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New Mexico Geological Society Guidebook, 54th Field Conference, Geology of the Zuni Plateau, 2003, p. 219-229.

UPPER PENNSYLVANIAN STRATA IN THE ZUNI MOUNTAINS, WEST-CENTRAL NEW MEXICO

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Abstract.—In the Zuni Mountains (west-central New Mexico), at Sawyer and La Jara Springs, a thin, limestone-bearing stratigraphic interval termed Oso Ridge Member is present between the Proterozoic basement rocks and the red beds of the Abo Formation. At these localities the Oso Ridge Member is up to 12 m thick and consists of two depositional sequences, each composed of red beds that are overlain by thin limestones. Locally, immature conglomerates and sandstones of fluvial origin fill paleorelief developed on the Proterozoic basement. The overlying siltstones and mudstones are interpreted as sheetflood deposits, and intercalated with thin, channel-fill conglomerates and sandstones. Microfacies and invertebrate fossils in the limestones indicate a shallow, open to restricted marine depositional environment with siliciclastic influx. The fossil assemblage indicates a Virgilian age. In central New Mexico, the stratigraphic interval underlying the Abo Formation, which is composed of alternating nonmarine clastics and shallow marine limestones and shales, is generally referred to the Bursum Formation. We remove the Oso Ridge Member from the Abo Formation and consider it a member of the Bursum Formation, representing a very thin and proximal facies of that unit.

INTRODUCTION

Darton (1928) first recognized the presence of about 10 m of strata with marine limestones at the base of the Phanerozoic section in the Zuni Mountains of west-central New Mexico (Fig. 1). These strata have since been included in the Abo Formation, though their precise age and regional correlation has not been agreed upon. Here, we present new stratigraphic, petrographic and paleontological data on these strata, argue that they are of Virgilian age and assign them to the Bursum Formation. NMMNH = New Mexico Museum of Natural History, Albuquerque.

PREVIOUS STUDIES

Gilbert (1875), Dutton (1885), Darton (1910), Gregory (1917) and other early workers in west-central New Mexico did not recognize the thin interval with marine limestones between the Proterozoic basement and the overlying red beds. Darton (1928, p. 140-141) first recognized this interval, calling it a "limestone member near the base of the Abo Formation." He identified two outcrops, one at the head of Zuni Canyon and the other near Sawyer (Fig. 2). Darton stated that at both localities about 12 m of limestone is underlain by about 6 m or more of conglomeratic sandstone, which rest on Precambrian granite. In Darton (1928), Girty identified macrofossils (bivalves, gastropods and brachiopods) from the Sawyer outcrop and regarded them as Permian in age. Darton (1928) readily correlated the "limestone member near the base of the Abo Formation" in the Zuni Mountains to the lower part of the Permian Supai Formation in Arizona.

Thompson (1942, p. 14-15) briefly mentioned the limestone strata in the Zuni Mountains. He stated they are probably Virgilian in age and represent a brief marine inundation of what he termed the late Paleozoic "Zuni Land Mass."

In parts of the Zuni Mountains, Smith (1958, 1959) mapped as Pennsylvanian "Arkose and Limestone" a thin and patchy unit, describing it in his map legend as composed "principally of rock fragments of the underlying Precambrian(?) schist, gneiss, and other metamorphic rocks; thin, sparsely fossiliferous limestone lenses are interbedded with the arkose." He mapped these rocks in parts of T11N, R14W, T12N, R14-15W and T13N, R15-16W. Goddard (1966) mapped these strata as part of the Abo Formation, but in his map legend noted that "at the base [of the Abo Formation] is 3 to 8 feet of arkosic conglomerate containing white quartz pebbles; above this is 30 feet or more of dusky red arkose containing thin, medium-gray limestone beds locally mottled dusky red."

Kottlowski (1960, p. 27) stated that in the Zuni Mountains the red beds above the Precambrian basement contain "lenses of limestone that yield bryozoa and brachiopods of Desmoinesean and Missourian aspect" based on determinations by A. Cheetham and A. Bowsher. He stated that the limestones crop out in secs. 2, 18 and 19, T11N, R13W and secs. 12, 13 and 24, T11N, R14W. Kottlowski also listed a generalized section by A. Cheetham of

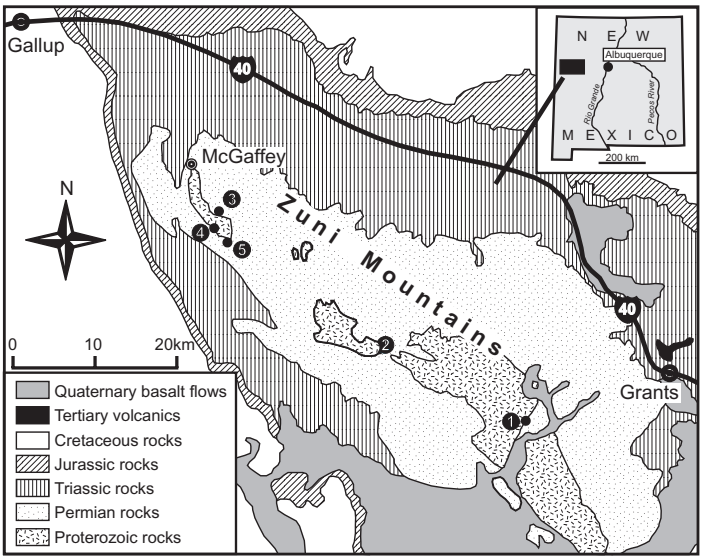


FIGURE 1. Generalized geologic map of the Zuni Mountains (modified from Armstrong et al., 1994) showing locations of principal outcrops of the Oso Ridge Member of the Bursum Formation. 1, La Jara Springs. 2, Sawyer. 3, Log House. 4, McQue Flat. 5, Oso Ridge.

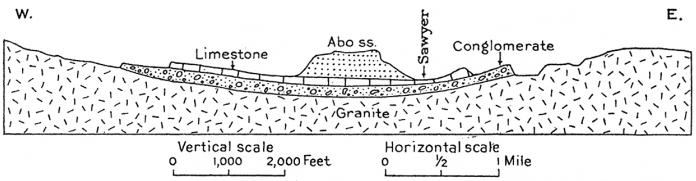


FIGURE 2. Darton's (1928, fig. 54) cross section at Sawyer, showing the limestone interval near the base of the Abo Formation. This cross section is located approximately at point 2 on Figure 1.

the interval above the basement as (in ascending order): 0-3 m of arkosic conglomerate, 0-10 m of arkose with lenses of gastropod limestone, 0-3 m of silty shale, 0-4 m of fossiliferous limestone and 0-1.5 m of dense limestone overlain by Abo red beds. Kottlowski (1960, p. 28) further stated that "oral reports from various petroleum geologists record collections of fusulinids from the limestone lenses in the lower Abo that have been identified as late-Pennsylvanian-early Permian *Triticites* types."

Read and Wanek (1961, table 2) assigned the limestones at the Abo base in the Zuni Mountains to the Red Tanks Member of the Madera Formation, a unit Kelley and Wood (1946) had named in the Lucero uplift of central New Mexico. Baars (1962) briefly discussed these limestones, considering them either Late Pennsylvanian or Early Permian in age and probably equivalent to Red Tanks and Bursum strata to the southeast.

In reviews of the Pennsylvanian strata in New Mexico, Bachman (1975) and Armstrong et al. (1979) indicated that there are no Pennsylvanian strata in the Zuni Mountains. This is almost certainly because these workers of the U. S. Geological Survey believed the limestone interval at the base of the Abo is of Permian age (also see McKee, 1967, p. 209; and Huffman and Condon, 1993, p. 16).

Colpitts (1989, p.177) stated that in the Zuni Mountains "near the base of the [Abo] formation are scattered lenticular, massive-to-nodular limestones." He noted that these limestones are 10 to 35 m above the Abo base and vary in thickness from 0.3 to 6 m thick. Colpitts described the limestones as medium to very light gray and ranging from nodular carbonate mudstone and wackestone to massive, bedded fossiliferous wackestone and packstone. Colpitts (1989) also noted that the limestone at La Jara Spring is fossiliferous and yields planispiral gastropods, brachiopod shell fragments and bryozoan fragments. He considered the age of the limestone to be either Virgilian or Wolfcampian.

Armstrong et al. (1994) presented the most comprehensive treatment thus far of the limestone-bearing interval at the base of the Abo Formation in the Zuni Mountains. They named it the Oso Ridge Member of the Abo Formation, describing its type section and other outcrops in some detail. Armstrong et al. (1994) also described a variety of macro- and microfossils from the Oso Ridge Member, including conodonts of probable Virgilian age.

LITHOSTRATIGRAPHY

Almost all previous workers in the Zuni Mountains included the limestone-bearing interval at the base of the Abo Formation in the Abo Formation, and Armstrong et al. (1994) formalized that assignment by naming it the Oso Ridge Member of the Abo Formation. However, at its type section, the Abo Formation was defined so as to explicitly exclude any marine limestones. Also, throughout the Abo Formation outcrop belt, which covers much of New Mexico, no marine limestones are included in the formation (e.g., Cook et al., 1998). Indeed, the base of the Abo Formation is usually defined as the base of the red-bed clastics above the stratigraphically highest limestone of marine origin. Below that base, an interval of mixed marine limestones and shales and nonmarine red-bed clastics is present throughout much of central New Mexico, and it is referred to the Bursum Formation (Lucas et al., 2002). Indeed, in the upper Paleozoic outcrop belt closest to the Zuni Mountains, in the Lucero uplift just southwest of Albuquerque, the Abo overlies the Red Tanks Member of the Bursum Formation (Lucas and Krainer, 2002).

Thus, we assign the Oso Ridge Member to the Bursum Formation based on its stratigraphic position (immediately beneath the Abo Formation) and lithotypes (mixture of red-bed siliciclastics and marine limestones). (One of us [BSK] prefers to elevate Red Tanks to formation rank and considers the Oso Ridge Member to be a member of the Red Tanks Formation). The thin Oso Ridge Member is dominated by sandy limestones and red beds that include a significant amount of locally reworked Proterozoic basement, making it lithologically distinct from Bursum strata to the southeast, especially the shale- and mudstone-dominated Red Tanks Member. Therefore, we retain Oso Ridge Member as a distinctive member of the Bursum Formation present in the Zuni Mountains of west-central New Mexico.

Armstrong et al. (1994) described the Sawyer section as the type section of the Oso Ridge Member. We remeasured this section (Fig. 3) and arrived at a lesser thickness estimate (~ 10 m) of the Oso Ridge Member than did Armstrong et al. (1994). Their section identifies three limestone intervals in the Oso Ridge Member, whereas our section identifies only two. We believe that the middle limestone interval of Armstrong et al.'s (1994) section (21-42 ft above the base in their section) is simply a fault repeat of the lower limestone interval (8-14 ft above the base of their section) not recognized by them. Note also that there are only two limestone intervals present in the Oso Ridge Member at La Jara Spring (Fig. 3).

In the Zuni Mountains, the Oso Ridge Member lies between Proterozoic basement (Mawer and Bauer, 1989) and the base of the Abo Formation. Typically, as at Sawyer, the Oso Ridge Member nonconformably overlies Precambrian gneisses with distinct paleorelief. The thickness of the Oso Ridge Member varies; at Sawyer, it measures 9.7 m at the roadcut and more than 12 m about 100 m west of the roadcut. At La Jara Springs, the Oso Ridge Member is 12 m thick and, as at Sawyer, it nonconformably rests on Precambrian gneisses.

LITHOFACIES

The Oso Ridge Member at Sawyer and La Jara Springs is composed of two transgressive depositional sequences. Each sequence consists of red beds that are overlain by thin limestone horizons (Fig. 3).

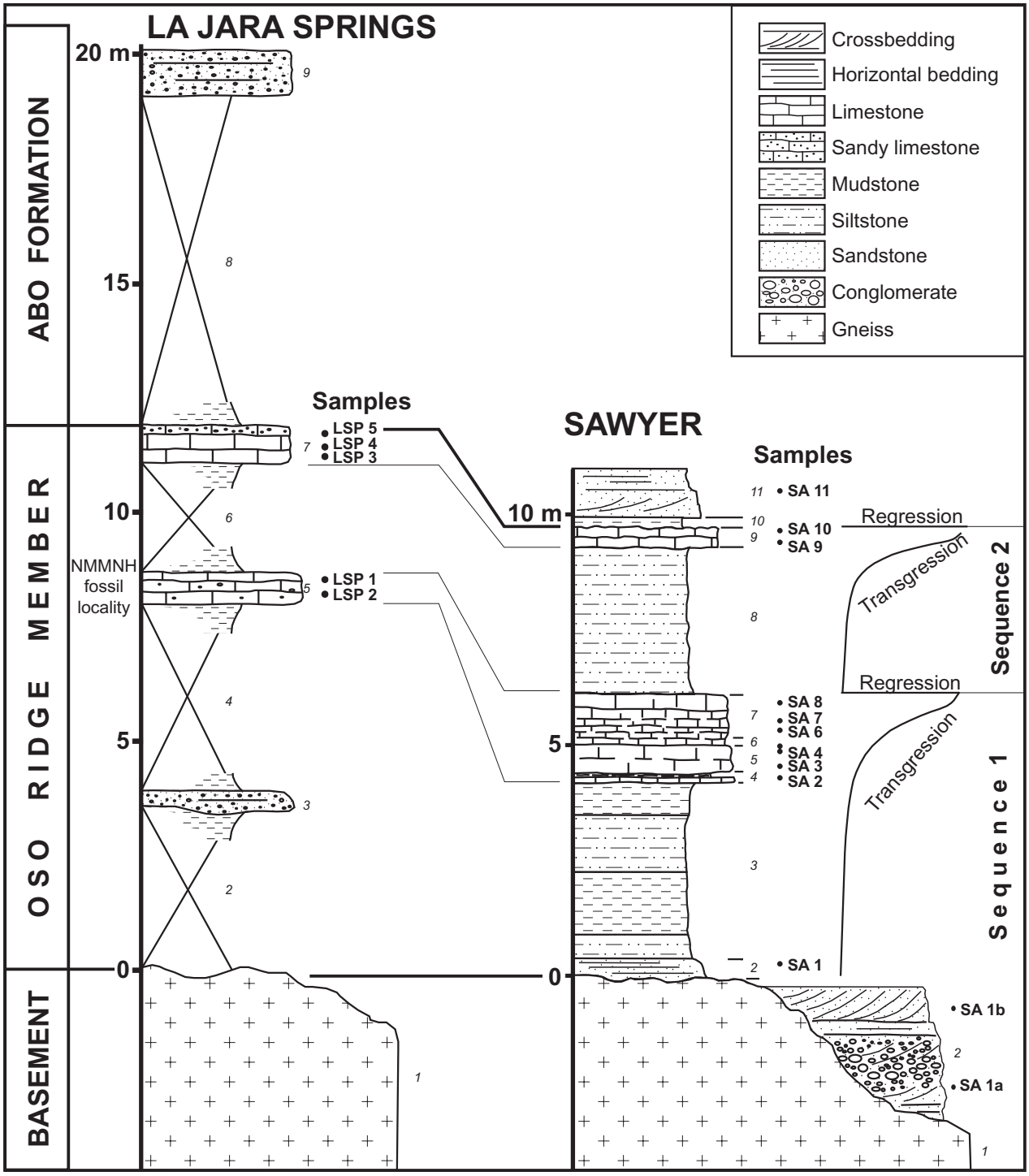


FIGURE 3. Measured sections of the Oso Ridge Member at Sawyer and La Jara Springs, Zuni Mountains. The location of the sections is shown on Figure 1, and the numbered lithologic units are described in the Appendix.

Sawyer

Depositional Sequence 1

The base of depositional sequence 1 is composed of quartz-rich conglomerates and coarse-grained, crossbedded sandstones of fluvial origin showing transport direction towards the SE (unit 2). Conglomerates and sandstones are poorly sorted, clast supported and carbonate-cemented. Sandstones are composed of mono- and polycrystalline quartz, granitic rock fragments, volcanic rock fragments, volcanic chert and volcanic quartz derived from acid volcanic rocks, and detrital feldspars (Figs. 4A, B, D).

These coarse clastics are overlain by 4 m of fine-grained red beds (fine-grained sandstones, siltstones and shales; poorly exposed, unit 3). The top of the sequence is formed by a 1.7-m

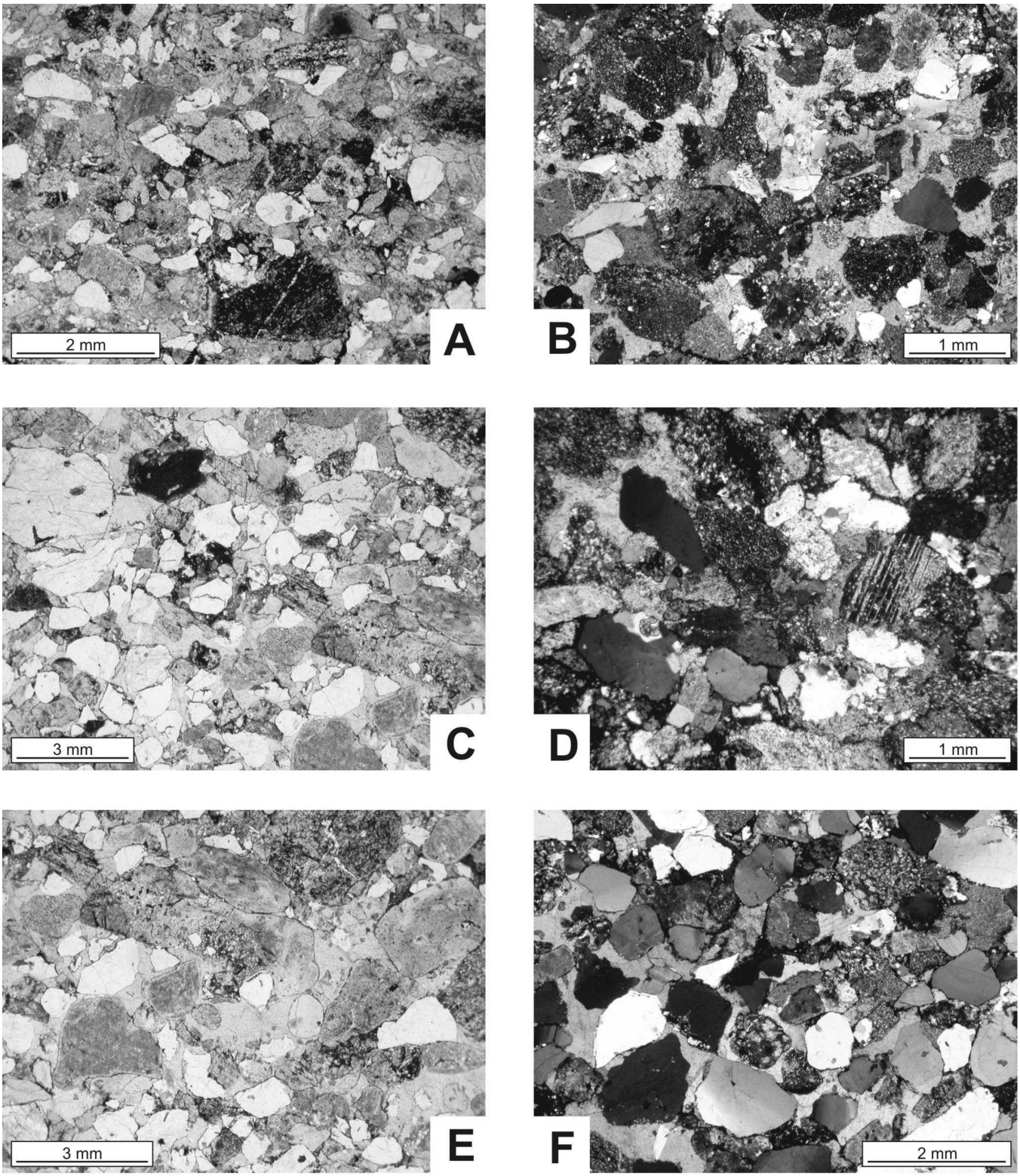


FIGURE 4. Thin section photographs of sandstones of the Oso Ridge Member of the Bursum Formation and of the Abo Formation at Sawyer, Zuni Mountains. A. Coarse-grained, poorly sorted, carbonate-cemented sandstone containing detrital quartz, feldspars, granitic and volcanic rock fragments. Plain light, sample SA 1 (unit 1). B. Coarse-grained sandstone, carbonate cemented, containing detrital quartz, feldspar, granitic and volcanic rock fragments. Crossed nicols, sample SA 1 (unit1). C and E. Coarse-grained, poorly sorted, pebbly sandstone, composed of angular to subrounded detrital quartz grains, volcanic rock fragments and many detrital feldspars. Plane light, sample SA 11 (unit 11). D. Arkosic sandstone composed of angular-subangular detrital quartz and feldspars and many fine-crystalline volcanic rock fragments. Crossed nicols, sample SA 1a, unit 1. F. Coarse-grained, carbonate-cemented sandstone containing subangular quartz, some detrital feldspars and fine-crystalline volcanic rock fragments. Crossed nicols, sample SA 11 (unit 11).

thick carbonate horizon containing abundant siliciclastic material, which is divided into 4 units (4-7)

The base of unit 4 is a 10-cm thick, reddish, poorly sorted calcarenaceous sandstone bed with wavy bedding, composed of abundant angular quartz grains and bioclasts (mostly recrystallized shell debris with thin micritic envelopes, subordinate gastropods, ostracods, echinoderms, a few bryozoans, smaller foraminifers and calcareous algae) embedded in micritic matrix (Fig. 5A).

Unit 5 is a 60-cm thick, indistinctly wavy-nodular bedded, reddish, fossiliferous limestone mixed with siliciclastic material (calcarenaceous siltstone/sandstone—a mixture of detrital quartz and feldspar grains and sand-sized bioclasts embedded in micritic matrix) (Fig. 5B).

Unit 6 is 15 cm thick and consists of poorly sorted grainstone/rudstone composed of bioclasts, mostly shell debris (bivalves, brachiopods, gastropods), a few echinoderms, ostracods, recrystallized phylloid algae (?*Eugonophyllum*), abundant small, well rounded carbonate grains with ooid-like structures, abundant small angular quartz grains with carbonate coatings, and a few strongly altered detrital feldspars (Fig. 5C). The groundmass is calcite cement. Intercalated are thin stromatolithic algal mats with thin peloidal packstone/grainstone layers. Algal mats (Fig. 5D) and peloidal packstone/grainstone are characterized by birdseye-structures filled with sparry calcite.

Unit 7 is a 90-cm thick, bedded, gray, siliciclastic limestone of different microfacies:

a) Poorly sorted bioclastic-siliciclastic grainstone/rudstone (calcarenaceous sandstone) composed of recrystallized bioclasts, mostly shell debris of bivalves, brachiopods, gastropods, phylloid algae (?*Eugonophyllum*), a few ostracods and echinoderms, small carbonate lithoclasts frequently displaying ooid-like structures, abundant small angular quartz grains with carbonate coatings (ooids) and a few altered detrital feldspars. Groundmass is calcite cement, and locally some micrite is present.

b) Inhomogenous micritic gray limestone with dark gray patches (micritic algae?) and abundant small and a few larger siliciclastic grains, mostly angular quartz and subordinate detrital feldspars, which are strongly altered or completely replaced by calcite (Fig. 5E). Bioclasts (mostly ostracods, some gastropod shells) are rare. Shrinkage fissures may indicate subaerial exposure.

c) Bioclastic-siliciclastic wackestone grading into bioclastic-siliciclastic grainstone, composed of abundant recrystallized shell fragments, gastropods and some phylloid algae (*Eugonophyllum*), ostracods and echinoderms (Fig. 5F). Most bioclasts show thin micritic envelopes. The rock also contains a few micritic carbonate clasts, abundant angular quartz grains, detrital feldspars and some rock fragments composed of quartz and feldspar. In the wackestone, the groundmass is recrystallized micrite. In the grainstone, two generations of cement are recognized: bladed prismatic calcite cement and blocky calcite cement.

Depositional Sequence 2

Depositional sequence 2 is composed of fine-grained red beds (sandstones, siltstones, shales, shaly sandstones), which are poorly exposed in a small arroyo south of the roadcut, capped by a 30-cm thick gray limestone containing siliciclastic grains. The limestone is composed of inhomogenous micrite with small, dark gray patches (Fig. 6A). Embedded are abundant angular quartz grains and some detrital feldspars. A few ostracods and gastropods are present. The uppermost part of the limestone consists of inhomogenous micrite with flaser structure. Embedded are a few bioclasts (ostracods and shell debris derived from gastropods, bivalves) (Fig. 6B), micritic lithoclasts containing bioclasts and quartz grains, some detrital feldspars and a few large granitic rock fragments composed of quartz and feldspar.

La Jara Springs

At La Jara Springs, the Oso Ridge Member is poorly exposed at a small hill immediately NE of the road. The sequence is composed of approximately 15 m of red beds, overlain by 1.1 m of reddish, fossiliferous limestone which forms the top of the hill. This sequence corresponds to depositional sequence 1 at Sawyer.

North of the hill there is a complete but mostly covered section of the Oso Ridge Member. As at Sawyer, the Oso Ridge Member is composed of two depositional sequences. The total thickness of the member is 12 m.

Depositional Sequence 1

The Precambrian basement (unit 1) is overlain by 8 m of fine-grained clastics (red mudstone and siltstone: units 2-4), which are mostly covered. In the middle of this interval, a 30 – 50 cm thick, fine-grained conglomerate is intercalated (unit 3). The conglomerate has an erosive base, displays crude horizontal stratification, is poorly sorted and contains subangular clasts with grain sizes up to 5 cm. Laterally, grain size decreases to a sandy lithofacies.

The clastic sequence is overlain by a 0.7-m thick gray, fossiliferous limestone with indistinctly developed wavy to nodular bedding. The limestone contains brachiopods and bryozoans, and rare quartz grains with diameters up to 3 cm. The limestone consists of two types of packstone. One type of packstone is composed of lithoclasts (reworked limestone) and bioclasts (recrystallized shell fragments) embedded in reddish-gray micrite (Fig. 6D). Irregular voids are filled with sparry calcite cement. Lithoclasts are reworked limestones, mostly micritic and containing small fossil fragments, locally peloids. Bioclasts are dominated by recrystallized shell fragments, and subordinate are echinoderms, ostracods, gastropods and other fossil fragments.

The second packstone type is a peloidal packstone composed of abundant densely packed micritic peloids (Fig. 6E). Some angular detrital quartz grains are present. Fossil fragments are represented by echinoderms, recrystallized mollusc shell fragments, abundant ostracods, and rare smaller foraminifers (*Syzrania*). Many bioclasts display micritic envelopes. Small irregular voids are filled with sparry calcite. Intercalated is a thin layer of an algal crust (stromatolite).

Depositional Sequence 2

The limestone forming the top of depositional sequence 1 is overlain by a 2.4-m thick covered interval (reddish fine-grained clastics: unit 6), followed by a 0.8-m thick limestone ledge (unit

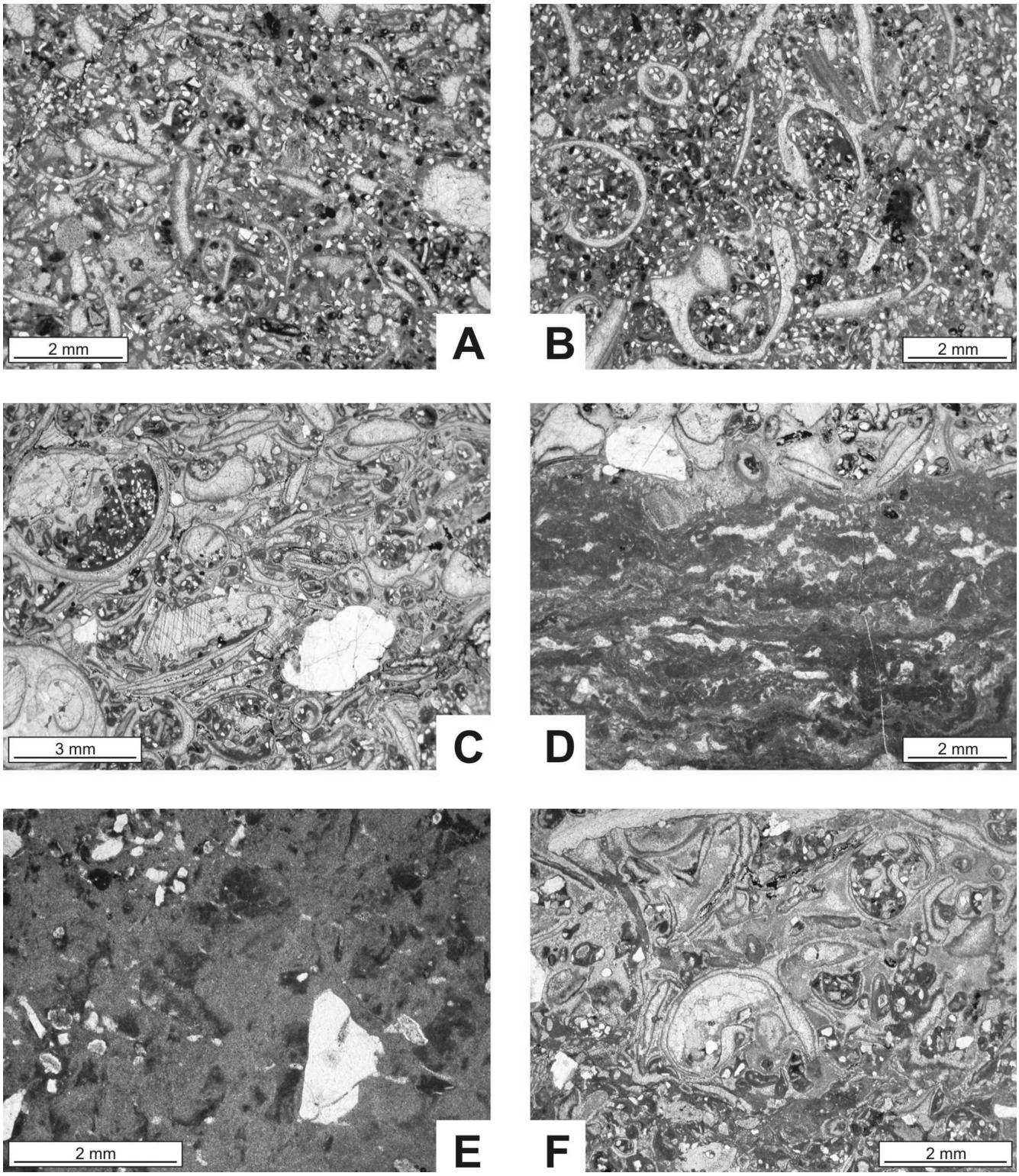


FIGURE 5. Thin section photographs of microfacies types of limestones of the Oso Ridge Member of the Bursum Formation (depositional sequence 1) at Sawyer, Zuni Mountains. A. Calcarenaceous sandstone containing abundant angular quartz grains and recrystallized bioclasts (mostly shell debris, subordinate gastropods, ostracods, echinoderms, a few bryozoans, smaller foraminifers and calcareous algae). Sample SA 2, unit 4. B. Calcarenaceous siltstone/sandstone composed of angular detrital quartz, feldspar and bioclasts (recrystallized fragments of bivalves, brachiopods, gastropods, rare echinoderms and ostracods) in micritic matrix. Sample SA 4, unit 5. C. Bioclastic/siliciclastic grainstone/rudstone, poorly sorted, with abundant recrystallized fossil fragments (bivalves, gastropods, rare echinoderm fragments, some ostracods) and angular quartz grains, cemented by calcite. Sample SA 5, unit 6. D. Thin algal mat overlain by grainstone. Sample SA 5, unit 6. E. Inhomogenous micritic limestone with small dark gray patches (?micritic algae) and angular quartz grains. A few ostracod shells are present. Sample SA 7, unit 7. F. Bioclastic-siliciclastic wackestone (lower part of photograph), grading into bioclastic-siliciclastic grainstone (upper part). Sample SA 8, unit 7.

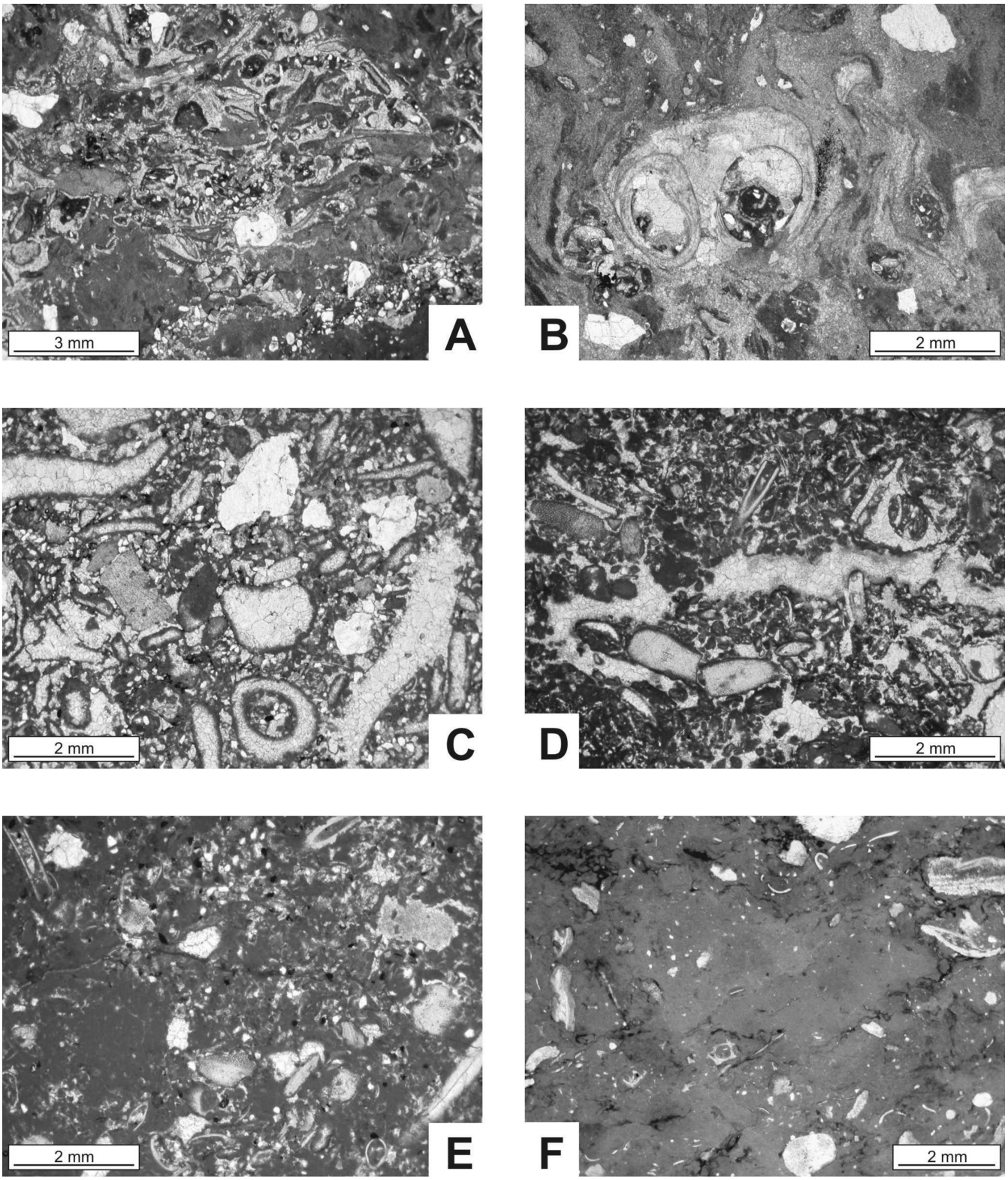


FIGURE 6. Thin section photographs of limestones of the Oso Ridge Member of Bursum Formation at Sawyer (A, B) and La Jara Springs (C-F). A. Micritic limestone, inhomogenous, containing detrital quartz and feldspar grains, and small patches of bioclastic grainstone with recrystallized shell debris. Sample SA 9, unit 9. B. Inhomogenous micritic limestone with detrital quartz and feldspar, and a few ostracods and small gastropods. Sample SA 10, unit 9. C. Calcarenaceous sandstone, poorly sorted, composed of angular siliciclastic grains and recrystallized bioclasts, cemented by calcite. Sample LSP 1, unit 4. D. Packstone composed of micritic lithoclasts (including peloids) and mostly recrystallized fossil fragments (bivalves, echinoderms, gastropods, ostracods), cemented by sparry calcite. Sample LSP 1, unit 4. E. peloidal packstone, bioturbated, containing echinoderms, recrystallized shell debris, ostracods and angular siliciclastic grains. Sample LSP 2, unit 4. F. Bioclastic wackestone, bioturbated, containing small angular siliciclastic grains, echinoderms, ostracods, bryozoans and brachiopod fragments. Sample LSP 3, unit 7.

7). The limestone is reddish-gray, indistinctly wavy to nodular bedded and sandy in the upper part, containing abundant small quartz grains with diameters up to 5 mm.

The microfacies of the limestone is bioclastic wackestone and bioclastic mudstone. Bioclastic wackestone is composed of inhomogenous, bioturbated micrite, locally peloidal, containing abundant small, angular to subangular siliciclastic grains up to 3 mm in diameter, and mostly polycrystalline quartz (Fig. 6F).

Bioclasts are large crinoid fragments, and some of them are encrusted by bryozoans. Less abundant are diverse shell fragments, ostracods, bryozoans, punctate brachiopod shells and rarely smaller foraminifers. Locally, the fossil fragments are bound together by cyanobacteria forming a boundstone. At places, bryozoans are the most abundant fossil fragments.

Bioclastic mudstone is composed of dark gray, bioturbated micritic matrix, locally containing abundant detrital angular silty quartz and feldspar grains. Subordinately small bioclasts, including bryozoans, echinoderms and ostracods occur.

Oso Ridge

The Oso Ridge outcrop (Fig. 1) is actually east of where Smith (1958) mapped it (it is at UTM zone 12, 731558E, 3908311N). Here, a low bench is capped by a sandy gray limestone. This limestones is a recrystallized, bioturbated, inhomogenous reddish-gray mudstone lacking fossils.

McQue Flats

At McQue Flats (Fig. 1; UTM zone 12, 729840E, 3912817E), a low limestone bench overlies about 3 m of poorly exposed red beds. The limestone consists of recrystallized reddish, inhomogenous mudstone lacking fossils, and of reddish-gray, inhomogenous, locally bioturbated peloidal packstone containing a few fossil fragments (ostracods, recrystallized shell fragments).

Log House

Armstrong et al. (1994) mislocated the Log House outcrop (Fig. 1), which was correctly located by Smith (1958). The outcrop (at UTM zone 12, 732321E, 3909851N) is a low swale of limestone that appears to rest directly on Proterozoic gneiss. The limestone from this locality is strongly recrystallized, reddish-gray mudstone, locally with thin breccia layers of dark reddish, angular sedimentary rock fragments. Fossils have not been recognized.

Red Beds of the Abo Formation

The Oso Ridge Member is overlain by red beds of the Abo Formation (red shales, siltstones, sandstones and fine-grained conglomerates). Conglomerates are moderately to poorly sorted, clast-supported, and most grains are angular to subangular. They are composed of monocrystalline quartz, frequently displaying authigenic overgrowths, some volcanic quartz grains with corrosional features, polycrystalline quartz and granitic rock fragments composed of quartz and feldspar, and abundant detrital feldspars, mostly untwinned and altered. The sandstone contains high amounts of grains derived from silicic volcanic rocks: fine-crystalline quartz – "volcanic chert" (recrystallized volcanic glass), volcanic rock fragments composed of recrystallized volcanic glass and large phenocrysts of volcanic quartz and feldspar. It is cemented by very coarse calcite (Figs. 4C, E, F).

PALEONTOLOGY

Armstrong et al. (1994) reported, but did not describe or illustrate, several brachiopod, bivalve, and scaphopod taxa, together with unidentified bellerophontoid and other gastropods, nautiloids, crinoids and echinoid spines, from the Oso Ridge Member at the La Jara Springs and Sawyer localities. They also illustrated the conodont taxa "*Ellisonia" conflexa* (Ellison), *Adetognathus lautus* (Gunnell) and *Streptognathodus elongatus* Gunnell from the La Jara Spring and Sawyer outcrops. We recovered the same conodont taxa from beds 5 and 7 at La Jara Springs, and they were examined by J. Barrick of Texas Tech University (written commun, 2002), who concurred with Armstrong et al. (1994) that these conodont taxa indicate a late Virgilian to earliest Wolfcampian age.

We collected a moderately diverse assemblage of macroinvertebrate fossils from the La Jara Springs locality at NMMNH Locality 4364 (UTM zone 12, 768893E, 3887585M, NAD 27). These fossils were eroding from a thin limestone (Fig. 3, bed 5) and were scattered sparingly across the surface of low hills near the road. Weathering and fragmentation of most specimens was severe, precluding identification to the species level in many cases.

Brachiopods dominate this assemblage, both in diversity and abundance. Approximately 75% of the brachiopod specimens, and nearly half of all specimens collected, are the brachiopod *Composita subtilita* (Hall) (Fig. 7A-C), a highly variable species (Grinnell and Andrews, 1964) that ranges from the Pennsylvanian well into the Wolfcampian in the Midcontinent region (e.g., Dunbar and Condra, 1932; Mudge and Yochelson, 1962) and is abundant in Virgilian strata in New Mexico. All sizes are present, up to large specimens as much as 35 mm long. Valve width and length are subequal, and the anterior fold and sulcus are well developed on the larger specimens. *Derbyia* is represented by small fragments. Several large (up to 55 mm wide) but incomplete and severely weathered specimens of *Neospirifer* (Fig. 7H-I) were also collected; these specimens have abnormally prominent groups of fasciculated radial ribs on their lateral valve surfaces. The small spiriferid *Punctospirifer kentuckyensis* (Shumard) (Fig. 7J) is rare in this assemblage.

Among productoid brachiopods, *Parajuresania nebrascensis* (Owen) (Fig. 7G) is most abundant, and several specimens are nearly complete, albeit weathered, but display the radial spine ribs and two ranks of spines characteristic of the species. Fragments of a relatively small *Linoproductus*, here identified as *L. prattenianus* (Norwood and Pratten) (Fig. 7D-E) display the abundant small spine bases across the pedicle valve that distinguish the species. A small *Antiquatonia* (Fig. 7F) also occurs in the La Jara Springs assemblage.

Bivalve steinkerns are moderately common. The most conspicuous are large (up to 80 mm long) but incomplete specimens

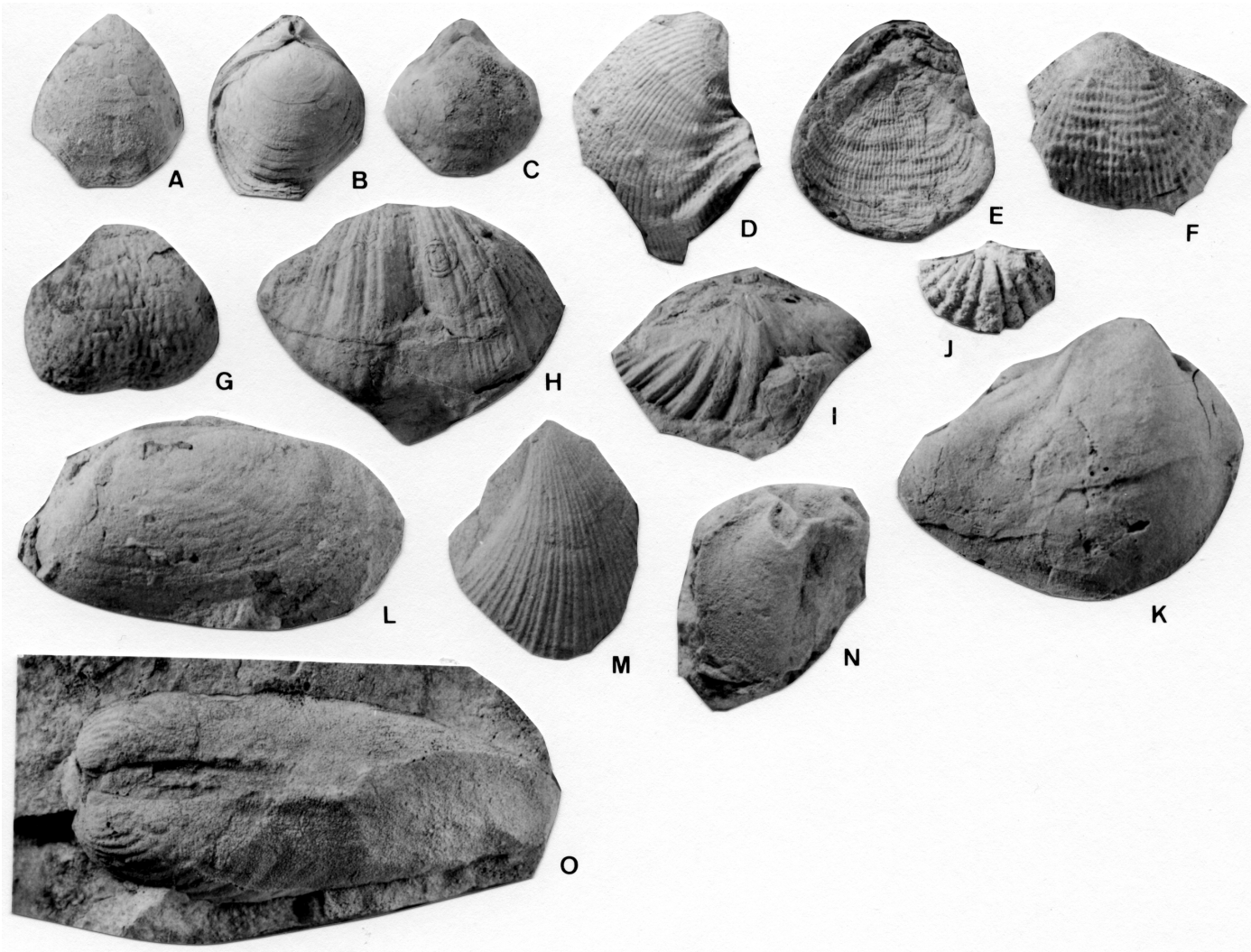


FIGURE 7. Brachiopods (A-J) and bivalves (K-O) from the Oso Ridge Member of the Bursum Formation at La Jara Springs, Zuni Mountains. A-C. *Composita subtilita* (Hall); A. pedicle valve, NMMNH 39,010, x1; B. brachial valve view, NMMNH 39,011, x1; C. brachial valve view of relatively wide specimen, NMMNH 39,012, x1. D, E. *Linoproductus prattenianus* (Norwood and Pratten); D. fragment of pedicle valve, NMMNH 39,013, x1.5; E. brachial valve view of specimen missing pedicle beak, NMMNH 39,014, x1. F. *Antiquatonia* sp., incomplete pedicle valve, NMMNH 39,015, x1.33. G. *Parajuresania nebracensis* (Owen), pedicle valve, NMMNH 39,016, x1.33. H, I. *Neospirifer* sp.; H. somewhat distorted and incomplete pedicle valve, NMMNH 39, 017, x1; I. brachial valve with strongly accentuated fasciculated radial costae, NMMNH 39,018, x1. J. *Punctospirifer kentuckyensis* (Shumard), brachial valve, NMMNH 39,019, x1.5. K, *Schizodus* sp., right valve view of steinkern with internal mold, NMMNH 39,020, x1. L. *Solemya trapezoides* Meek, right valve view of steinkern with external mold, NMMNH 39,021, x1. M. *Aviculopecten* sp., left valve steinkern with external mold, NMMNH 39,022, x1.4. N. *Septimyalina burmai* Newell, small, incomplete stienkern with internal mold of right valve, NMMNH 39,023, x2. O. *Wilkingia terminale* (Hall), dorsal view of steinkern of articulated valves in matrix, NMMNH 39,024, x1.

of *Wilkingia terminale* (Hall) (Fig. 7O), characterized by its elongate shape, inflated, nearly terminal beaks, and ornamentation of coarse, comarginal wrinkles. Steinkerns of *Schizodus* are also moderately common, including one speicmen (Fig. 7K) that is unusually large (length = 51 mm) and has an unusually extended posterior margin compared with most New Mexico Virgilian representatives of the genus. One large (length = 58 mm) steinkern with laterally compressed valves and subterminal beaks appears to be *Solemya trapezoides* Meek (Fig. 7L), a species known from the Virgilian of the Manzanita Mountains of central New Mexico (Kues, 1992). Pectinid bivalves, represented by incomplete molds of *Aviculopecten* (Fig. 7M), are moderately common but cannot be more precisely identified in the absence of preserved shell material. One coarsely recrystallized specimen with the distinctive extended and slightly curved posterior margin of *Polidevcia* was also recovered from the La Jara Springs locality. Small shell fragments indicate the presence of the myalinid bivalve *Septimyalina burmai* Newell (Fig. 7N), reported as *Myalina apachesi* Marcou by Armstrong et al. (1994).

Gastropods are limited to moderately common bellerophontoid steinkerns and steinkerns of a few small, unidentifiable low-spired forms. Crinoid stem segments, generally consisting of a few articulated columnals, and several types of bryozoans, including encrusting fistuliporoids and stick-like rhomboporoid

fragments, are also important elements of this assemblage. One small, coiled nautiloid about 45 mm in maximum diameter is too severely weathered for even generic identification, and several fish teeth and spines complete the roster of macrofossils observed in the Oso Ridge Member at the La Jara Springs locality.

Samples collected from the main limestone sequence at the Sawyer locality (units 5-7, Fig. 3) locally contain thin horizons of dense bioclastic debris, together with grains of quartz, but severe weathering, fragmentation, and the absence of specimens eroded from the limestone made faunal identification impossible in most cases. Among the dominantly brachiopod and gastropod shell debris, two taxa were observed that were not found at the La Jara Springs locality, the gastropod *Naticopsis* and a fragment of an orthoconic nautiloid.

Macrofossils from the Oso Ridge Member indicate an offshore marine environment of normal marine salinity, supporting the interpretation from petrographic study of the limestones. The marine invertebrate taxa, insofar as they could be identified to species, are typical of Virgilian strata elsewhere in New Mexico and in the Midcontinent. Two of the brachiopods (*Composita subtilita* and *Parajuresania nebrascensis*) and the bivalves *Wilkingia terminale* and *Septimyalina burmai*, also range into the Wolfcampian of the Midcontinent (Mudge and Yochelson, 1962), based on the recently raised Virgilian-Wolfcampian boundary of Sanderson et al. (2001).

INTERPRETATION

Locally in the Zuni Mountains, the Precambrian basement is nonconformably overlain by red-colored, immature conglomerates and sandstones of fluvial origin filling a paleorelief. The material is derived locally from granitic-gneissic rocks and from silicic volcanic rocks. Crossbedded sandstones indicate transport direction towards the southeast.

The overlying fine-grained red beds probably represent sheetflood deposits. Transgression of the sea caused deposition of fossiliferous limestone mixed with abundant siliciclastic material. Biota and microfacies indicate that the limestones of sequence 1 formed in a shallow marine environment of normal salinity with strong local clastic influx. Intercalated algal mats point to a short period of a restricted, very shallow environment. At Sawyer the limestone is thicker and contains high-energy sediments (grainstones), which are absent at La Jara Springs. Limestones at Sawyer also show a higher taxonomic diversity (e.g., phylloid algae, trilobite fragments) compared to La Jara Springs. At both localities the limestones contain conodonts (mostly broken fragments).

A regressive event caused deposition of fine-grained red beds, which sharply overlie the limestone horizon. The limestone horizon on top of depositional sequence 2 represents a short transgressive event and was deposited in a restricted shallow marine environment with clastic influx at Sawyer and in a shallow, open marine environment at La Jara Springs, where the limestone is thicker and contains a higher diversity fauna, including well preserved conodonts.

A second regression caused deposition of immature red beds of the Abo Formation.

We interpret the sediments of the Oso Ridge Member to represent a northwestern proximal facies of the Bursum Formation. Both the Oso Ridge and Red Tanks members of the Bursum appear to be late Virgilian in age, so at this level of temporal resolution they are correlative. Nevertheless, a detailed correlation of the Oso Ridge Member to the closest exposed section of the Red Tanks Member, in the Lucero uplift at Carrizo Arroyo, about 100 km southeast of La Jara Springs, is difficult because deposition was strongly influenced by tectonic processes. The two limestone horizons of the Oso Ridge Member may correlate to the open marine limestones in the middle part (depositional sequences 2 and 3: Lucas and Krainer, 2002) of the Red Tanks Member (Bursum Formation) at Carrizo Arroyo, as in the upper part of the Red Tanks Member only thin limestones containing a restricted, low diversity marine fauna are present. Correlation with the Bursum Formation of the southern Lucero uplift (Red Tanks Arroyo, Coyote Draw) is even more difficult as there open marine limestones occur throughout the sequence.

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APPENDIX-MEASURED SECTIONS

Sawyer

Type section of the Oso Ridge Member of the Bursum Formation. At a roadcut at UTM zone 12, 749885E, 3895847N. Strata dip 17° to S30°W.

Abo Formation:

11. Sandstone; moderate reddish brown (10 R 4/6) and very dusky red (10 R 4/2); fine to very coarse grained; trough crossbedded; calcareous **0.5**
10. Muddy sandstone; pale redish brown (10 R 5/4); fine grained; calcareous **0.2**

Bursum Formation:

Oso Ridge Member:

9. Limestone; medium light gray (N6) to light brownish gray (5 YR 6/1); nodular **0.3**
8. Muddy siltstone; pale reddish brown (10 R 5/4); contains lenses of coarse, pebbly sandstone. **3.2**
7. Limestone; grayish red (5 R 4/2) with some speckles of medium light gray (N6) silicified shell fragments. **0.9**
6. Limestone; light gray (N7) and medium light gray (N6); algal boundstone. **0.7**
5. Limestone; pale red (10 R 6/2) with speckles of medium light gray (N6); massive; much siliciclastic debris; shell fragments. **0.6**
4. Limestone; pale red (10 R 6/2) with speckles of medium light gray (N6); nodular; brachiopods; cuesta. **0.1**
3. Muddy and sandy siltstone; pale reddish brown (10 R 5/4); contains lenses of coarse, pebbly sandstone. **4.0**
2. Sandstone; pale red (10 R 5/4); coarse to very coarse grained; rip-ups; note that ~100 m to the west this unit is a 2.5-m thick, pale red (5 R 6/2 and 10 R 6/2), trough crossbedded (trough axes dip to S60°E) sandstone and conglomerate of angular quartzite clasts. **0.1**

nonconformity

Proterozoic:

1. Gneiss and quartzite.

La Jara Spring

Base of section at UTM zone 12, 768919E, 3887654N, top at UTM zone 12, 768772E, 3887858N. Strata are flat lying.

Abo Formation:

9. Sandstone; grayish red (5 R 4/2); coarse grained; arkosic; not calcareous. **1.0**
8. Mudstone; pale reddish brown (10 R 5/4); calcareous; mostly a covered slope. **7.2**

Bursum Formation:

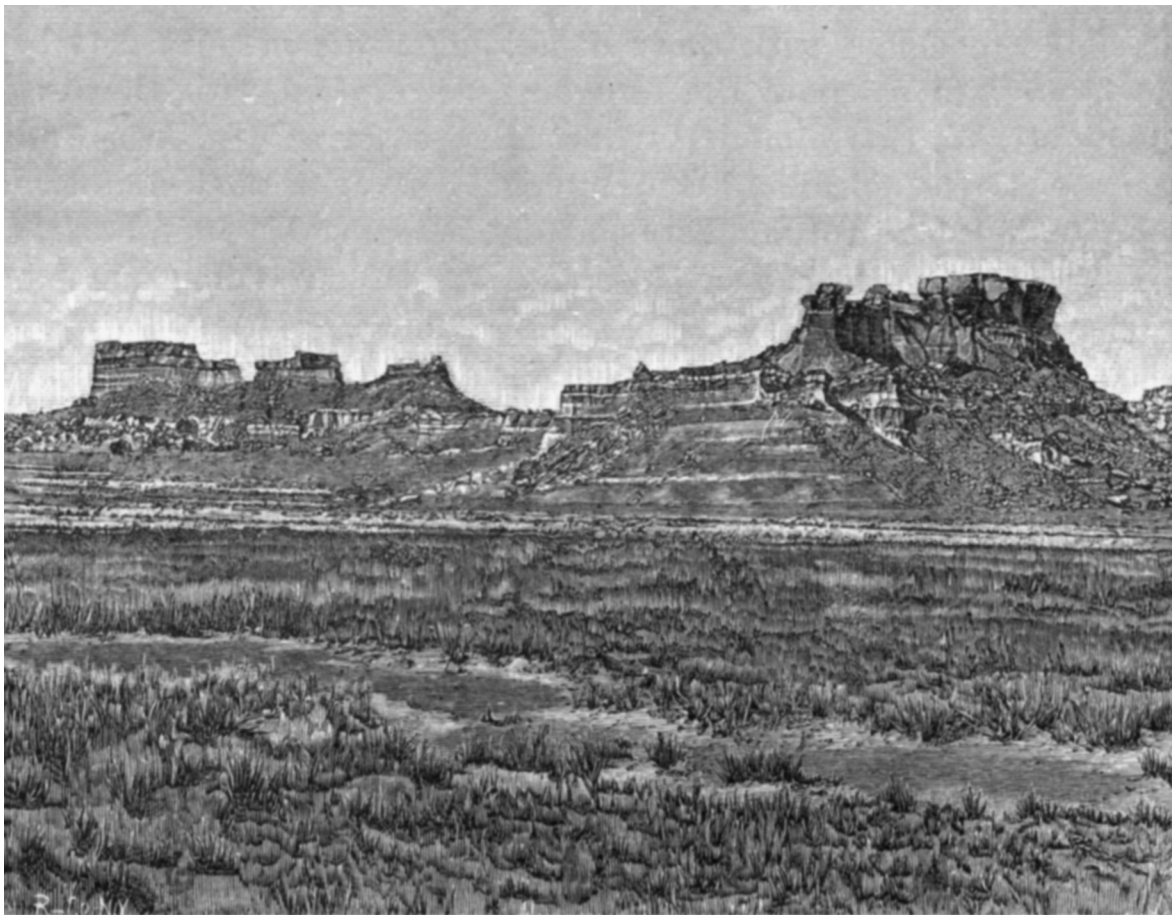
Oso Ridge Member:

7. Limestone; light brownish gray (5 YR 6/1); wackestone ledge. **0.8**
6. Covered slope. **2.4**
5. Limestone; medium light gray (N6); sandy; ledge; wackestone; NMMNH locality 4364. **0.7**
4. Sandy mudstone; pale reddish brown (10 R 5/4); calcareous; mostly a covered slope. **4.1**
3. Conglomeratic sandstone; pale reddish brown (10 R 5/4) and pale red (10 R 6/2); trough crossbedded; quartzite clasts. **0.3**
2. Sandy mudstone; pale reddish brown (10 R 5/4); calcareous; mostly a covered slope. **3.6**

nonconformity

Proterozoic:

1. Gneiss.



Dutton's (1885, fig. 4) woodcut photograph of Cretaceous strata, described as "buttes and mesa of the Middle Cretaceous." We are not certain of the exact location of this outcrop but believe it to be Crevasse Canyon or Menefee strata just north of Gallup in T15N, R18W.