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Abstract

The Oso Ridge Member (new), at the base of the Abo Formation in the Zuni Mountains, nonconformably overlies Proterozoic rocks. The member consists of some 30 ft (9 m) of conglomerate and arkose composed principally of fragments of the underlying Proterozoic schist, gneiss, and other metamorphic rocks; thin, fossiliferous limestone lenses are interbedded with the arkose. Biota from the lenses include a phylloid alga *Eugonophyllum* sp.; the foraminifers *Globivalvulina* sp., *Biseriella* sp., and *Syzrania* sp.; the conodonts *Adetognathus lautus* (Gunnell), *Streptognathodus elongatus* Gunnell, and *"Ellisonia"* conflexa (Ellison); the brachiopods *Juresania* cf. *J. nebraskensis* (Owen), *Spiriferella* sp., *Composita* cf. *C. mexicana* Hall; and the mollusks *Myalina apachesi* Marcou, *"Pleurophorus"* cf. *"P." mexicanus* Girty, a bellerophontid indet., gastropods, and orthocone nautiloids indet., *Plagioglypta* cf. *"P." canna* White, and a coiled nautiloid indet. The age of the Oso Ridge Member is Virgilian (Late Pennsylvanian) to Wolfcampian (Early Permian).

Introduction

Field studies in the Zuni Mountains of west-central New Mexico were conducted by Armstrong during the spring and summer of 1990 to determine both facies and age relationships of the carbonate rock at the base of the Abo Formation (Fig. 1). The petrographic studies of the carbonate rocks were done by Mamet and Armstrong; Mamet identified the calcareous alga and foraminifers; Stamm identified the conodonts, which were processed by Weary; Dutro reexamined the brachiopods and mollusks collected by Darton.

Previous studies

Darton (1928, p. 137) found that in the Zuni Mountains of New Mexico "the Magdalena (Pennsylvanian) and older sedimentary formations are absent, at least in the central part of the uplift, owing doubtless to the presence of a land surface in this area which continued until Permian time." He described and illustrated the Abo Formation as resting on Proterozoic rocks. The Abo is 600–700 ft (about 200 m) thick and consists of massive sandstone, brown slabby sandstone, sandy shale, and, locally, thin limestones in the lower part. Darton's collecting near Sawyer (90P–4 area) at the headwaters of Bluewater Creek yielded brachiopods and mollusks determined by G. H. Girty (*in* Darton, 1928, p. 140) as a "Manzano (Permian) fauna." Lee and Girty (1909) described and illustrated the Manzano fauna from the Rio Grande valley of New Mexico. In modern terms, Girty's age determination would indicate a Virgilian–Wolfcampian age range.

Smith (1958, 1959) published a series of 1:48,000-scale geologic maps of the Zuni Mountains in which he mapped and described Pennsylvanian arkoses and limestones beneath the Abo Formation. His map unit is composed "principally of fragments of the underlying Precambrian schist, gneiss, and other metamorphic rocks, and thin, sparsely fossiliferous limestone lenses that are interbedded with the arkose." He assigned these sedimentary rocks a Pennsylvanian age but did not give any paleontological evidence for his age assignment.

Colpitts (1989) found megafossils in the basal limestones of the Abo Formation at La Jara Springs (90P–1 area), which include planispiral gastropods, brachiopod-shell fragments, and bryozoan fragments. The age of this basal limestone and conglomerate sequence has been the subject of some discussion and controversy for several decades. Cheetham (1950, *in* Kottlowski, 1960) suggested that bryozoans collected from these carbonates are Virgilian in age.

Proterozoic basement

Goddard's (1966) geologic map and studies by Mawer and Bauer (1989) indicate that the Proterozoic rocks of the Zuni Mountains are metamorphic felsic to ultramafic schist, gneiss, and foliated plutonic rocks. Regional metamorphism is at the lower amphibolite grade. Isotopic U-Pb ages based on zircon from felsic igneous rocks indicate crystallization at about 1.655 Ga (Bowring and Condie, 1982).

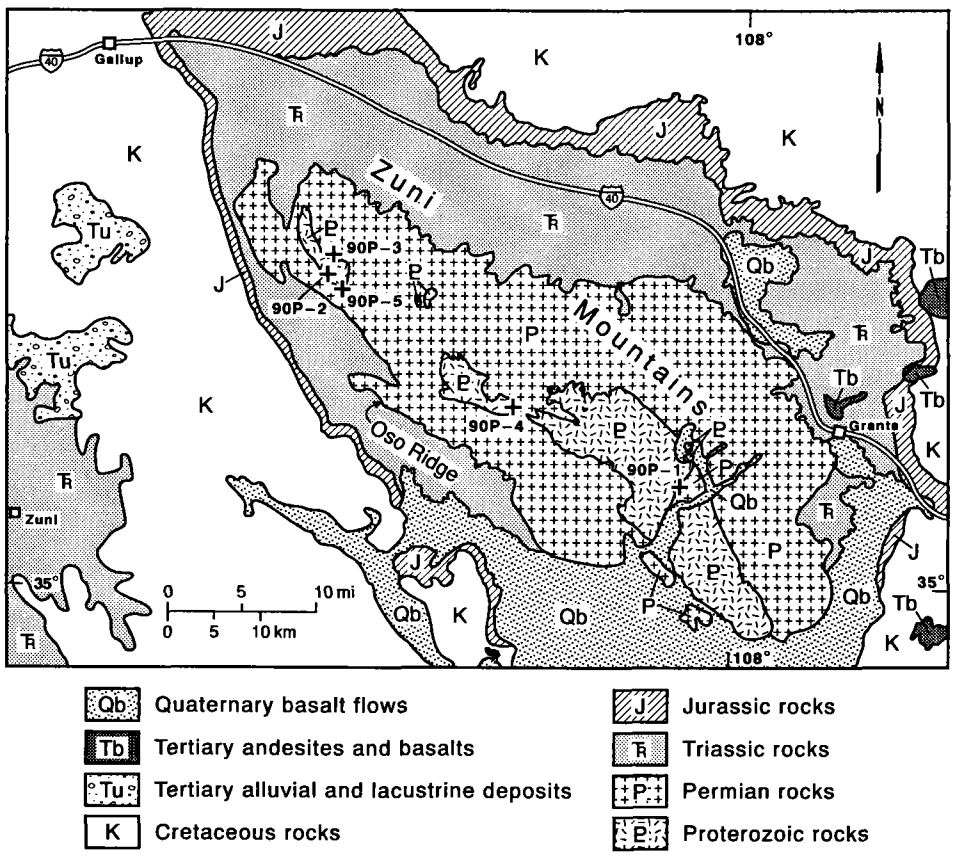

FIGURE 1—Generalized geologic map (modified from Dane and Bachman, 1965) of the Zuni Mountains showing the studied outcrops of the Oso Ridge Member of the Abo Formation. **90P–1**, La Jara Springs; **90P–2**, McQue Flat; **90P–3**, Log House; **90P–4**, Sawyer; and **90P–5**, Oso Ridge.

Outcrops

The Oso Ridge Member is here named as the basal unit of the Abo Formation. The name is derived from a northwest- to southeast-trending ridge that forms the crest of the southern Zuni Mountains. The Sawyer section (90P–4) provides the best exposures and is the proposed type section for the Oso Ridge Member of the Abo Formation. Goddard's (1966) geologic map provides coverage of the proposed type section. To the northwest of the Sawyer section, Smith's (1958) geologic map shows the arkose and bedded limestones occurring above the Proterozoic and beneath the typical Abo over an area of several square miles.

The basal conglomerates of the Oso Ridge Member overlie deeply weathered Proterozoic gneiss. The lower 8 ft (2.4 m) are water-deposited coarse clastics composed of the weathered Proterozoic rocks and include maroon to brownish-red pebble conglomerates, sandstones, and siltstones (Figs. 2, 3). Limestones occur at 8–14 ft (2.4–4.6 m), 21–24 ft (6.4–7.3 m), and a thin bed at 30 ft (9.1 m) and are separated by intervals of brownish-red siltstones and sandstones (Fig. 2). The upper contact of the Oso Ridge Member is placed at the last occurrence of carbonate, which is overlain by nearly continuous arkosic sandstones of the Abo Formation. The limestones are fossiliferous arenaceous packstones to grainstones. The calcareous phylloid alga *Eugonophyllum* is abundant and is associated with a rich molluskan fauna of gastropods, pelecypods, and nautiloids. Field observations, petrography, and paleontology all indicate that these carbonate rocks were deposited in estuarine or lagoonal environments.

At La Jara Springs exposure, 90P–1, the limestone is about 3.5 (1.1 m) thick and is exposed in the crest of a low ridge. Goddard's (1966) geologic map shows the outcrop location and the regional geology. The arenaceous limestones are underlain by some 50 ft (15.2 m) of maroon siltstone and quartz-conglomerate that rest on Proterozoic metamorphic rocks. The calcareous alga *Eugonophyllum* is abundant and is associated with brachiopods, echinoderms, bryzoans, ostracodes, and a molluskan fauna of gastropods and pelecypods. The depositional environment of the limestone was subtidal marine.

The McQue Flat exposure, 90P–2, is shown on Smith's (1959) geologic map with the location of the limestone that was sampled at two outcrops near the northwest edge of Sec. 30. Poor exposures of the nodular limestone bed are found on low hills. Construction of a stratigraphic section is not possible because of the discontinuous outcrops and soil cover. Petrographic studies show that the stratigraphically youngest limestone nodules consist of brachiopod–ostracode–echinoderm peloid packstone to wacke- ☞

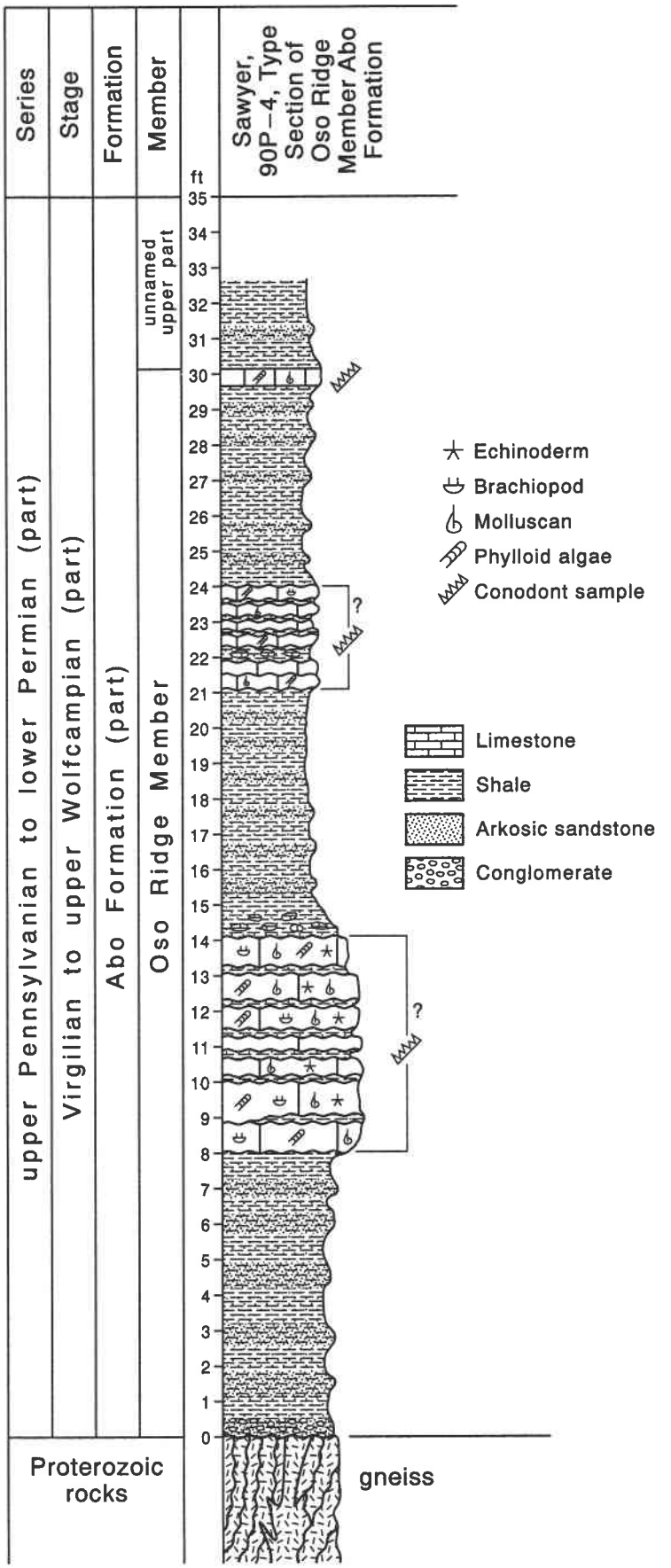

FIGURE 2—Graphic illustration of the measured type section Sawyer 90P–4, of the Oso Ridge Member, Abo Formation, at Sawyer–Bluewater Canyon. The limestones contain the alga *Eugonophyllum*, a large molluskan fauna of bivalves, gastropods, and nautiloid cephalopods, and conodonts.

FIGURE 3—Pennsylvanian limestones exposed in a roadcut near Sawyer (90P–4). The arkosic bed below the limestones is clearly visible. The blocky nature of the lower limestone and the somewhat nodular-bedded limestone near the top of the section are apparent. These carbonates contain abundant phylloid algae, brachiopods, conodonts, gastropods, and echinoderms. The light meter is 3 in. (7.5 cm) long.

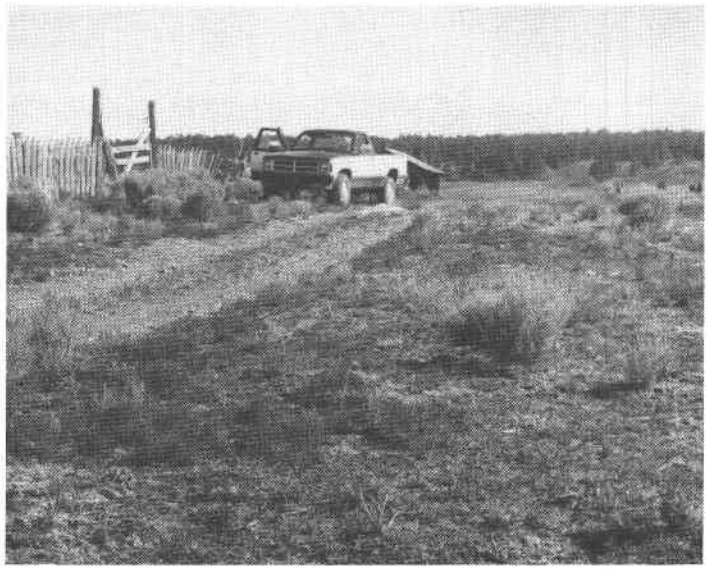

FIGURE 4—Log House outcrop 90P–3. View to the east, illustrating the generally poor exposures in the west Zuni Mountains. The low ridge beneath the truck is formed by the nodular dolostones in a siltstone matrix. The soil in the foreground, beneath the ridge, is formed by the basal siltstone and sandstone overlying Proterozoic rocks. The petrographic and microfossil samples were collected from bedrock exposed in the roadcut.

stone. The carbonate rocks near the Proterozoic contact are arenaceous-dolomitic lime mudstones.

The Log House exposure, 90P–3, also on Smith's (1958) geologic map, shows that the outcrop of carbonate rocks is about 0.3 mi (0.48 km) long. The nodular dolostone is exposed as a low ridge some 20 ft (6.1 m) above the Proterozoic contact (Fig. 4). Petrographic studies show that the dolostone is formed of euhedral dolomite rhombs 25 to 300 μm across.

The Oso Ridge outcrop, 90P–5, provides the poorest exposures of all those discussed above. Above the Paleozoic nonconformity and weathered Proterozoic gneiss are 2–4 ft (0.6–1.2 m) of maroon to reddish-brown siltstone and sandstone overlain by a 1-ft-(0.3-m-) thick, nodular dolomitic limestone.

Paleontology, lithology, and age

La Jara Springs, 90P–1

Dissolved, mud-coated phylloid-algal grainstone contains bioclasts of echinoderms, brachiopods, numerous productid-brachiopod spines, and ostracodes. Phylloid blades are mostly *Eugonophyllum* sp. Identifiable foraminifers are apterrinellids, *Globivalvulina* sp., *Biseriella* sp., and *Syzrania* sp. The latter is a cosmopolitan genus that first occurs in the Moscovian, and the oldest possible age thus is Desmoinesian (late Middle Pennsylvanian). Megafossils include *Juresania* cf. *J. nebraskaensis* (Owen), *Spiriferella* sp., *Composita* cf. *C. mexicana* Hall, *Plagioglypta* cf. *P. canna* White, a bellerophontid indet., and a pelecypod indet. A conodont sample of 6.6 kg from 0–3.5 ft in the section yielded 11 Pa elements of *Adetognathus lautus* (Gunnell), 4 Pa elements of *Streptognathodus elongatus* Gunnell, 18 elements of *"Ellisonia" conflexa* (Ellison), and 13 fragments (Fig. 5). These species indicate an age range of Late Pennsylvanian to Early Permian (Virgilian to late Wolfcampian).

McQue Flats, 90P–2

Sponge-lump lime mudstone with bird's-eye structures, formed in a very shallow marine to supratidal environment.

Log House, 90P–3

Dolomitized recrystallized sponge-lump grainstone.

Sawyer, 90P–4

Phylloid-algal buildup associated with abundant gastropods, nautiloids, some crinoids, and echinoid spines. This is a molluskan facies. Reworking this 90P–4 lithology could result in the 90P–1 facies. Algae again belong to *Eugonophyllum*. The mollusks are *Myalina apachesi* Marcou, *"Pleurophorus"* cf. *"P." mexicanus* Girty, an orthocone indet., and a coiled nautiloid indet. Conodonts from a 9.4-kg sample at 8–14 ft in the section include 9 Pa elements of *Adetognathus lautus* (Gunnell), 1 Pa element of *Streptognathodus elongatus* Gunnell, 32 elements of *"Ellisonia" conflexa* (Ellison), and 60 fragments. A 3.8-kg sample from 21–24 ft in the section yielded one *Streptognathodus* sp., 29 elements of *"Ellisonia" conflexa* (Ellison), and 61 fragments (Fig. 5). The environment of deposition was a supratidal flat at the base of the carbonate section, immediately overlain by phylloid-algal mats.

G. H. Girty (*in* Darton 1928, p. 141) identified several brachiopods and mollusks that he thought could indicate either a Virgilian or Wolfcampian age. The foraminifers, algae, and conodonts, and Dutro's reexamination of these collections, all support Girty's original age assignment for the limestone.

Paleoenvironments

The outcrops at Sawyer (90P–4) and La Jara Springs (90P–1) both contain echinoderm fragments that indicate normal marine salinities, but the restricted nature of the fauna (no fusulinids, paucity of brachiopods) suggests some inhibiting factors in the environment. The calcareous alga *Eugonophyllum* is abundant in the carbonate rocks at both La Jara Springs and Sawyer. The Sawyer outcrop has a rich molluskan fauna of gastropods, pelecypods, and nautiloids. Field observations, petrography, and paleontology all suggest that these carbonate rocks were deposited in shallow estuarine or lagoonal environments.

The Log House (90P–3), McQue Flat (90P–2), and Oso Ridge (90P–5) outcrops in the western part of the Zuni Mountains contain thin or nodular beds of carbonate rocks that are composed of limestone and dolostone in gray to dark red shale and siltstone. The carbonate rocks have very few fossils and sedimentary features, suggesting intertidal to supratidal environments of deposition. The sedimentary features include laminations formed by microbial mats, small rip-up clasts, and

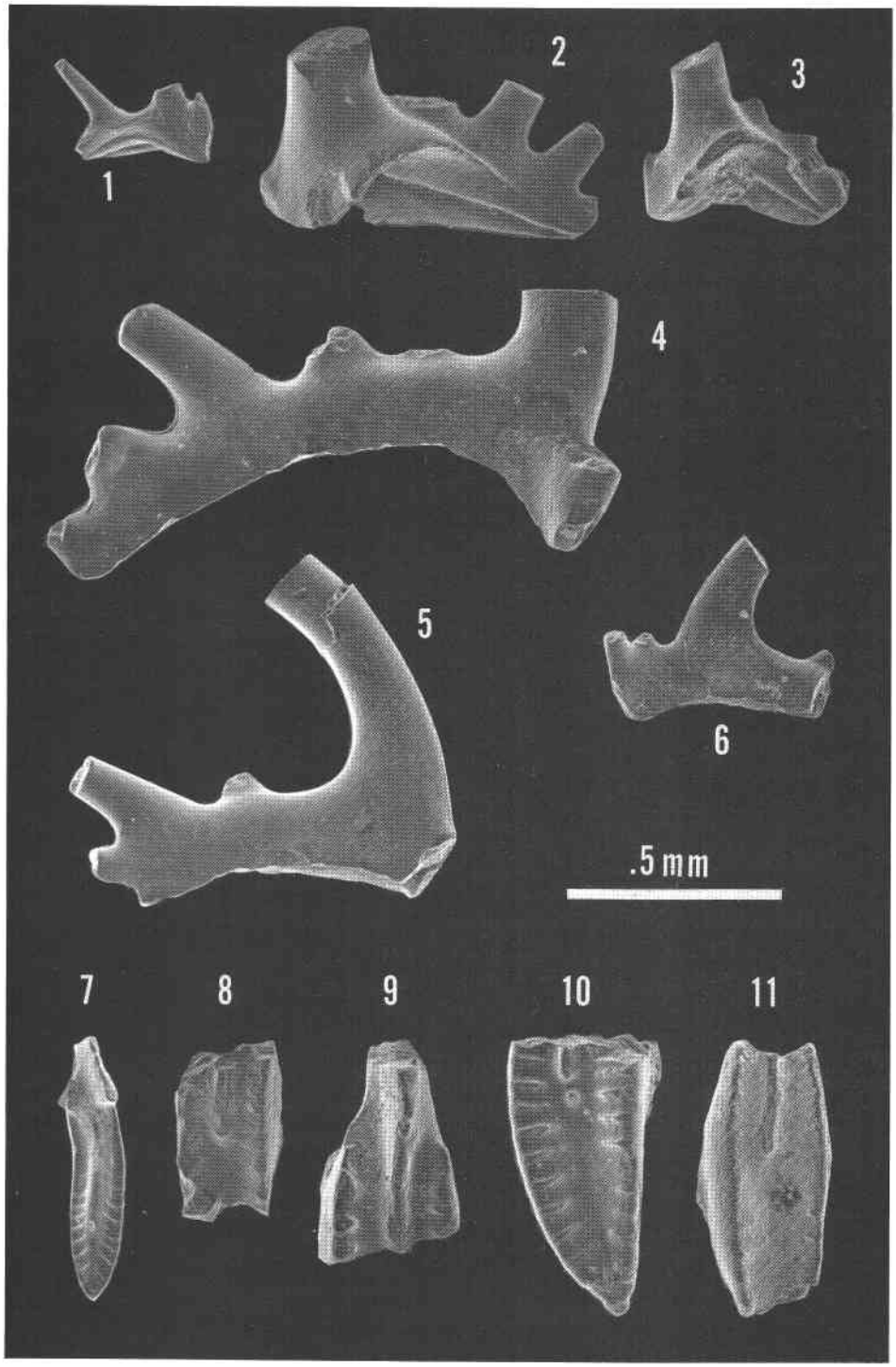

FIGURE 5—*"Ellisonia" conflexa* (Ellison); **1** (USNM 476050), Pb element, La Jara Springs 90P–1, 0–3.5 ft; **2, 3** (USNM 476051, 476052), M elements, Sawyer 90P–4, 8–14 ft; **4, 5, 6** (USNM 476053, 476054, 476055), Sa, Sb?, Sc elements, respectively, Sawyer 90P–4, 21–24 ft.

Adetognathus lautus (Gunnell); **7** (USBM 476056), Pa element, Sawyer 90P–4, 8–14 ft.

Streptognathodus elongatus Gunnell; **8, 9, 10** (USNM 476057, 476058, 476059), Pa elements, La Jara Springs 90P–1, 0–3.5 ft; **11** (USNM 476060), Pa element, Sawyer 90P–4, 8–14 ft.

mudcracks. These carbonate rocks appear to represent a shoreward facies to the northwest of the Sawyer and La Jara outcrops.

Correlations

The nearest outcrops of Pennsylvanian–Permian limestones interbedded with red beds are east of Mesa Lucero in the Carrizo Mesa area, 60 mi (97 km) to the east–southeast of La Jara Springs. This is the northmost outcrop of the Virgilian–Wolfcampian Red Tanks Member of the Madera Formation (which extends southward to the west side of the Ladron Mountains). The Red Tanks is similar to the Oso Ridge Member in containing an apparent Virgilian–Wolfcampian fauna without definitive fusulinids. As described by Kues and Kietzke (1976), the member is about 450 ft (137 m) thick and consists of red and green interdistributary or delta-embayment shales and siltstones intertongued with fossiliferous gray calcareous marine shales and limestones. Kues' (1984; Zidek and Kietzke, 1993) detailed study of the faunas suggests that the lower 90 ft (27 m) are Virgilian and the middle and upper parts are Wolfcampian.

Along Bonito Canyon in the Defiance uplift, 40 mi (64 km) northwest of Log House, Supai red beds (Permian or Pennsylvanian–Permian) overlie Proterozoic quartzites. There are no limestones in the lower Supai.

In the north Nacimiento Mountains, 90 mi (145 km) northeast of Oso Ridge on the east side of the San Juan Basin, Woodward (1987) reported intertonguing of upper Madera (Pennsylvanian) marine limestone with lower Abo (Permian) red beds. Thus the Oso Ridge Member equivalent is in the gradational Pennsylvanian–Permian sequence.

Subsurface control around the Zuni Mountains is sparse. Petroleum tests drilled show Abo red beds, with no limestones, unconformable on Proterozoic rocks at least as far south as Quemado, 55 mi (89 km) south of Oso Ridge. Twenty miles (32 km) east of La Jara Springs, about 480 ft (146 m) of marine Pennsylvanian strata (in Larrazolo–Gottlieb oil test) overlie the Proterozoic. Uppermost beds may interfinger with the Abo, a facies similar to the Red Tanks Member. Similar relationships may be recorded in wells drilled 20 (32 km) to 30 mi (48 km) to the northeast and north.

Interestingly, Colpitts (1989) noted a carbonate-rock bed 65 ft (20 m) above the Proterozoic–Abo contact, using the resistivity log from the Southland Royalty Lucero 1–14 Federal well drilled 20 mi (32 km) south of La Jara Springs. Thus lenses of the Oso Ridge Member of the Abo may extend that far south.

Thermal alteration

The color-alteration index (CAI) is 1 for the Oso Ridge Member conodonts in the Zuni Mountains (Epstein et al., 1977). This CAI value indicates that the rocks have not been heated to more than 50°C; therefore, they have not been subjected to a regional metamorphic event and have not been buried under more than about 3,500 to 4,000 ft (1,000–1,200 m) of overburden.

The persistent positive relief of the Zuni Mountains region from the Paleozoic to the Holocene is in marked contrast to the San Juan Basin some 90 mi (145 km) to the north, where there is at least 15,000 ft (5,000 m) of sedimentary rock above the Proterozoic (Huffman, 1987). ☞

Conclusions

Throughout the early Paleozoic and Mississippian, the Zuni Mountains remained a positive area in comparison to adjacent areas such as the San Juan Basin to the north, the Black Mesa Basin to the west, and the Pedregosa Basin to the south (Armstrong et al., 1992).

During the Late Mississippian and Early Pennsylvanian, the Zuni highlands were rejuvenated by tectonic events related to the Carboniferous Ouachita orogeny (Szabo and Wengard, 1975; Ross and Ross, 1985). However, by the Late Pennsylvanian they were eroded to low hills and lowlands of Proterozoic rocks; a marine transgression resulted in carbonate-sediment production.

Smith's (1958, 1959) and Goddard's (1966) geologic maps show many miles of exposed contact between the basal Abo Formation and the Proterozoic metamorphic rocks. The contact was walked out for this study, and it was verified that the basal carbonate rocks of the Oso Ridge Member are found at only a few localities. This disjunct distribution of the carbonate rocks indicates that they were deposited in low areas over an irregular surface. The carbonate beds in the Oso Ridge Member are 6–8 ft (1.8–2.4 m) thick, which suggests only a short period, perhaps a few thousand years, of sediment deposition.

Outcrop register

Sawyer: field locality 90P–4; NW1/4 sec. 19 T11N R13W; Lat. 35°10.5′, Long. 108°15.0′; Kettner Canyon 7.5′ quadrangle; Cibola County. Section can be found west of junction of Forest Routes 50 and 482. See Goddard, 1966.

La Jara Springs: field locality 90P–1; NE 1/4 sec. 13 T10N R12W; Lat. 35°6.0′, Long. 108°2.58′; Paxton Springs 7.5′ quadrangle; Cibola County. Section is on side of low hill a few hundred feet north of Forest Route 49. See Goddard, 1966.

McQue Flat: field locality 90P–2; NW1/4 sec. 30 T13N R15W; Lat. 35°20.0′, Long. 108°29.0′; Page 7.5′ quadrangle; McKinley County. Exposures are 200 to 500 ft (61–152 m) south of Forest Route 402. See Smith, 1959.

Log House: field locality 90P–3; SW1/4 sec. 32 T13N R15W; Lat. 35°18.0′, Long. 108°26.5′; Page 7.5′ quadrangle; Cibola County. Exposures are located on an east–west dirt road, next to and south of an abandoned farm house, approximately 300 ft (91 m), east of Forest Route 157. See Smith, 1958.

Oso Ridge: field locality 90P–5; SW1/4SE 1/4 sec. 6 T12N R15W; Lat. 35°17.5′, Long. 108°28.0′; Page 7.5′ quadrangle; Cibola County. Poorly exposed outcrops on dip slope in dry stream beds of large valley.

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