specimens); *indicates index species; conodont samples average 5.5 kg (the smallest, 2-12-83I in subunit 34, is 3.5 kg and the largest, 2-17-83A in subunit 39 is 7.2 kg). CAI, conodont color alteration index. This section experienced contact metamorphism so that a range of CAI values can occur in a single sample; CAI values are listed in order of decreasing abundance.

Field no. (USGS colln. no.)	**Stratigraphic Position in Section**	**Conodont Species and Relative Abundance**	**Age**	**CAI**
2-14-83B (11175-CO)	16 m above base of subunit 14	*Cordylodus caboti** (R) *Cordylodus lindstromi** (C) ?*Eoconodontus notchpeakensis* (R) *Phakelodus elongatus* (R) *Phakelodus tenuis* (R)	*C. lindstromi* Zone through *R. manitouensis* Zone, early Early Ordovician	5, 5.5
2-14-83D (11176-CO)	8 m above base of subunit 16	*Laurentoscandodus triangularis* (R) *Rossodus manitouensis** (R)	*R. manitouensis* Zone, early Early Ordovician	5, 5.5 5, 5.5
2-14-83E and JS-82-7-42 m (11177-CO and 11178-CO)	42 m above base of subunit 16	"*Acanthodus*" *lineatus* (R) *Chosonodina herfurthi** (C) *Cordylodus angulatus* (C) *Cordylodus intermedius* (R) *Cordylodus lindstromi* (R) *Drepanoistodus* cf. *D. pervetus* (C) *Oneotodus* sp. (R) *Rossodus manitouensis** (A) *Rossodus?* n. sp. (R) *Scolopodus? sulcatus** (R) *Variabiloconus bassleri* (R)		
JS-82-7-67 m (11179-CO)	67 m above base of subunit 16	aff. *Rossodus manitouensis* (R) *Rossodus*? n. sp. (R) cf. "*Scolopodus*" *bolites** (R)	"low-diversity interval" or *M. dianae* Zone, early medial Early Ordovician	5, 5.5
JS-82-7-150 m (11180-CO)	150 m above base of subunit 16	*Histiodella* aff. *H. donnae* (C) *Paroistodus* sp. (R) *Protopanderodus*? n. sp. 2 of Repetski (1982)* (C)		6, 5.5, 5
JS-82-7-225 m (11181-CO)	225 m above base of subunit 16	*Drepanodus arcuatus* (C) *Drepanoistodus* cf. *D. forceps* (C) *Histiodella aff. H. donnae** (A) *Protopanderodus elongatus** (A) *Protopanderodus*? n. sp. 1 of Repetski (1982)* (A) *Protopanderodus*? n. sp. 2 of Repetski (1982)* (A)		6, 5.5, 5, 7
JS-82-7-300 m (11182-CO)	300 m above base of subunit 16	*Drepanodus arcuatus* (R) *Protopanderodus elongatus** (C) *Protopanderodus*? n. sp. 1 of Repetski (1982)* (C) *Protopanderodus*? n. sp. 2 of Repetski (1982)* (R)		6, 5.5, 5, 7
JS-82-7-352 m (11183-CO)	352 m above base of	*Colaptoconus quadraplicatus* (R) *Histiodella* cf. *H. donnae** (C) *Paroistodus* cf. *P. proteus* (R) *Protopanderodus elongatus** (A) *Protopanderodus leei** (R) *Protopanderodus*? n. sp. 1 of Repetski (1982)* (A) *Protopanderodus*? n. sp. 2 of Repetski (1982)* (A) *Scolopodus filosus* (R) *Scolopodus* aff. *S. rex* (R) *Scolopodus rex paltodiformis* (C)	"low-diversity interval" or *M. dianae* Zone, early medial Early Ordovician	6, 5.5, 5

Table 1. Continued.

Field no. (USGS colln. no.)	**Stratigraphic Position in Section**	**Conodont Species and Relative Abundance**	**Age**	**CAI**
JS-82-7-466 m (11184-CO)	466 m above base of subunit 16	aff. "*Acanthodus*" *lineatus* (R) *Colaptoconus quadraplicatus* (R) *Drepanodus pseudoconcavus* (R) *Drepanoistodus* sp. cf. *Drepanoistodus forceps* (C) *Paltodus*? n. sp. (C) *Protopanderodus elongatus** (C) cf. *Protopanderodus*? n. sp. 2 of Repetski (1982)* (C) *Protopanderodus* sp. (C) *Scolopodus filosus* (R) *Scolopodus filosus xyron* (R) *Scolopodus* aff. *S. rex* (C) *Scolopodus rex paltodiformis* (C) *Striatodontus prolificus* (R)	"low diversity interval" or *M. dianae* Zone, early medial Early Ordovician	6, 5.5, 5
JS-82-8-15 m (11185-CO)	15 m above base of subunit 17	*Drepanodus* sp. s.f. (R) *Drepanoistodus* sp. (R) *Eucharodus parallelus* (C) *Histiodella donnae** (R) *Oistodus*? *lecheguillensis** (R) *Oistodus* cf. O. *selenopsis* s.f. (R) *Paracordylodus gracilis* (R) *Paroistodus* cf. *P. proteus* (R) cf. *Paroistodus parallelus* (R) *Protopanderodus elongatus* (C) *Protopanderodus leei** (R) *Scandodus* aff. *S. furnishi* of Repetski (1982) (R) *Scolopodus bolites** (R) *Scolopodus filosus* (R) *Scolopodus filosus xyron* (R) *Scolopodus* aff. *S. rex* (R) *Scolopodus rex paltodiformis* (R) *Striatodontus prolificus* (C)	*M. dianae* Zone, medial Early Ordovician	6, 5.5, 5, 7
JS-82-9-7.5 m (11186-CO)	7.5 m above base of subunit 18	*Drepanodus* aff. *D.* sp. 3 of Serpagli (1974) (R) *Drepanoistodus* sp. (R) *Drepanoistodus* sp. (R) *Histiodella donnae** (R) ?*Macerodus dianae** (R) *Oistodus*? *lecheguillensis** (R) *Paracordylodus gracilis* (R) *Paroistodus* cf. *P. proteus* (R) *Protopanderodus elongatus* (A) *Protopanderodus leei** (R) *Protopanderodus*? n. sp. 2 of Repetski (1982) (R) ?*Scandodus furnishi* (R) *Scolopodus bolites** (C) *Scolopodus filosus* (C) *Scolopodus* aff. *S. rex* (R) *Scolopodus rex paltodiformis* (C) *Striatodontus prolificus* (A)		8, 7, 5, 6
JS-82-9-37.5 m (11187-CO)	37.5 m above base of subunit 18	*Colaptoconus quadraplicatus* (C) *Drepanodus arcuatus* (C) *Drepanoistodus* sp. (C) *Macerodus dianae** (R) *Paroistodus* cf. *P. proteus* (C) *Protopanderodus elongatus* (A) *Protopanderodus leei** (A) *Scolopodus filosus* (A) *Scolopodus* aff. *S. rex* (C) *Scolopodus rex paltodiformis* (A) *Striatodontus prolificus* (A)		

Table 1. Continued.

Field no. (USGS colln. no.)	Stratigraphic Position in Section	Conodont Species and Relative Abundance	Age	CAI
JS-82-9- 67.5 m (11188-CO)	67.5 m above base of subunit 18	*Acodus deltatus** (A) *Drepanoistodus* cf. *D. forceps* (A) *Eucharodus parallelus* (A) *"Scolopodus" acontiodiformis* (C) *Scolopodus filosus* (C) *Scolopodus rex paltodiformis* (A)	*A. deltatus - On. costatus* Zone, late medial Early Ordovician	5.5, 6, 5, 7
JS-82-9- 97.5 m (11189-CO)	97.5 m above base of subunit 18	*Acodus deltatus** (A) *Colaptoconus quadraplicatus* (C) *Drepanodus arcuatus* (C) *Parapanderodus striatus* (C) *Paroistodus* cf. *P. proteus* (A) *Protopanderodus* cf. *P. elongatus* (A) *Protopanderodus*? n. sp. 1 of Repetski (1982) (A) *"Scolopodus" acontiodiformis* (C) *Scolopodus filosus* (C) *Scolopodus* aff. *S. rex* (C) *Scolopodus rex paltodiformis* (A) *Tropodus comptus* (C)		6, 7, 5.5, 5
JS-82-9- 127.5 m (11190-CO)	127.5 m above base of subunit 18	*Acodus deltatus** (A) *Eucharodus parallelus* (C) *Protopanderodus* cf. *P. elongatus* (A) *Scolopodus rex paltodiformis* (A)		6, 6.5, 7, 5.5
JS-82-9- 157.5 m (11191-CO)	157.5 m above base of subunit 18	*Acodus deltatus** (A) *Colaptoconus quadraplicatus* (C) *Drepanodus arcuatus* (C) *Drepanoistodus forceps* (C) *Eucharodus parallelus* (C) *Oelandodus* cf. *O. elongatus* of Repetski (1982) *Parapanderodus striatus* (C) *Scolopodus filosus* (C) *Scolopodus rex paltodiformis* (C) *Scolopodus* aff. *S. parabruptus* of Repetski (1982) (R) *Toxotodus*? *carlae* (R) *Tropodus comptus* (C) *Ulrichodina wisconsinensis* (R)		6, 5.5, 6.5
JS-82-9- 187.5 m (11192-CO)	187.5 m above base of subunit 18	*Acodus deltatus** (A) *Colaptoconus quadraplicatus* (A) *Drepanodus arcuatus* (C) *Drepanoistodus* cf. *D. forceps* (C) *Eucharodus parallelus* (A) *Oistodus* cf. *O. lanceolatus* (C) *Oneotodus costatus* (R) *Paracordylodus gracilis* (R) *Parapanderodus striatus* (A) *Paroistodus parallelus* (C) cf. *Protopanderodus longibasis* (C) *"Scolopodus" emarginatus* (R) *Scolopodus filosus* (A) *Scolopodus* aff. *S. parabruptus* of Repetski (1982) (C) *Triangulodus* cf. *T. brevibasis* of Repetski (1982)(C) *Ulrichodina abnormalis* (R) *Ulrichodina wisconsinensis* (R)		6, 6.5, 5, 7
JS-82-9- 217.5 m (11193-CO)	217.5 m above base of subunit 18	*Acodus deltatus** (A) *Colaptoconus quadraplicatus* (A) *Drepanodus arcuatus* (C) *Drepanoistodus* cf. *D. forceps* (C) *Glyptoconus quadraplicatus* (A) *Oelandodus* cf. *O. costatus* of Repetski (1982) (C)	*Oe. communis* Zone, late Early Ordovician	5.5, 6, 5, 7
		*Oepikodus communis** (A) *Oistodus lanceolatus* (R) *Parapanderodus striatus* (A) *Paraserratognathus abruptus**(R) *Paroistodus parallelus* (C) *Scolopodus cornutiformis* (C) *Scolopodus filosus* (A) *Scolopodus* aff. *S. rex* (C) *Triangulodus* cf. *T. brevibasis* of Repetski (1982) (R) *Ulrichodina wisconsinensis* (C)	*Oe. communis* Zone, late Early Ordovician	5.5, 6 5, 7
JS-82-9- 247.5 m (11194-CO)	247.5 m above base of subunit 18	*Colaptoconus quadraplicatus* (A) *Cristodus loxoides** (R) *Drepanodus arcuatus* (A) *Drepanoistodus forceps* (A) *Eucharodus parallelus* (A) *Fahraeusodus marathonensis** (A) *Oepikodus communis** (A) *Oistodus* cf. *O. lanceolatus* (R) *Oneotodus costatus* (A) *Parapanderodus striatus* (A) *Paroistodus* cf. *P. parallelus* (C) *Protopanderodus* cf. *P. gradatus* (R) *"Scolopodus" emarginatus** (R) *Scolopodus rex paltodiformis* (R) *Tropodus* sp. (R) *Ulrichodina wisconsinensis* (C) *Walliserodus* cf. *W. ethingtoni* of Löfgren (1978) (R)		5.5, 6, 6.5, 5, 7
JS-82-9- 277.5 m (11195-CO)	277.5 m above base of subunit 18	*Acodus* aff. *A. emanuelensis* of Ethington & Clark (1981) (A) *Chionoconus avangna** (C) *Colaptoconus quadraplicatus* (A) *Drepanodus arcuatus* (A) *Drepanoistodus* sp. (C) *Eucharodus toomeyi* (C) *Fahraeusodus marathonensis* (A) *Glyptoconus quadraplicatus* (A) *Juanognathus variabilis** (A) *Jumudontus gananda** (R) *Oepikodus communis* (A) *Oepikodus*? n. sp. of Repetski (1982)* (R) *Oneotodus costatus* (A) *Parapanderodus striatus* (A) *Paroistodus parallelus* (A) *Protopanderodus gradatus** (A) *Protopanderodus leonardii** (R) *Protopanderodus* cf. *P. rectus* (C) *Reutterodus andinus** (A) *Scalpellodus*? cf. *S.*? *narhvalensis* (A) *Scolopodus parabruptus* (C) *Scolopodus* aff. *S. rex* (R) *Scolopodus rex paltodiformis* (C) *Tropodus australis** (R) *Tropodus comptus* (C) *Walliserodus* cf. *W. ethingtoni* of Löfgren (1978) (A)	*R. andinus* Zone, latest Early Ordovician	5, 5.5, 6
JS-82-9- 307.5 m (11196-CO)	307.5 m above base of subunit 18	*Acodus* aff. *A. emanuelensis* of Ethington & Clark (1981)(C) *Colaptoconus quadraplicatus* (A) *Drepanodus arcuatus* (C) *Drepanoistodus* cf. *D. inaequalis* of van Wamel (1974) (C) *Eucharodus parallelus* (C)		6, 6.5, 7, 8

Table 1. Continued.

Field no. (USGS colln. no.)	Stratigraphic Position in Section	Conodont Species and Relative Abundance	Age	CAI
		Glyptoconus quadraplicatus (A) *Juanognathus jaanussoni** (C) *Juanognathus variabilis** (A) *Jumudontus gananda** (R) *Oepikodus communis* (A) *Oepikodus*? n. sp. of Repetski (1982)* (C) *Oistodus lanceolatus* (R) *Parapanderodus striatus* (A) *Paraserratognathus abruptus* (R) *Paroistodus parallelus* (C) *Protopanderodus gradatus* (A) *Protopanderodus leonardii** (C) *Protopanderodus* cf. *P. rectus* (C) *Reutterodus andinus** (C) *Scolopodus paracornuformis** (C) *Scolopodus* n. sp. C of Ethington & Clark (1981) (R) *Tropodus comptus* (C)	*R. andinus* Zone latest Early	6, 6.5 7, 8
JS-82-9-331.5 m (11197-CO)	331.5 m above base of subunit 18	*Acodus* aff. *A. emanuelensis* of Ethington & Clark (1981) (C) *Bergstroemognathus extensus** (R) *Colaptoconus quadraplicatus* (R) *Drepanodus arcuatus* (C) *Drepanoistodus forceps* (C) *Eucharodus parallelus* (R) *Fahraeusodus marathonensis* (C) *Glyptoconus quadraplicatus* (R) *Juanognathus jaanussoni** (R) *Juanognathus variabilis** (R) *Oepikodus communis* (A) *Oepikodus*? n. sp. of Repetski (1982) (C) *Oistodus lanceolatus* (R) *Oistodus* cf. *O. multicorrugatus* of Repetski (1982)* (C) *Parapanderodus striatus* (A) *Paraserratognathus abruptus* (R) *Paroistodus parallelus* (C) *Periodon* sp. (R) *Protopanderodus gradatus* (A) *Reutterodus andinus** (C) "*Scandodus*" *robustus** (C) *Scolopodus paracornuformis** (R) *Scolopodus* aff. *S. rex* (R) *Scolopodus rex paltodiformis* (R) *Tropodus australis* (C) + *Milaculum* sp. (*incertae sedis*) (R)		5.5, 5, 6, 6.5
JS-82-9-353 m (9575-CO)	353 m above base of subunit 18	*Drepanodus arcuatus* (R) *Drepanoistodus* cf. *D. forceps* (C) *Juanognathus jaanussoni** (R) *Juanognathus variabilis** (R) *Fahraeusodus marathonensis* (R) cf. *Oelandodus elongatus* (R) *Oepikodus communis* (A) *Oepikodus*? n. sp. of Repetski (1982)* (R) *Oistodus* cf. *O. multicorrugatus* of Repetski (1982)* (R) *Oneotodus costatus* (R) *Parapanderodus striatus* (C) *Paroistodus parallelus* (C) *Periodon* cf. *P. flabellum** (R) *Parapanderodus*? *asymmetricus* (R)		7, 8, 6, 5.5

Table 1. Continued.

Field no. (USGS colln. no.)	Stratigraphic Position in Section	Conodont Species and Relative Abundance	Age	CAI
		Protopanderodus gradatus (C) *Protopanderodus leonardii** (R) *Protopanderodus* cf. *P. rectus* (R) *Protoprioniodus aranda** (C) *Reutterodus andinus** (R) *Scolopodus paracornuformis** (R)	*R. andinus* Zone latest Early Ordovician	7, 8 6, 5.5
2-11-83A (11198-C0)	360 m above base of subunit 18	*Acodus*? aff. *A. emanuelensis* of Ethington & Clark, 1981 (C) *Drepanodus arcuatus* (C) *Drepanoistodus forceps* (C) *Oepikodus communis** (A) *Oepikodus* n. sp. of Repetski (1982)* (C) *Paroistodus parallelus* (R) *Parapanderodus striatus* (C) *Protopanderodus gradatus* (C) *Protoprioniodus aranda** (R) *Tropodus* sp. (R)		6, 6.5, 5.5, 5
2-11-83B (11199-C0)	366 m above base of subunit 18	*Oepikodus communis** (C) *Oepikodus* n. sp. of Repetski (1982)* (R) *Parapanderodus striatus* (C) *Protopanderodus gradatus* (R)		6.5, 7, 5
82FP-114F (10605-SD)	subunit 19	*Icriodus* sp. (C) *Mesotaxis asymmetrica** (R) *Palmatolepis transitans** (R) *Polygnathus dubius* (A) *Polygnathus linguiformis linguiformis* γ morphotype (C)	*Pa. transitans* Zone into *Pa. punctata* Zone, early Frasnian	5.5
2-11-83C (12364-SD)	3.7 m above base of subunit 23	*Ancyrodella* sp. indet. (C) *Icriodus* sp. indet. (R) *Polygnathus* sp. indet. (R)		5, 5.5
2-11-83D (12365-SD)	21.0 m above base of subunit 23	*Ancyrodella* sp. indet. (C) *Mesotaxis asymmetrica** (R) *Pandorinellina insita* (C) *Playfordia primitiva** (R) *Polygnathus* sp. indet. (R)		5, 5.5, 6
2-11-83E (12366-SD)	6.4 m above base of subunit 25	*Polygnathus* sp. indet. (R)	*Pa. transitans* Zone to Upper *Pa. rhenana* Zone, early to late Frasnian	7, 8
2-11-83G (12367-SD)	37.8 m above base of subunit 25	*Polygnathus* aff. *Po. brevicarina** (R)	Upper *Pa. hassi* Zone to Upper *Pa. rhenana* Zone, middle to late Frasnian	5.5, 5, 6
2-11-83H (12368-SD)	52.7 m above base of subunit 25	*Ancyrodella* sp. indet. (R) *Palmatolepis* sp. indet. (R) *Polygnathus* sp. (R)		5, 5.5
2-11-83I (12369-SD)	67.7 m above base of subunit 25	*Icriodus* sp. (R) *Mehlina* sp. (C) *Palmatolepis* spp. indet. (incomplete or broken) (C) *Polygnathus evidens* (A)		5, 5.5
2-11-83J (12370-SD)	81.4 m above base of subunit 25	*Ancyrognathus triangularis** (R) *Belodella triangularis* (A) *Mehlina* spp. (C) *Palmatolepis foliacea** (C) *Palmatolepis hassi** (A)	*Pa. jamieae* Zone into Upper *Pa. rhenana* Zone, middle to late Frasnian	5.5, 6, 5

Table 1. Continued.

Field no. (USGS colln. no.)	Stratigraphic Position in Section	Conodont Species and Relative Abundance	Age	CAI
2-11-83J (12370-SD) [continued]	81.4 m above base of subunit 25	*Polygnathus evidens* (A) *Polygnathus lodinensis** (A)	*Pa. jamieae* Zone into Upper *Pa. rhenana* Zone	5.5, 6,
2-11-83K (12371-SD)	99.7 m above base of subunit 25	*Polygnathus* sp. indet. (R)		5, 5.5
2-11-83L (12372-SD)	115.2 m above base of subunit 25	*Ancyrodella buckeyensis** (R) *Belodella triangularis* (R) *Palmatolepis subrecta*?* (R) *Polygnathus evidens* (C) *Polygnathus morgani**? (C)	Upper *Pa. rhenana* Zone, late Frasnian	5, 5.5
2-11-83M (12373-SD)	129.2 m above base of subunit 25	*Polygnathus* aff. *Po. samueli** (R)	late Frasnian	7
2-11-83N (12374-SD)	143.6 m above base of subunit 25	*Polygnathus* sp. indet. (R)	late Frasnian-Famennian	5, 5.5
2-12-83A (12375-SD)	0.7 m above base of subunit 27	*Polygnathus semicostatus* (R)	Middle *Pa. crepida* Zone into *Pa. expansa* Zone, Famennian	5
2-12-83B (12376-SD)	Topmost part of subunit 28	*Icriodus costatus* (A) *Pelekysgnathus inclinatus*? (A) *Polygnathus depressus** (A)	Uppermost *Pa. marginifera* Zone into *Pa. expansa* Zone, Famennian	5.5, 5, 6
2-12-83D (12377-SD)	4.6 m above base of subunit 31	"*Ozarkodina*" sp. (R) *Pelekysgnathus* sp. indet. (R)		5.5, 5
2-12-83E (12378-SD)	9.1 m above base of subunit 32	*Mehlina strigosa* (R) *Polygnathus communis* (R)		5, 5.5
2-12-83F (12379-SD)	22.9 m above base of subunit 32	*Apatognathus varians* (R) *Bispathodus costatus** (R) *Bispathodus stabilis** (R) icriodontid coniform elements (C) *Palmatolepis* sp. indet. of Famennian but not latest Famennian morphotype (R) *Polygnathus semicostatus* (A)	Middle to Upper *Pa. expansa* Zone, late Famennian	5, 5.5, 6
2-12-83G (12380-SD)	38.4 m above base of subunit 32	*Apatognathus varians* (A) *Bispathodus stabilis* (C) *Branmehla inornata* (R) *Palmatolepis gracilis sigmoidalis** (C) *Pelekysgnathus* sp. indet. (C) *Polygnathus semicostatus* (A) *Pseudopolygnathus marburgensis trigonicus** (R)	Upper *Pa. expansa* Zone, late Famennian	5, 5.5, 6
2-12-83H (12381-SD)	53.6 m above base of subunit 32	*Apatognathus varians* (A) *Bispathodus stabilis* (A) *Delotaxis* sp. (C) *Icriodus*? *raymondi* (A) *Palmatolepis gracilis sigmoidalis** (C) *Polygnathus communis* (C) *Polygnathus semicostatus* (A)		5, 5.5, 6
2-12-83I (12382-SD)	2.7 m above base of subunit 34	*Bispathodus aculeatus aculeatus* (R) icriodontid coniform elements (R) *Polygnathus semicostatus* (C)		5, 5.5 6

Table 1. Continued.

Field no. (USGS colln. no.)	Stratigraphic Position in Section	Conodont Species and Relative Abundance	Age	CAI
2-12-83J (12383-SD)	9.8 m above base of subunit 35	*Apatognathus varians* (R) *Bispathodus stabilis* (R) *Icriodus costatus darbyensis* (C) *Icriodus? raymondi*? (R) *Pelekysgnathus inclinatus* (R) *Polygnathus communis* (C) *Polygnathus semicostatus* (A)	Upper Pa. expansa Zone, late Fammenian	5, 5.5
2-13-83A (32365-PC)	14.9 m above base of subunit 36	*Bispathodus aculeatus* (R) *Bispathodus stabilis* (R) *Polygnathus inornatus* (C) *Polygnathus longiposticus** (A) *Polygnathus* aff. *Po. longiposticus* of Gagiev and Kononova*, 1990 (C)	Kinderhookian	5.5, 6, 6.5, 5
2-13-83B (32366-PC)	33.8 m above base of subunit 36	*Polygnathus communis* (R) *Siphonodella isosticha** (A) *Siphonodella isosticha-Si. obsoleta** (A)	*S. isosticha*-Upper *S. crenulata* Zone, late Kinderhookian	5, 5.5, 6
2-13-83C (32367-PC)	45.1 m above base of subunit 36	*Gnathodus delicatus** (R) *Polygnathus communis* (R) *Polygnathus inornatus* (R) *Protognathodus praedelicatus*? (R) *Siphonodella isosticha-Si. obsoleta** (R)		5, 5.5
2-13-83D (32368-PC)	60.0 m above base of subunit 36	*Bispathodus stabilis* (C) *Gnathodus delicatus** (R) *Hindeodus crassidentatus* (R) *Polygnathus communis* (A) *Polygnathus longiposticus** (R) *Siphonodella duplicata** (R) *Siphonodella isosticha-obsoleta** (A)		5, 5.5
2-13-83F (32369-PC)	20.4 m above base of subunit 39	*Bispathodus utahensis*? (R) *Polygnathus communis* (R)	late Kinderhookian-Osagean	5, 5.5
2-17-83A (32370-PC)	30.5 m above base of subunit 39	*Bispathodus utahensis* (C) *Gnathodus cuneiformis** (C) *Polygnathus communis* (C)	*G. typicus* Zone to within *Sc. anchoralis-D. latus* Zone, Osagean	5, 5.5, 6
2-17-83B (32371-PC)	2.1 m above base of subunit 40	*Bispathodus aculeatus* (Reworked?) (R) *Gnathodus typicus* morphotype 2* (C) *Polygnathus communis* (A) *Siphonodella* sp. indet. (Reworked?) (R)		6.5, 6, 5, 5.5
2-17-83C (32372-PC)	17.4 m above base of subunit 40	*Hindeodus crassidentatus* (C) *Polygnathus communis* (A) *Pseudopolygnathus multistriatus* morphotype 1 (A)		6.5, 5, 6, 7, 5.5
2-17-83D (32373-PC)	4.6 m above base of subunit 41	*Bispathodus utahensis* (R) *Polygnathus communis* (A) *Pseudopolygnathus oxypageus* morphotypes 1-3* (A)	Upper *G. typicus* Subzone to within *Sc. anchoralis-D latus* Zone, Osagean	5, 6, 6.5, 7, 5.5
2-17-83E (32374-PC)	35.4 m above base of subunit 41	*Gnathodus typicus*?* (R) *Hindeodus crassidentatus* (R) *Polygnathus communis* (C) *Pseudopolygnathus nudus** (C) *Pseudopolygnathus oxypageus** (C)		5.5, 5, 6, 6.5

Table 1. Continued.

Field no. (USGS colln. no.)	Stratigraphic Position in Section	Conodont Species and Relative Abundance	Age	CAI
2-17-83F (32375-PC)	50.0 m above base of subunit 41	*Bispathodus utahensis* (C) *Gnathodus typicus** (C) *Hindeodus crassidentatus* (R) *Kladognathus* sp. (R) *Polygnathus communis* (R) *Pseudopolygnathus oxypageus** (R)	Upper *G. typicus* Subzone to within *Sc. anchoralis-D. latus* Zone, Osagean	5, 5.5, 6, 6.5
2-17-83G (32376-PC)	10.7 m above base of subunit 42	*Bispathodus utahensis* (C) *Hindeodus crassidentatus* (A) *Kladognathus* sp. (A) *Polygnathus communis* (A)	Upper *G. typicus* Subzone to Lower *G. texanus* Zone; conodonts indicate an Osagean or	5, 5.5, 6
2-17-83H (32377-PC)	25.3 m above base of subunit 42	*Bispathodus utahensis* (R) *Hindeodus crassidentatus* (C) *Kladognathus* sp. (R) *Polygnathus communis* (C)	earliest Meramecian age but calcareous micro-fossils restrict the age to the Osagean	5, 5.5
2-17-83I (32378-PC)	43.0 m above base of subunit 42	*Bispathodus utahensis* (R) *Kladognathus* sp. (R)	(Table 2)	5.5, 5, 6
2-17-83J (32379-PC)	56.4 m above base of subunit 42	*Bispathodus utahensis* (A) *Kladognathus* sp. (C) *Polygnathus communis* (A)		5, 5.5
2-17-83K (32380-PC)	86.9 m above base of subunit 42	*Polygnathus communis* (C)		5, 5.5
2-17-83L (32380-PC)	102.4 m above base of subunit 42	*Bispathodus utahensis* (R) *Eotaphrus burlingtonensis** (R) *Hindeodus crassidentatus* (A) *Kladognathus* sp. (A) *Polygnathus communis* (A)	*Sc. anchoralis-D. latus* Zone to Lower *G. texanus* Zone, late Osagean on the basis of conodonts and	5, 5.5, 6
2-17-83M (32381-PC)	117 m above base of subunit 42	*Eotaphrus burlingtonensis** (C) *Hindeodus cristulus** (C) *Kladognathus* sp. (C) *Polygnathus communis* (R)	calcareous microfossils (Table 2)	5, 5.5, 6
2-17-83N (32382-PC)	133.2 m above base of subunit 42	*Bispathodus utahensis* (A) *Eotaphrus burlingtonensis** (C) *Hindeodus crassidentatus* (C) *Kladognathus* sp. (A)		5.5, 5, 6, 6.5
2-17-83O (32383-PC)	153.9 m above base of subunit 42	*Bispathodus utahensis* (C) *Eotaphrus burlingtonensis** (A) *Hindeodus crassidentatus* (C) *Kladognathus* sp. (A)		5, 5.5
2-18-83A (32384-PC)	165.5 m above base of subunit 42	*Eotaphrus burlingtonensis** (R) *Gnathodus* sp. (R) *Hindeodus crassidentatus* (C) *Kladognathus* sp. (A) *Polygnathus* mehli* (A)	Within *Sc. anchoralis-D. latus* Zone to Lower *G. texanus* Zone, late Osagean on the basis of conodonts	5, 5.5, 6
2-18-83B (32385-PC)	178.6 m above base of subunit 42	*Eotaphrus burlingtonensis** (R) *Hindeodus cristulus** (C) *Kladognathus* sp. (C) *Polygnathus mehli** (C)	and calcareous microfossils (Table 2)	5, 5.5, 6
2-18-83C (32386-PC)	193.5 m above base of subunit 42	*Bispathodus utahensis* (R) *Kladognathus* sp. (R) *Polygnathus mehli** (R)		5, 5.5

Table 1. Continued.

Field no. (USGS colln. no.)	Stratigraphic Position in Section	Conodont Species and Relative Abundance	Age	CAI
2-18-83D (32387-PC)	9.8 m above base of subunit 43	*Bispathodus utahensis* (C) *Capricornognathus capricornis*?* (R) *Gnathodus texanus** (R) *Kladognathus* sp. (C) *Taphrognathus varians** (R) *Windsorgnathus windsorensis* (R)	Lower *G. texanus* Zone, latest Osagean or early Meramecian; likely early Meramecian on the basis of calcareous microfossils	5, 5.5, 6
2-18-83E (32388-PC)	15.8 m above base of subunit 44	*Eotaphrus burlingtonensis** (R) *Hindeodus crassidentatus* (C) *Kladognathus* sp. (C)	(Table 2)	5, 5.5
2-18-83F (32389-PC)	31.1 m above base of subunit 44	*Eotaphrus burlingtonensis** (R) *Hindeodus crassidentatus* (C) *Kladognathus* sp. (A) *Polygnathus mehli** (R)		5, 5.5, 6, 6.5
2-18-83G (32390-PC)	46.3 m above base of subunit 44	*Bispathodus utahensis* (R) *Hindeodus crassidentatus* (R) *Kladognathus* sp. (C) *Polygnathus mehli** (R)		5, 5.5
2-18-83H (32391-PC)	1.5 m above base of subunit 46	*Windsorgnathus windsorensis** (R) *Gnathodus texanus** (A)	Upper *G. texanus* Zone, early Meramecian	5.5, 5, 6
2-18-83I (32392-PC)	13.1 m above base of subunit 46	*Cloghergnathus globenskii** (R) *Gnathodus texanus** (C) *Hindeodus* sp. indet. (R) *Kladognathus* sp. (A)		5.5, 5, 6
2-18-83J (32393-PC)	32.0 m above base of subunit 46	*Cloghergnathus globenskii*?* (R) *Gnathodus texanus** (C) *Kladognathus* sp. (R)		5, 5.5, 6
2-18-83K (32394-PC)	47.2 m above base of subunit 46	*Cloghergnathus rhodesi*?* (C) *Gnathodus texanus** (C) *Kladognathus* sp. (C) *Rhachistognathus*? sp. (R) *Taphrognathus varians** (R)		5, 5.5, 6, 6.5
2-18-83L (32395-PC)	62.2 m above base of subunit 46	*Bispathodus utahensis* (R) *Cloghergnathus rhodesi*?* (A) *Gnathodus texanus** (C) *Hindeodus cristulus** (C) *Idioprioniodus* sp. (C)		5.5, 5, 6, 6.5
2-18-83M (32396-PC)	80.8 m above base of subunit 46	*Gnathodus texanus** (C) *Hindeodus cristulus** (R) *Idioprioniodus* sp. (R) *Kladognathus* sp. (R) *Taphrognathus*? sp. (R)		6, 5.5, 5
2-18-83N (32397-PC)	96.0 m above base of subunit 46	*Gnathodus texanus** (C) *Idioprioniodus* sp. (R) *Kladognathus* sp. (A) *Taphrognathus varians** (A)		5, 5.5, 6
2-18-83O (32398-PC)	109.4 m above base of subunit 46	*Gnathodus* sp. (R) *Kladognathus* sp. (C) *Taphrognathus varians** (A)		5, 5.5
2-17-83AA (32399-PC)	122.2 m above base of subunit 46	*Gnathodus texanus** (A) *Hindeodus cristulus* (C) *Idioprioniodus* sp. (R) *Kladognathus* sp. (C) *Taphrognathus varians** (C)		5, 5.5, 6

Table 1. Continued.

Field no. (USGS colln. no.)	Stratigraphic Position in Section	Conodont Species and Relative Abundance	Age	CAI
2-17-83AB (32400-PC)	133.8 m above base of subunit 46	*Gnathodus texanus** (A) *Hindeodus* aff. *H. minutus* (C) *Kladognathus* sp. (A) *Synclydognathus? pinnatus** (C) *Taphrognathus varians** (A)	Upper *G. Texanus* Zone, early	5, 5.5, 6
2-17-83AC (32401-PC)	150.9 m above base of subunit 46	*Kladognathus* sp.(R)	middle Meramecian on the basis of calcareous microfossils (Table 2)	5.5, 5, 6
2-17-83AD (32402-PC)	167.0 m above base of subunit 46	*Gnathodus texanus** (C) *Kladognathus* sp. (C) *Taphrognathus varians** (A)		5.5, 5, 6
2-17-83AE (32403-PC)	0.3 m above base of subunit 47	*Gnathodus texanus** (C) *Kladognathus* sp. (C) *Taphrognathus varians** (A)	late Meramecian on the basis of calcareous microfossils (Table 2)	5.5, 5, 6
2-17-83AF (32403-PC)	16.2 m above base of subunit 47	*Cavusgnathus unicornis** (A) *Hindeodus cristulus** (C) *Kladognathus* sp. (A) *Taphrognathus varians** (C) *Vogelgnathus pesaquidi*? (R)	Lower *Cavusgnathus* Zone, late Meramecian	5.5, 5, 6
2-17-83AG (32404-PC)	26.8 m above base of subunit 47	*Cavusgnathus unicornis* (R) *Kladognathus* sp. (R)	late Meramecian-Chesterian, Late Mississippian	5, 5.5
2-17-83AH (32405-PC)	45.7 m above base of subunit 47	*Cavusgnathus* sp. indet. (R) *Hindeodus* sp. indet. (R)	middle Chesterian on the basis of calcareous microfossils (Table 2)	5, 5.5
2-17-83AI (32406-PC)	61.0 m above base of subunit 47	Cavusgnathoids (R) *Kladognathus* sp. indet. (C) (conodonts are rounded fragments due to hydraulic abrasion)	late Chesterian, latest Mississippian on the basis of calcareous microfossils (Table 2)	5, 5.5
2-17-83AJ	6.1 m above base of subunit 48	*Adetognathus lautus* *Neognathodus* sp.	Morrowan, Pennsylvanian, on the basis of calcareous microfossils (Table 2)	5, 5.5, rare 6
2-17-83AK	16.2 m above base of subunit 48	*Adetognathus lautus* *Rhachistognathus muricatus* *Idiognathodus sinuosus*		5, 5.5

inner shelf successions in eastern California and southern Nevada (Brown, 1991).

Upper Devonian shelf strata in Sierra Agua Verde consist of 342 m of carbonate and siliciclastic rocks. Lithologically similar shelf rocks are recognized in Sierra Los Leyva, 25 km east of Hermosillo. Other localities of Devonian shelf strata in Sonora are Middle or Upper Devonian carbonate rocks near Cerro Cobachi, 80 km east-southeast of Hermosillo, identified on the basis of a single conodont (Ketner and Noll, 1987); Eifelian (lower Middle Devonian) carbonate strata near Placercitas, about 35 km northwest of Hermosillo, dated on the basis of conodonts identified by J.E. Repetski (oral communication, 1987); Middle or possibly Upper Devonian strata in

Table 2. Foraminifera, algae, and *incertae sedis* from Sierra Agua Verde, identified by B.L. Mamet.

Stratigraphic position	Foraminifera, algae, and *incertae sedis*	Age
6.4 to 68.0 m above base of subunit 25	*"Archaesphaera"* sp. *Auroria* sp. *Bisphaera* sp. *Calcisphaera laevis* Williamson *Evlania* sp. *Eogeinitzina* sp. *Issinella devonica* Reitlinger *Kamaena* sp. *Nanicella* sp. *Nanicella gallowayi* (Thomas) *Palaeoberesella* sp. *Parathurammina* sp. *Protoumbella* sp. *Sphaerocodium* sp. *Tikhinella measpis* Bykova	Frasnian
Topmost part of subunit 28 to 29.3 m above base of subunit 32	*Bisphaera* sp. *Issinella sainsii* Mamet and Roux (abundant) *Parathurammina* sp. *Proninella* sp. primitive Tournayellidae	*Issinella sainsii* biofacies. Famennian
2.7 m above base of subunit 34	*Bisphaera* sp. *Earlandia* sp. *Latiendothyra* sp. *Paracaligelloides* sp. *Septaglomospiranella* sp.	late Famennian-Kinderhookian
45.1 m above base of subunit 36 to 7.0 m above base of subunit 38	*Calcisphaera laevis* Williamso *Earlandia* ex.gr. *elegans* (Rauzer-Chernoussova) *Earlandia minima* (Birina) *Radiosphaera* sp. *Septaglomospiranella* aff. *S. granulosa* (Zeller)	*Earlandia minima* biofacies Kinderhookian
59.4 m to 89.9 m above base of subunit 42	*Asphaltinella* sp. *Calcisphaera laevis* Williamson *Septabrunsiina* sp. *Septaglomospiranella* sp.	*Asphaltinella* biofacies. In the Pedregosa basin, this biofacies is usually associated with the upper part of Zones 7 and 8 (middle to late Tournaisian, Osagean)
157.0 m to 181.7 m above base of of subunit 42	*Calcisphaera laevis* Williamson *Calcisphaera pachysphaerica* (Pronina) *Earlandia* sp. *Earlandia* ex. gr. *clavatula* (Howchin) *Earlandia* ex. gr. *moderata* (Malakhova) *Earlandia vulgaris* (Rauzer-Chernoussova and Reitlinger) *Endothyra* sp. *Priscella* sp. *Pseudotaxis* sp. Salebridae *Sphaerinvia* sp.	*Earlandia vulgaris* biofacies (=Zone 10, early Viséan, about Osagean/ Meramecian
12.5 m above base of subunit 43 to 35.1 m above base of subunit 46	*Calcisphaera pachysphaerica* (Pronina) *Earlandia* ex.gr. *clavatula* (Howchin) *Earlandia vulgaris* (Rauzer-Chernoussova and Reitlinger) *Endothyra* sp. *Globoendothyra* sp. *Mametella skimoensis* (Mamet and Rudloff) *Parathurammina* sp. *Priscella* sp. *Tetrataxis* sp.	*Mametella* biofacies (= Zone 11, early Viséan Meramecian)

Table 2. Continued.

Stratigraphic position	**Foraminifera, algae, and *incertae sedis***	**Age**
135.9 m to 166.7 m above base of subunit 46	*Archaediscus* ex. gr. *A. krestovnikovi* Rauzer-Chernoussova *Earlandia* ex. gr. *clavatula* (Howchin) *Earlandia vulgaris* (Rauzer-Chernoussova and Reitlinger) *Endothyra* sp. *Globoendothyra* sp. *Mediocris* sp. *Planoarchaediscus* sp. *Priscella* sp.	Zone 13, middle Viséan, mid-Meramecian
Lowermost part of subunit 47	*Brunsia* sp. (abundant) *Calcisphaera* sp. *Planoarchaediscus* sp. *Priscella* sp.	*Brunsia* biofacies (in North American Cordillera =Zone 14-15, late Viséan, upper Meramecian)
16.2 m above base of subunit 47	*Eotuberitina* sp. cf. *Neoarchaediscus* sp. *Priscella* sp. *Tetrataxis* sp. *Zellerinella* sp.	Zones 16i or 16s, latest Viséan, early Chesterian equivalent
45.1 m above base of subunit 47	*Asteroarchaediscus* sp. *Eotuberitina* sp. *Endothyra* sp. *Neoarchaediscus* sp. *Planospirodiscus* sp. *Pseudoammodiscus* sp. *Pseudoglomospira* sp.	Zone 17, early Namurian (early Serpukhovian) middle Chesterian equivalent)
60.7 m above base of subunit 47	*Asphaltina cordillerensis* Mamet and Petryk *Asteroarchaediscus* sp. *Calcisphaera* sp. *Endothyra* sp. *Eostaffella* sp.? or *Eostaffellina*? sp. *Globoendothyra* sp. *Neoarchaediscus* sp. *Proninella* sp. *Pseudoammodiscus* sp. *Pseudoglomospira* sp. *Stacheoides* sp. *Tetrataxis* sp. *Tuberitina* sp.	Zone 18, early Namurian (middle Serpukhovian) late Chesterian equivalent
5.8 m to 15.8 m above base of subunit 48	Apterrinellids *Asphaltina cordillerensis* Mamet and Petryk *Asteroarchaediscus* sp. *Claracrusta* sp. *Donezella* sp. *Endothyra* sp. *Epistacheoides* sp. *Globivalvulina* sp. ex.gr. *G. moderata* Reitlinger *Glomospiroides* sp. *Haplophragmina*? sp. *Monotaxinoides* sp. *Neoarchaediscus* sp. *Planoendothyra* sp. *Pseudoglomospira* sp. *Ungdarella* sp.	Zone 20, early Bashkirian (=Morrowan, Early Pennsylvanian)
111.9 m to 231.6 m above base of subunit 48	Apterrinellids *Archaeolithophyllum* sp. *Asphaltina cordillerensis* Mamet and Petryk *Asteroarchaediscus* sp. *Biseriella* sp. *Calcitornella* sp. *Claracrusta* sp.	Zone 20, early Bashkirian (=Morrowan Early Pennsylvanian)

Table 2. Continued.

Stratigraphic position	**Foraminifera, algae, and *incertae sedis***	**Age**
	Cuneiphycus sp. *Donezella* sp. *Endothyra* sp. *Eostaffella* sp. *Globivalvulina* ex. gr. *G. moderata* Reitlinger *"Hemigordius" harltoni* Cushman and Waters *Monotaxinoides* sp. *Neoarchaediscus* sp. *Planoendothyra* sp. *Pseudoendothyra* sp. *Stacheoides* sp. *Ungdarella* sp. *Volvotextularia* sp.	
351.7 m to 397.5 m above base of subunit 48	*Ammovertella* sp. *Asphaltina cordillerensis* Mamet and Petryk *Biseriella* sp. *Claracrusta* sp. *Climacammina* sp. *Cuneiphycus* sp. *Donezella* sp. *Foliophycus* sp. *Globivalvulina* ex. gr. *G. moderata* Reitlinger *Millerella* sp. *Neoarchaediscus* sp. *Pseudoendothyra* sp. *Ungdarella* sp. *Volvotextularia* sp.	Zone 20, early Bashkirian (=Morrowan, Early Pennsylvanian)
431.3 m to 491.9 m above base of subunit 48	*Ammovertella* sp. *Anthrocoporella* sp. *Biseriella* sp. *Claracrusta* sp. *Climacammina* sp. *Cuneiphycus* sp. *Donezella* sp. *Endothyra* sp. *Eoschubertella* sp. *Eostaffella* sp. *Globivalvulina bulloides* (Brady) *Millerella* sp. *Pseudoendothyra* sp. *Pseudostaffella* sp. *Tetrataxis* sp. *Tuberitina* sp. *Ungdarella* sp. *Volvotextularia* sp. Numerous levels of dissolved phylloid algae	Zone 21 (=Atokan, mid-Bashkirian)
538.9 m to 565.4 m above base of subunit 48	*Claracrusta* sp. *Climacammina* sp. *Cuneiphycus* sp. *Donezella* sp. *Endothyra* sp. *Eostaffella* sp. *Eoschubertella* sp. *Globivalvulina bulloides* (Brady) *Komia* sp. *Millerella* sp. *Planoendothyra* sp. *Profusulinella* sp. *Pseudoendothyra* sp. *Pseudostaffella* sp. *Staffella* sp. *Tetrataxis* sp. *Ungdarella* sp. *Volvotextularia* sp.	Zone 22 late Bashkirian (=Atokan)

Table 2. Continued.

Stratigraphic position	Foraminifera, algae, and *incertae sedis*	Age
674.2 m above base of subunit 48	*Anthracoporellopsis* sp. *Beresella* sp. *Biseriella* sp. *Climacammina* sp. *Deckerella* sp. *Dvinella* sp. *Eostaffella* sp. *Eoschubertella* sp. *Globivalvulina* sp. *Fusulinella* sp. *Komia* sp. *Monotaxinoides* sp. *Planoendothyra* sp. *Polytaxis* sp. *Profusulinella* sp. *Pseudoendothyra* sp. *Staffella* sp. *Syzrania* sp. *Tetrataxis* sp. *Tuberitina* sp. *Volvotextularia* sp.	Zone 23, early Moscovian (= Atokan?)

Table 3. Devonian and Mississippian corals and stromatoporoids from Sierra Agua Verde. Devonian corals and stromatoporoids identified by W.A. Oliver, Jr., and Mississippian and Pennsylvanian corals by W.J. Sando.

Field no. (USGS colln. no.)	Stratigraphic position	Coral genera (Number of specimens)	Age
82FP-114F (10615-SD)	Subunit 19	*Alveolites* sp. *Favosites* sp. *Cystiphylloides* sp. *Hexagonaria* sp. *Tabulophyllum* sp.	Reworked corals of probable Middle Devonian age
82FP-95F (10441-SD)	Subunit 25	Massive stromatoporoid Auloporoid coral *Alveolites*? sp.	Middle or Late Devonian
82FP-119F (10442-SD)	Subunit 25	*Alveolites* sp. Favositid coral (ramose?) *Thamnopora* sp. *Tabulophyllum*? sp.	Middle or Late Devonian
83FP-14F (29116-PC)	26 m above base of subunit 47	*Michelinia* sp. (9)	Chesterian or Morrowan (Mississippian)
83FP-15F (29118-PC)	32 m above base of subunit 47	*Michelinia* sp. (1)	Chesterian or Morrowan (Mississippian)
83FP-16F (29117-PC)	45 m above base of subunit 47	*Amplexizaphrentis* sp. (4)	Probably Chesterian (Mississippian)
83FP-17F (29119-PC)	566 m above base of subunit 48	*Michelinia* sp. (1) *Multithecopora* morphogroup C (3)	Chesterian or Morrowan (Mississippian) to Permian
83FP-18F (29120-PC)	655 to 658 m above base of subunit 48	*Chaetetes* sp. (3)	Morrowan to Desmoinesian, probably Middle Pennsylvanian

Sierra El Carnero, 60 km northwest of Hermosillo dated on the basis of conodonts (C.A. Sandberg, oral communication, 1995); Upper Devonian strata near Sierra El Tule in northern Sonora (González-León, 1986); and Devonian strata near Caborca (Brunner, 1975). The presence of sandstone and quartzite, some containing feldspar, in the Sierra Agua Verde section is characteristic of Devonian strata in many areas of the southwestern and western United States.

The Upper Devonian and Mississippian cliff-forming carbonate unit in Sierra Agua Verde is 860 m thick and is composed of pelmatozoan-rich lime mudstone, packstone, and wackestone. Mississippian shelf strata in Sonora have not been studied in detail, although strata of this age appear to be fairly extensively exposed. Mississippian strata have been reported near Rancho Sobechi (conodonts in limestone identified by A. Harris, oral communication, 1995); southwest of Sierra Mazatán (conodonts in limestone identified by C.A. Sandberg, oral communication, 1995); in Sierra Santa Teresa (Stewart and others, 1997); near Cobachi (Ketner and Noll, 1987); and near Bízani in the Caborca region (Brunner, 1976). Armstrong and others (1981) indicate that Mississippian strata near Caborca have similarities to strata in southeastern Arizona and southwestern New Mexico, but not to strata in eastern California.

The Pennsylvanian ledge-and-slope-forming carbonate unit in Sierra Agua Verde is cut by several faults that make estimates of thickness uncertain. An incomplete section is at least 789 m thick and consists mostly of lime mudstone, packstone, very fine gained sandstone, crystallized limestone, and clayey lime mudstone. Shelf strata of comparable age to the ledge-and-slope-forming unit are well defined in Sierra Santa Teresa, about 20 km southeast of Hermosillo. These Pennsylvanian strata are about 1,500 m thick and consist of generally massive cliff-forming units that do not have the typical ledge-and-slope character of the unit at Sierra Agua Verde. The section at Sierra Santa Teresa does not contain quartz-rich silty and sandy packstone and wackestone or fine- to medium-grained quartz sandstone like those characteristic of the section at Sierra Agua Verde. The lithology of the ledge-and-slope forming unit at Sierra Agua Verde is similar to that of the Pennsylvanian and Lower Permian Bird Spring Formation in eastern California and southern Nevada, and to a lesser extent to that of the Pennsylvanian and Lower Permian Horquilla Formation of southeastern Arizona.

PALEOGEOGRAPHIC AND TECTONIC SETTING

Discussion of the paleogeography and tectonic setting of the Paleozoic rocks in Sierra Agua Verde focuses on two distinctly different concepts (Figure 11A, B). One concept (Figure 11A) is that the Paleozoic rocks in Sonora are autochthonous or parautochthonous relative to a stable Paleozoic North American continent (many references including Eardley, 1951; Poole and Hayes, 1971; Stewart and others, 1984; Poole and others, 1995). The other concept (Figure 11B) is that Paleozoic and Mesozoic rocks in Sonora have been displaced left laterally as much as 1,000 km by Mesozoic, or perhaps late Paleozoic, strike-slip faulting on a major fault or fault system, the hypo-

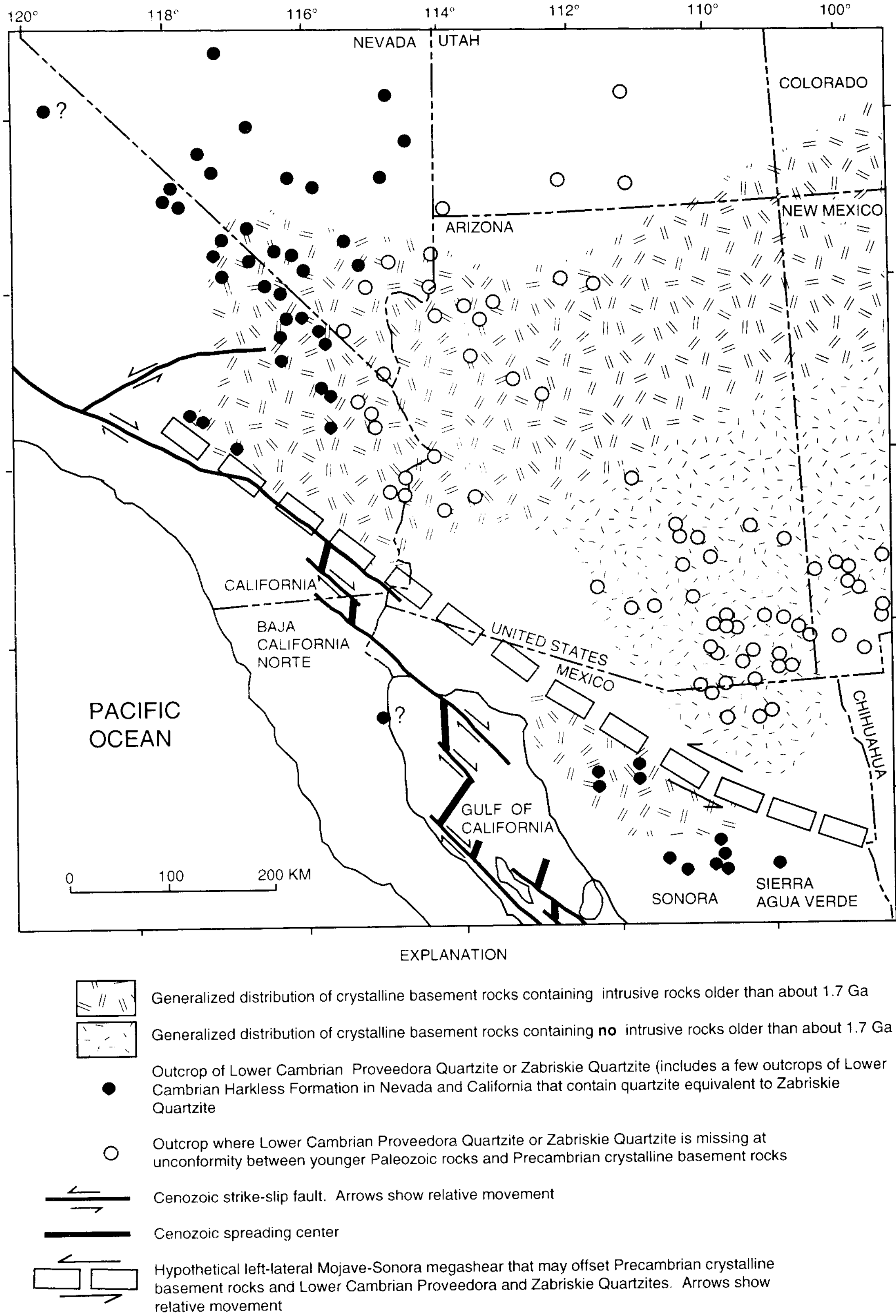


Figure 10. Map showing hypothetical left-lateral Mojave-Sonora megashear, generalized distribution of crystalline basement rocks, and outcrop localities of Lower Cambrian Proveedora Quartzite and equivalent Zabriskie Quartzite in the western United States and northern Mexico. Age of basement rocks based on Anderson and Silver (1981), Anderson ans Schmidt (1983), Karlstrom and Bowring (1993), T.H. Anderson (writen communication, 1996), and J.L. Wooden (writen communication, 1997).

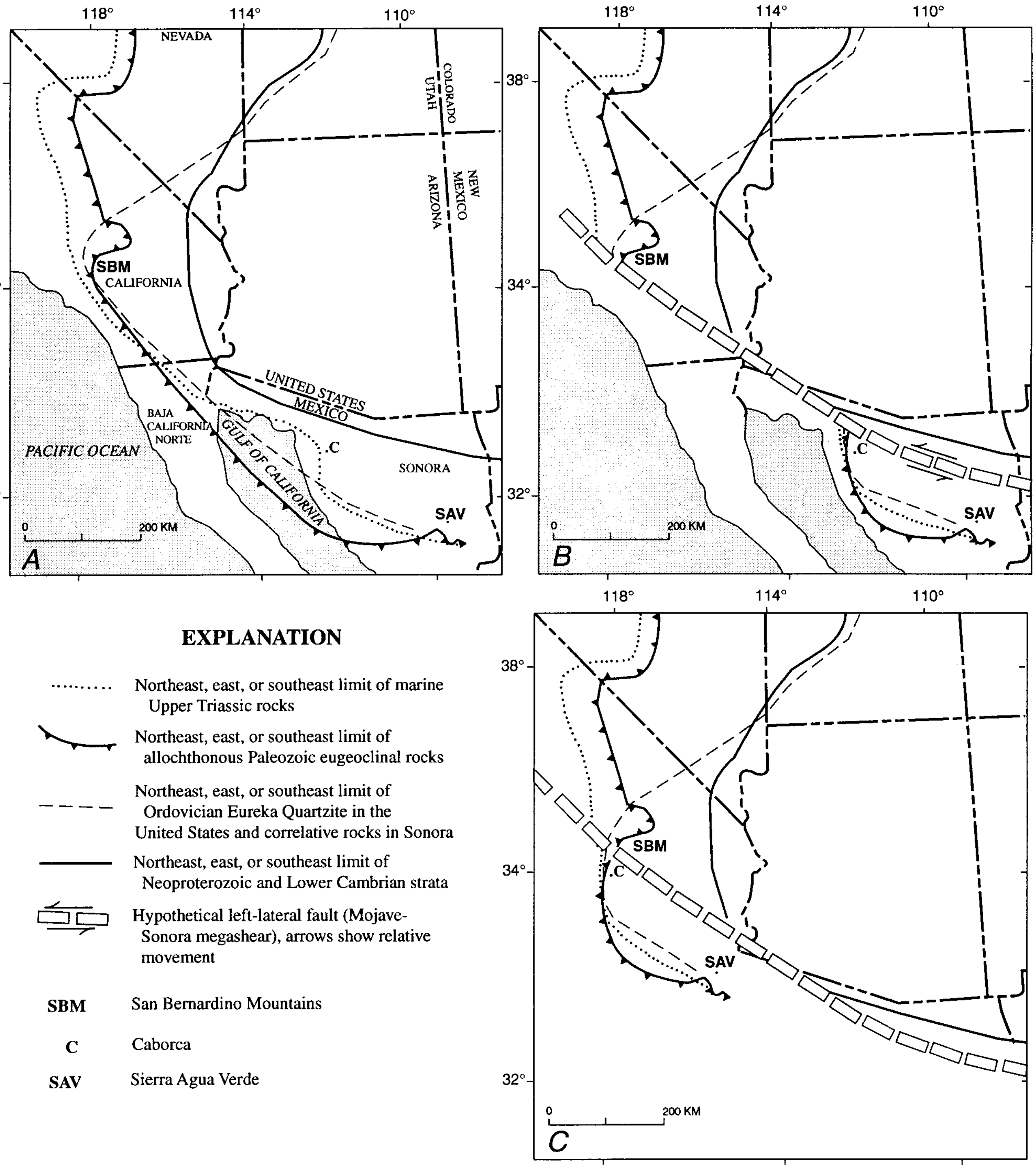


Figure 11. Tectonic and paleogeographic models of Paleozoic rocks in the western United States and northern Mexico. A, model in which the Mojave-Sonora megashear does not exist; B, model in which Paleozoic and Triassic rocks have been offset 600 km left laterally from an originalposition near the San Bernardino Mountains; C, palinspastic reconstruction on faults or structures other than Mojave-Sonora megashear not shown.

thetical Mojave-Sonora megashear (Silver and Anderson, 1974; Dickinson, 1981; Anderson and Schmidt, 1983; Stewart and others, 1984; Ketner, 1986; Stevens and others, 1992; Stanley and González-León, 1995; Jones and others, 1995). We here summarize arguments for each of these concepts and indicate how the stratigraphy of Sierra Agua Verde fits with each concept. With present knowledge neither of these hypotheses can be clearly proven, and our aim here is to provide a discussion of the merits of each idea with specific reference to the strata at Sierra Agua Verde.

The concept that the Paleozoic rocks in Sonora are autochthonous or parautochthonous relative to Paleozoic North

America is based on a combination of relationships that indicate that no major displacements are needed to explain the distribution of Paleozoic rocks in Sonora. In addition, some strata may correlate more closely with strata in southern Arizona and New Mexico than with strata in southern or eastern California, where comparable rocks should be if the megashear concept is correct. In the autochthonous or parautochthonous concept, strata thicken and change facies gradually southward or southwestward from relatively thin Paleozoic sections in Arizona and New Mexico to relatively thick miogeoclinal strata in central Sonora. In this view, for example, Neoproterozoic and Lower Cambrian rocks which are over 3,000 m thick in the Caborca area (Stewart and others, 1984) but are absent in southern Arizona and New Mexico and represent an intact thickening of shelf deposits along a stable continental margin. Ordovician strata in Sonora (Poole and others, 1995) also show apparent increased thickening and more inclusive ages of deposition outward on a possibly intact continental margin.

The hypothesis of major left-lateral offset of Paleozoic rocks in Sonora is built on the distribution pattern of Precambrian crystalline basement rocks and the similarity of the distribution patterns of these Precambrian rocks with those of Neoproterozoic and Paleozoic strata. Anderson and Silver (1979, 1981) noted two age groups of Precambrian rocks, one in northeastern Sonora where ages range from approximately 1.7 to 1.6 Ga and the other to the southwest where ages range from 1.8 to 1.7 Ga. Both terranes are intruded by younger Precambrian intrusive rocks. This distribution pattern led Silver and Anderson (1974) to propose that the 1.8 to 1.7 Ga rocks in Sonora had been displaced left laterally from eastern California where undisplaced rocks of similar age are found. Silver and Anderson (1979) and Anderson and Schmidt (1983) also noted that Neoproterozoic and Lower Cambrian strata unconformably overlying the 1.8 to 1.7 Ga basement in the Caborca region are similar lithologically and stratigraphically to rocks in the Death Valley region of eastern California which lie on a basement of similar age. On the basis of these relations, they proposed that the Caborca rocks had been displaced 700 to 800 km left laterally along a proposed fault (Mojave-Sonora megashear) to their present position in the Caborca region. Silver and Anderson (1974), Anderson and Silver (1979), and Anderson and Schmidt (1983) considered the megashear to be Jurassic in age, whereas Stevens and others (1992) alternatively argued that it might be late Paleozoic.

Since its initial proposal, several complexities have developed in the concept of the megashear. Neoproterozoic and Paleozoic rocks in the San Bernardino Mountains, and locally elsewhere in the western Mojave Desert region, that lie southwest of the proposed trace of the megashear as defined by Silver and Anderson (1974), are similar in lithology, stratigraphy, and age to rocks northeast of the megashear. Thickness and facies trends (Brown, 1991) in these rocks in the San Bernardino Mountains and elsewhere in the Mojave Desert region do not appear to be offset by the megashear in the position specified by Silver and Anderson (1974). Another seemingly anomalous outcrop is in the El Capitán area in northwesternmost Sonora southeast of Yuma and in the Gila Mountains in southwesternmost Arizona (Leveille and Frost, 1984; Fitts, 1986; Hamilton, 1987). Here, Paleozoic cratonal platform rocks crop out southwest of the trace of the proposed megashear, yet apparently are closely related to cratonal platform rocks northeast of the megashear in southeastern California and southeastern Arizona. These significant problems with the position of the megashear can be resolved by repositioning the megashear southwest of the San Bernardino Mountains (Stewart and others, 1984) and the El Capitán area. However, this repositioning of the megashear is in conflict with the position of the megashear based on the ages of Precambrian rocks. Silver (*in* Stewart and others, 1984; and oral commun., 1995) reconciles this apparent conflict by proposing westward or southwestward transport of large slices of rocks (including the San Bernardino Mountains and El Capitán) across the megashear. Such complexities certainly challenge the original simplicity of the megashear as originally proposed by Silver and Anderson (1974), but does not invalidate the hypothesis of major left-lateral offset in eastern California and Sonora. In the palinspastic reconstruction shown in Figure 11, the megashear is southwest of the San Bernardino Mountains, whereas cratonal shelf rocks at El Capitán are considered to have been originally northeast of the megashear and to have been transported southwestward across the megashear to their present positions. In this reconstruction, the Caborca region has been offset from southwest of the San Bernardino Mountains and not from areas as far north as Death Valley, as originally proposed by Silver and Anderson (1974), Anderson and Silver (1979) and Anderson and Schmidt (1983). The displacement in the model described here is about 600 km. If restored to its original position before the proposed offset on the megashear, Sierra Agua Verde would lie southwest of southwesternmost part of Arizona. Clearly other reconstructions are possible, including the model discussed previously that little or no left-lateral offset has occurred between southern California and central Sonora (Figure 11A).

Figure 10 summarizes some information that appears to favor the concept of major left-lateral offset on the Mojave-Sonora megashear. This figure shows the distribution pattern of the Lower Cambrian Proveedora Quartzite and the correlative Zabriskie Quartzite, and of Precambrian crystalline basement terranes. Outcrops of the Proveedora-Zabriskie Quartzite are widespread in eastern California and southern Nevada, and also in central Sonora, including Sierra Agua Verde. No outcrops are known between these two regions except for quartzite on the east coast of Baja California that have been correlated (Anderson, 1993), although with uncertainty, with the Proveedora Quartzite of Sonora. However, if this quartzite in Baja California Norte is palinspastically restored to its position before movement on the Cenozoic San Andreas fault, it would lie 300 km farther southeast and not fill the gap in outcrops between Sonora and California. The two-region distribution pattern is compatible with left-lateral offset of the Zabriskie-Proveedora from California to central Sonora. This possibility is enhanced by the similar pattern of distribution of Precambrian crystalline basement rocks. Basement rocks in Sonora southwest of the proposed megashear contain intrusive rocks older than about 1.7 Ga and are seemingly displaced southeastward from southeastern California (Figure 10) where basement rocks of similar age are known, as originally proposed by Silver and Anderson (1974). Other units also show a two-region distribution pattern. In particular, a distinctive 1- to 2-m-thick oolite, and distinctive overlying and underlying units in the Neoproterozoic Johnnie Formation in eastern California and southern Nevada, are lithologically similar to units in the Clemente Formation in the Caborca region (Stewart and others, 1984). Furthermore, Ketner (1986) and Stewart and others (1990) have noted the similarity of age and lithology of the Eureka Quartzite of eastern California and Middle Ordovician quartzites in Sonora. Correlation of these Ordovician quartzites is supported by similar ages of detrital zircons in these units in the western United States and Sonora (Gehrels and others, 1995). Many other Neoproterozoic and Paleozoic units show less lithologic similarity between eastern California and Sonora than these marker units. However, even though changes in the lithologic character of some comparable age strata are evident between Sonora and eastern California, many of these changes seem no more significant than, for example, facies changes in Neoproterozoic strata between Death Valley and the San Bernardino Mountains in eastern California (Stewart and others, 1984). Thus, such changes between Sonora and eastern California do not necessarily preclude the existence of the megashear, although the degree of change that can be accommodated within the concept of the megashear remains open to question.

As mentioned previously, Sierra Agua Verde would lie south of the southwesternmost part of Arizona, if restored to its original position before the 600 km of proposed left-lateral displacement on the Mojave-Sonora megashear (Figure 11C). In this position, Sierra Agua Verde would lie about 450 km west of southeastern Arizona, rather than in its present position which is about 300 km south of southeastern Arizona. The proposed correlations of strata in Sierra Agua Verde with those in southeastern Arizona in the context of this reconstruction would perhaps be as realistic as they are with Sierra Agua Verde in its present position relative to southeastern Arizona. If Paleozoic trends in Arizona are mainly east-west as suggested by some isopach and facies trends (Hayes, 1975), the palinspastic position of Sierra Agua Verde west of southeastern Arizona might place it in a more logical paleogeographic position relative to southeastern Arizona than it is in its present position.

Regardless of whether or not Neoproterozoic and Paleozoic rocks in Sonora have been offset left-laterally on the hypothetical Mojave-Sonora megashear, they originally were a wraparound continuation of Cordilleran miogeoclinal rocks of the southwestern United States (Figure 11 A, B, C). This conclusion is based on the overall similarity of the Neoproterozoic and Paleozoic rocks in Sonora and the southwestern United States, on the general north to northeast trend of miogeoclinal rocks in the Great Basin (Poole and others, 1992), and on an east-southeast to east trend in central Sonora (Stewart and others, 1990). Within this miogeoclinal belt, the strata at Sierra Agua Verde are considered to represent inner-shelf deposits comparable in position on the shelf to strata in the San Bernardino Mountains or the Las Vegas Range-eastern Spring Mountains of southern Nevada. In these areas, the Zabriskie Quartzite (equivalent to the Proveedora Quartzite in Sierra Agua Verde) is present, but thin (Stewart, 1970), Middle and Upper Cambrian carbonate rocks are thick (Poole and others, 1992), and a pre-Devonian unconformity is present (Gans, 1974; Brown, 1991). However, the inner shelf position of these rocks and of those in Sierra Santa Teresa does not by itself provide definitive evidence for proving or disproving the existence of the Mojave-Sonora megashear.

ACKNOWLEDGMENTS

We wish to thank Ted Bolich and Guillermo Salas, who at the time of our work were with Minera Báucarit, for their assistance in the field and for supplying housing in Cobachi. We also wish to thank the people at Matape and El Rancho Agua Caliente for their help in gaining access to the range and in carrying samples.

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