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Upper Devonian–Lower Mississippian conodont biostratigraphy and depositional patterns, southwestern New Mexico and southeastern Arizona

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Introduction

Upper Devonian and Lower Mississippian strata in southwestern New Mexico comprise more than 200 m of fine terrigenous clastics and marine carbonates. Although excellent exposures exist in many of the mountain ranges of New Mexico and adjacent Arizona, the discontinuous outcrop pattern of Paleozoic rocks, a product of Mesozoic and Cenozoic tectonics, has hindered accurate reconstruction of original depositional patterns. This region has special paleogeographic significance, for here two different Lower Mississippian carbonate shelves apparently merge at the corner of a southeastward-opening basin. Strata of the Mississippian Lake Valley Shelf (Lane and De Keyser, 1980) represent an east–west-trending shelf and shelf margin that is best developed in the Sacramento and San Andres Mountain ranges of central New Mexico (Lane, 1982; De Keyser, 1983; De Keyser et al., 1985) and has been interpreted to extend as far west as the Silver City area of New Mexico (Fig. 1, BM). In southeastern Arizona a different combination of depositional factors produced a thick Mississippian carbonate package that has been called the Escabrosa Shelf (Gutschick and Sandberg, 1983). The Escabrosa Shelf has been traced as far east as the Klondike Hills, New Mexico (Armstrong, 1970), south of the supposed western extent of the Lake Valley Shelf.

Because of apparent differences in the lithologic succession between the Lake Valley Shelf and the Escabrosa Shelf, direct correlation of depositional sequences between the two regions has been difficult. Biostratigraphic information derived from shelly fossils (Armstrong, 1962, 1970) and foraminifera (Armstrong and Mamet, 1978b) has indicated possible correlations from the Lake Valley Shelf to the Escabrosa Shelf, but this evidence is weakest in the basal part of the Mississippian sequence.

Recent work on depositional patterns and conodont faunas in Upper Devonian and Lower Mississippian strata in southwestern New Mexico provides a clearer picture of the timing of depositional events in the region and reconstruction of paleogeographic features. The focus of this work is a new interpretation of the depositional sequence in the Upper Devonian Percha Formation and Lower Mississippian Escabrosa Group at the Mescal Canyon section in the Big Hatchet Mountains. Conodont faunas obtained from the Mescal Canyon section permit new correlations from the Escabrosa Shelf to the Lake Valley Shelf.

Mescal Canyon section, Big Hatchet Mountains

Previous studies

One of the best exposed and most thoroughly studied sections of the Escabrosa Group occurs in Mescal Canyon, located in the northwestern part of the Big Hatchet Mountains (Fig. 1, MC). However, each of several workers has interpreted the lithologic succession of Upper Devonian and Lower Mississippian strata in different ways.

In a regional study of Mississippian strata of southeastern Arizona and southwestern New Mexico, Armstrong (1962) presented information on the stratigraphic distribution

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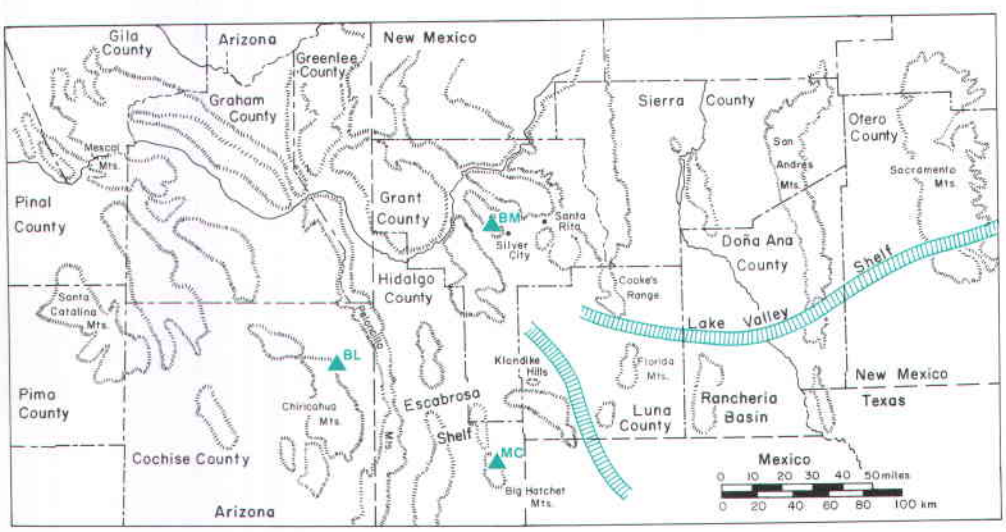

FIGURE 1—Geographic localities in southwestern New Mexico and adjacent Arizona discussed in text. Solid triangles indicate the locations of sections described in detail. **BL**, Blue Mountain; **BM**, Bear Mountain; **MC**, Mescal Canyon. The approximate positions of the margins of the Lake Valley Shelf and Escabrosa Shelf relative to the Rancheria Basin are indicated in blue.

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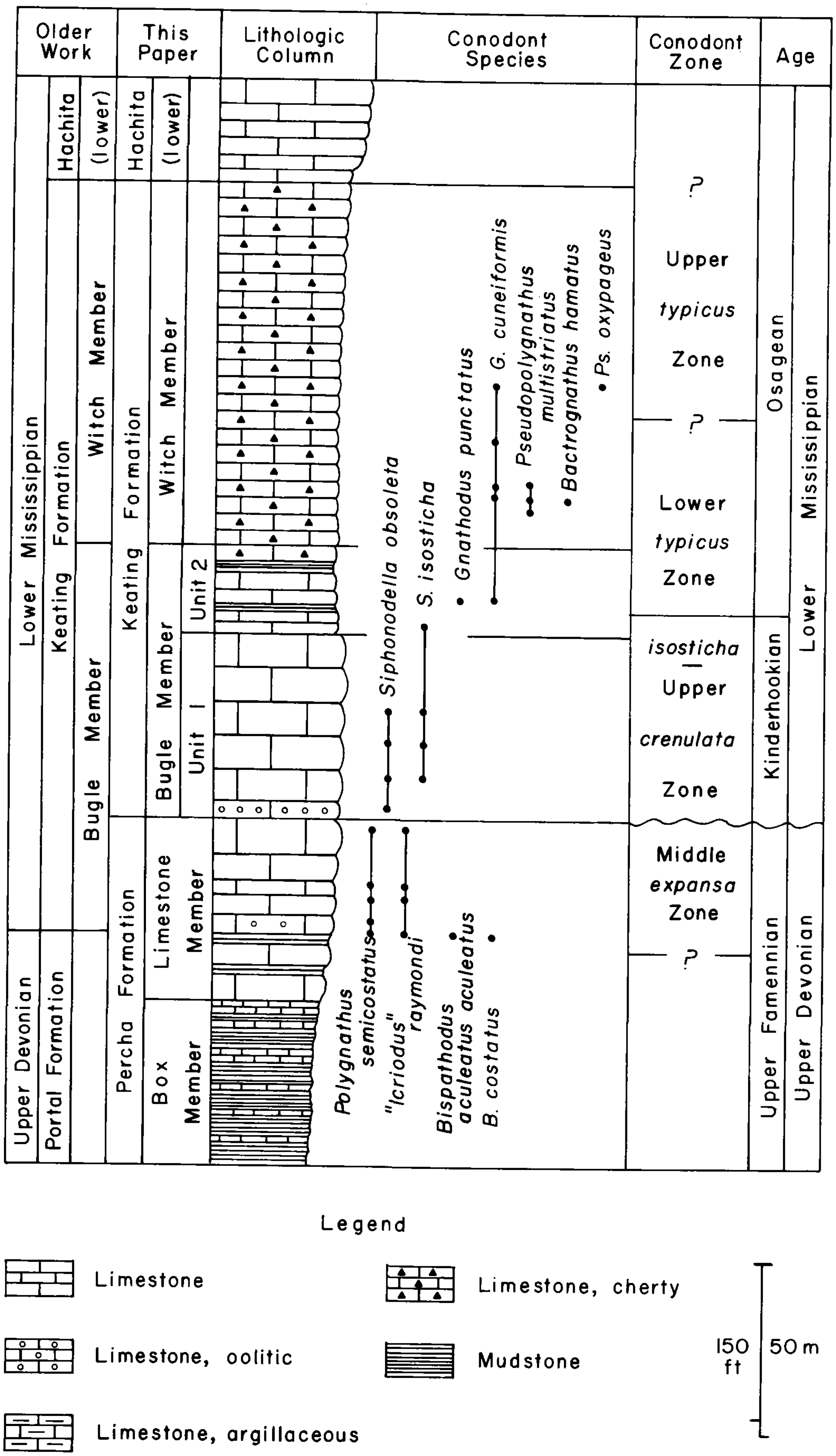

FIGURE 2—Stratigraphic column of Upper Devonian and Lower Mississippian strata at the Mescal Canyon section (NE1/4 SE1/4 sec. 29, T30S, R15W) in the Big Hatchet Mountains, New Mexico. "Older work" refers primarily to papers by Armstrong and Mamet (1978a, 1978b) and Armstrong et al. (1980). Ranges of important conodont species are shown as are ages inferred from conodont distribution.

of macrofossil taxa in the Escabrosa Group in Mescal Canyon. In that publication, Armstrong proposed that the Escabrosa Limestone of Girty (1904) be elevated to group status and divided into two formations. The lower formation, the Keating Formation, comprises a sequence of encrinites and calcilutites that rests unconformably on Upper Devonian units. The overlying Hachita Formation is a massive encrinite unit. The type section for both formations is at Blue Mountain, in the Chiricahua Mountains of southeastern Arizona (Fig. 1, BL). Eastward from the Chiricahua Mountains, including the Big Hatchet Mountains, the Keating Formation was divided by Armstrong (1962) into two members. Member A consists of a basal unit of coarse encrinite, 15 m thick at most sections, that is overlain by dark-gray limestones with minor amounts of nodular chert. Member B comprises thinly bedded dark-gray limestone characterized by significant quantities of chert occurring as lenticular and nodular masses.

At the Mescal Canyon section in the Big Hatchet Mountains, the base of Member A of the Keating Formation was depicted as resting unconformably on the argillaceous carbonates of the Upper Devonian Portal Formation (Armstrong, 1962, figs. 2 and 3, plate in pocket). No precise lithologic boundary was described or indicated, but the illustrated faunal distributions (figs. 2 and 3) show that Mississippian fossils appear abruptly in the section at a level approximately 175 m

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below the top of the Keating Formation, or near the prominent oolitic limestone shown in Figure 2. Armstrong (1962) reviewed earlier arguments regarding the age of the Escabrosa Group, most of which assigned at least the lower part to the Kinderhookian. Brachiopods and corals reported from Member A of the Keating Formation at Mescal Canyon by Armstrong (1962) included species that characterize both Kinderhookian and Osagean strata elsewhere. Member B of the Keating Formation contained typical Osagean forms.

Zeller (1965) provided the first detailed lithologic description of the Devonian–Mississippian succession at Mescal Canyon. Although he rejected the stratigraphic nomenclature of Armstrong (1962) on the basis of a lack of mappability, Zeller (1965) recognized three informal members of the Escabrosa Limestone. The upper member corresponds to the Hachita Formation of Armstrong and the middle member is the cherty Member B of the Keating Formation. The lower member of Zeller, however, extended nearly 50 m below the base of Member A of the Keating Formation as used by Armstrong (1962). Zeller could find no lithologic evidence for an unconformity between the Upper Devonian Percha Formation and the Mississippian Escabrosa Limestone. He placed the base of the Escabrosa at the point where carbonates began to dominate the section, just above a deeply weathered dike that cuts the section. Lacking any faunal evidence to the contrary, Zeller (1965) proposed that deposition may have been continuous from the Late Devonian into the Early Mississippian. Neither Armstrong (1962) nor Zeller (1965) reported any diagnostic faunal elements from the interval that lies between their respective bases of the Escabrosa Group.

Kocurek (1977), during a study of the sedimentology of the Percha Formation in southwestern New Mexico, also failed to detect any obvious break in deposition between the Devonian and Mississippian at the Mescal Canyon section. Kocurek arbitrarily chose the base of the oolitic limestone used by Armstrong (1962) to mark the base of the Escabrosa Group as the level at which to terminate his study, but Kocurek did not attribute any special sedimentological significance to this occurrence.

Armstrong and Mamet (1978a) formally named Armstrong's (1962) Member A and Member B of the Keating Formation, the Bugle and Witch members, respectively. The Mescal Canyon section was chosen to be the type section for both members. Armstrong and Mamet (1978a) described the Bugle Member as a massively bedded bryozoan–echinoderm to ooid packstone and wackestone, and argillaceous, crinoidal–bryozoan packstone that rests with sharp contact on the yellow-gray calcareous shale of the Box Member of the Percha Formation. The base of the Bugle Member (and Keating Formation) at the type section was placed 35 m below where Armstrong (1962) had originally placed the base

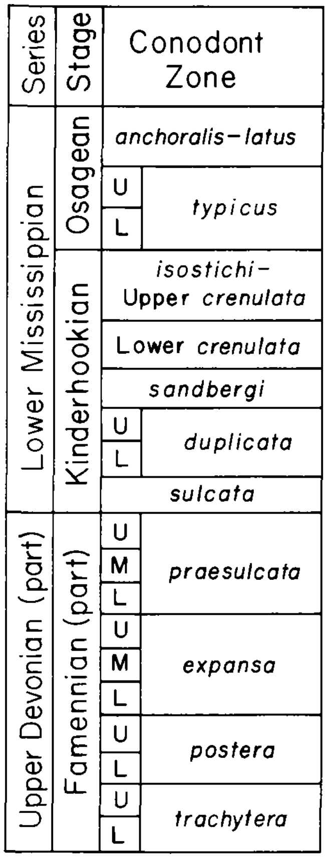

FIGURE 3—Composite conodont zonation for Upper Devonian through Lower Mississippian strata as used in this report. Upper Devonian zones are derived from Ziegler and Sandberg (1984), Kinderhookian zones from Sandberg et al. (1978), and Osagean zones from Lane et al. (1980).

of the Keating Formation and 15 m above the level where Zeller (1965) placed the base of the Escabrosa Limestone. Less than a meter below the Bugle–Box contact a brachiopod fauna had been obtained that was identified by Dutro (*in* Armstrong and Mamet, 1978a, p. 92), who indicated that it was probably middle Famennian (Late Devonian) and that it had been described by Stainbrook (1947) from the Box Member of the Percha at other localities. The Bugle Member was given a late–early to early–middle Tournaisian age (approximately the Kinderhookian–Osagean boundary) based on Armstrong's (1962) faunal collections (now 30 to 60 m above the base of the Bugle) and a microfossil assemblage (foraminifera) of pre-Zone 7 age found by Mamet 68 to 70 m above the base.

Conodont biostratigraphy

During the spring of 1983 the authors, with the assistance of Thomas De Keyser, Marathon Oil Company, and Sam Thompson, New Mexico Bureau of Mines and Mineral Resources, redescribed the Upper Devonian–Lower Mississippian succession at Mescal Canyon and sampled for conodonts. Originally, the stratigraphic boundary proposed by Armstrong and Mamet (1978a) was used, but the conodont faunas obtained indicate that a reinterpretation of the sequence is necessary (Fig. 2).

Based on conodont faunas, the break between the Devonian and Mississippian Systems at Mescal Canyon lies at the base of the distinctive oolitic limestone originally used by Armstrong (1962) to mark the base of the Escabrosa Group. Below this oolitic horizon are conodont faunas characterized by elements of *Polygnathus semicostatus* and *"Icriodus" raymondi*. Both species are characteristic of the Late Devonian (Famennian), but *"I." raymondi* has the shorter range (Uppermost *marginifera* Zone through the Middle *expansa* Zone of the standard conodont zonation, Sandberg and Dreesen, 1984, fig. 3; Fig. 3 herein). A sample from the base of the Escabrosa Group as used by Armstrong and Mamet (1978a; Fig. 2, herein) also contains *Bispathodus costatus* and *B. aculeatus*. The ranges of both species begin in the Middle *expansa* Zone and extend higher; *B. aculeatus* extends into the Mississippian and *B. costatus* into the Middle *praesulcata* Zone, near the end of the Devonian. The interval from the base of the Escabrosa Group of Armstrong and Mamet to the base of the oolitic limestone can be assigned to the Middle *expansa* Zone, indicating a late, but not latest Famennian age. We recommend that this interval be designated informally as an upper limestone member of the Percha Formation (Fig. 2). Samples from underlying beds have yielded less diagnostic Famennian conodonts.

Conodont faunas from the oolitic limestone and the overlying 55 m of coarse crinoidal packstones and grainstones of Unit 1 of the Bugle Member (Fig. 2) are characterized by elements of *Polygnathus communis*, *P. inornatus*, *P. longiposticus*, and *P. symmetricus*. Two species of *Siphonodella*, *S. obsoleta* and *S. isosticha*, occur in the lower two-thirds of this interval. The co-occurrence of these two species permits this interval to be assigned to the Early Mississippian, late Kinderhookian *isosticha*–Upper *crenulata* Zone (Sandberg et al., 1978; Fig. 3 herein). A substantial hiatus, encompassing the latest Devonian and most of the Kinderhookian exists at the base of the oolitic limestone.

Dark-gray argillaceous wackestones rest with sharp contact on the light-gray coarse crinoidal carbonates at Mescal Canyon (Unit 2 of the Bugle Member, Fig. 2). Although a sharp lithologic contact is present, no hiatus can be identified from the conodont faunas. Because a sample just above the contact yielded a small fauna containing *Siphonodella isosticha*, the base of the argillaceous wackestone belongs to the *isosticha*–Upper *crenulata* Zone. A few meters higher appears a conodont fauna dominated by *Polygnathus communis communis*, and bearing *P. c. carina*, *Gnathodus punctatus*, and an early morphotype of *G. cuneiformis* (morphotype 1 of Lane et al., 1980). This combination of species is characteristic of the Lower *typicus* Zone (Lane et al., 1980) and Faunal Unit 3 of Lane (1974, 1982), which are thought to be early Osagean in age (Fig. 3). ☞

The base of the Witch Member, as defined by Armstrong and Mamet (1978a), lies at the point where significant quantities of chert occur as lenticular and nodular masses. As so defined, the base of the Witch Member can be placed about 27 m above the base of the argillaceous wackestones of Unit 2 of the Bugle Member. The conodont fauna from the lower part of the Witch Member is similar to that of Unit 2 of the Bugle Member but has somewhat greater diversity and abundance. *Polygnathus communis* strongly dominates the collections, and *Pseudopolygnathus multistriatus* morphotype 1 and *Gnathodus* species are present. Although few short-ranging species were recovered (Fig. 2), the cherty carbonates assigned to the base of the Witch Member by Armstrong and Mamet (1978a) appear to lie within the Lower *typicus* Zone. Samples from higher in the Witch Member yielded small conodont faunas dominated by *P. communis,* which lack diagnostic forms. *Pseudopolygnathus oxypageus,* which appears at the base of the Upper *typicus* Zone, occurs in the middle of the Witch Member (Fig. 2).

No zonal diagnostic conodonts were obtained from the uppermost beds of the Witch Member or the lower beds of the overlying Hachita Formation. Armstrong and Mamet (1978a) reported a foraminiferal assemblage of Zone 7 (Osagean) from the upper 4 m of the Witch Member at Mescal Canyon. Armstrong and Mamet (1978a) did not find diagnostic fossils in the lower part of the Hachita Formation, but the uppermost 20 m of the Hachita Formation were interpreted to be late Meramecian in age on the basis of foraminifera and brachiopods.

Depositional history

Three Upper Devonian and Lower Mississippian depositional sequences can be identified at the Mescal Canyon section: 1) an Upper Devonian (Famennian) shoaling sequence; 2) a Lower Mississippian (upper Kinderhookian) sequence of coarse-grained skeletal grainstones that rest unconformably on the Upper Devonian carbonates; 3) an Osagean shoaling sequence that formed after a rapid submergence in the latest Kinderhookian.

Upper Devonian shoaling sequence—At Mescal Canyon, the Box Member of the Percha Formation comprises unfossiliferous terrigenous mudstones that contain occasional layers of carbonate nodules. Few skeletal remains are apparent in the nodules; articulated ostracodes and sponge spicules are the most common components. The frequency and thickness of carbonate intercalations increase toward the top of the Box Member.

The base of the upper limestone member is placed where the proportion of carbonate beds abruptly predominates over that of the terrigenous mudstones. The boundary recognized here coincides with the level at which Zeller (1965) placed his base of the Escabrosa Group, just above a deeply weathered dike that cuts through the section. The lower part of the limestone member contains skeletal wackestones in layers 3 to 6 cm thick, interbedded with yellow-brown to gray terrigenous mudstones. Higher in the section the proportion of carbonates increases and skeletal packstones and grainstones become common. A diverse fauna of pelmatozoans, bryozoans, brachiopods, and ostracodes are represented by their skeletal grains. Locally, oolitic limestone and beds bearing intraclasts of terrigenous mudstones occur. The uppermost beds of the upper carbonate member are almost free of fine terrigenous clastics, and skeletal grains, mostly pelmatozoan and bryozoan debris, are badly broken and abraded.

The overall facies transition from the Box Member to the top of the upper carbonate member represents a gradual shift from a low-energy environment characterized by fine terrigenous muds to a high-energy carbonate-shoal setting. Kocurek (1977) proposed that this lithofacies transition was the result of a change from a shallow-water lagoon and tidal flat dominated by terrigenous muds to an offshore carbonate platform. His arguments for a shallow-water origin for the Box mudstones are based largely on the sequence of sedimentary structures that characterize the facies transition; however, many of the sedimentary structures provide largely equivocal evidence. Regional stratigraphic relations (e.g. Kottlowski, 1963) suggest that the Box mudstones may have accumulated in subtidal environments.

Conodont biofacies in the upper part of the Percha Formation at Mescal Canyon do not provide any clear indication of the depositional setting of the Percha mudstones. No conodonts were recovered from carbonate nodules in the Box Member. Sparse faunas characterized by small carminate elements appear in the lower part of the upper limestone member, associated with small indeterminate icriodids. Samples from the upper two-thirds of the upper limestone member are dominated by elements of *Polygnathus semicostatus* and *"Icriodus" raymondi* and lesser numbers of *P. communis, Bispathodus* species, other species with carminate elements, and *Apatognathus* elements. This association is like that of the polygnathid–"icriodid" biofacies of Sandberg and Dreesen (1984, fig. 6). These authors proposed that the polygnathid–"icriodid" biofacies is typical of normal marine, shallow-water, outer-shelf environments. This interpretation applies well to the greater part of the upper limestone member of the Percha. Unfortunately, conodont faunas from the basal portion of the upper limestone member lack conodont species that would indicate a deeper water environment (e.g., *Palmatolepis* species) or nearshore environments (e.g., *Pandorinellina* or *Clydagnathus* species, Sandberg and Dreesen, 1984).

Upper Kinderhookian shallow-water carbonate sequence—After a major hiatus that included most of Kinderhookian time, shallow-water, high-energy environments again characterized the region. At the base of the sequence lies a prominent 3-m-thick oolitic grainstone that defines the basal part of Unit 1 of the Bugle Member of the Keating Formation (Fig. 2). The basal oolite is overlain by evenly bedded, coarse-grained skeletal packstones and grainstones. Pelmatozoan and bryozoan detritus compose 90% of the grains, and remains of corals, calcareous forminifera, ostracodes, and brachiopods are present. Except for the appearance of algal-coated grains near the top of the unit, there are no obvious trends in composition or texture that can be attributed to changes in environmental setting.

Conodont faunas from Unit 1 of the Bugle Member are sparse and badly fragmented. The predominance of robust elements of *Polygnathus longiposticus* and closely related species is like that reported from similar high-energy carbonates of late Kinderhookian age (lower Andrecito Formation) in the San Andres Mountains (De Keyser et al., 1985, p. 76.)

Osagean shoaling sequence—Near the end of the Kinderhookian an abrupt deepening event occurred, and subtidal shelf sediments spread over the shallow platform area. The base of an interval of 27 m of dark-gray argillaceous wackestones (Unit 2 of the Bugle Member) rests with sharp contact on the light-gray, abraded skeletal grainstones of the underlying depositional sequence. The sparse skeletal debris is poorly sorted and moderately well preserved. Pelmatozoan and bryozoan detritus is common. Small, structureless peloids, perhaps fecal pellets, are abundant.

The slope-forming dark-gray argillaceous wackstones of Unit 2 of the Bugle grade upward into cherty, cliff-forming dark-gray carbonates that contain a substantially smaller proportion of fine terrigenous detritus, the Witch Member. Elongate chert nodules oriented parallel to bedding are pervasive and often coalesce into thin discontinuous layers that break the thicker carbonate beds into thin intercalations of chert and carbonate. Skeletal wackestones with diverse fauna characterize the lower 20 m of the Witch Member. Pelmatozoan debris, bryozoan remains, sponge spicules, ostracodes, and brachiopods occur in nearly equal proportions. Twenty meters above the base of the Witch Member a fossil-poor facies of ostracode carbonate mudstones appears. Besides ostracodes, sparse sponge spicules occur with abundant peloids, like those found in the carbonates of Unit 2 of the Bugle Member. This fossil-poor facies is 60 m thick and grades upward into pelmatozoan and bryozoan packstones and grainstones that form the top 30 m of the Witch Member (Fig. 2). Skeletal debris is well sorted and finely comminuted in the uppermost beds, and carbonate intraclasts up to 10 mm in diameter are present.

Unit 2 of the Bugle Member and the greater part of the Witch Member represent deposition in quiet water, shallow subtidal environments. During the initial stage of deposition, a moderate influx of fine terrigenous clastics produced argillaceous carbonates. When the influx of terrigenous detritus decreased, clearer water conditions prevailed that permitted a relative abundance of sponges, whose siliceous spicules were later mobilized by diagenetic fluids to produce the characteristic cherts of the Witch Member. A final shoaling event is indicated by the appearance of packstones and grainstones at the top of the Witch Member.

Conodont faunas from Unit 2 of the Bugle Member and the Witch Member provide little additional information about the environments of deposition because the paleoecologic distribution of early Osagean conodonts remains unclear. Conodont diversity is low (3–5 species) in the low-abundance faunas from Unit 2 of the Bugle Member. *Polygnathus communis* dominates, and *Gnathodus punctatus* occurs near the base. Chauff (1983) considered the association of abundant *P. communis* with *G. punctatus* on the Burlington Shelf (Missouri–Illinois) to represent a nearshore shallow-water transgressive fauna. However, *G. punctatus* was recovered from only shelf-margin sections in the San Andres Mountains (De Keyser et al., 1985). A maximum in diversity (8 species) is attained at the base of the Witch Member, where relatively abundant faunas are strongly dominated by *P. communis* and contain common *Pseudopolygnathus* and *Gnathodus* species. A similar conodont association occurs in foreslope deposits on the eastern shelf margin of the Deseret starved basin in Utah (Sandberg and Gutschick, 1979; Gutschick and Sandberg, 1983; Sandberg and Gutschick, 1984), but has been interpreted to be a shallow-water subtidal conodont biofacies in the midcontinent area (Chauff, 1983). Higher in the Witch Member faunal diversity falls to a few species (2–4), and *P. communis* remains the dominant form to the top of the member.

Regional stratigraphic relations

Schumacher (1978) summarized lithostratigraphic and biostratigraphic relations of Upper Devonian strata in southeastern Arizona. He recognized an upper Devonian (Famennian) depositional complex consisting chiefly of yellow-gray to gray and black shales and overlying carbonates. This interval ranges in age from the middle Famennian *trachytera* Zone to possibly as high as the late Famennian Middle *expansa* Zone (Schumacher, 1978, fig. 2). The Box Member of the Percha Shale of western New Mexico was assigned to this Famennian depositional complex based on brachiopods (Stainbrook, 1947) and conodonts (Sandberg, 1976).

The upper limestone member of the Percha Formation at Mescal Canyon is similar to Member 4 of the Portal Formation (Sabins, 1957) in the Chiricahua Mountains of southeastern Arizona (Fig. 1). Member 4 of the Portal comprises thick-bedded skeletal packstones and grainstones that may be as young as the Middle *expansa* Zone. Similar shallow-water carbonates occur in the upper part of the Devonian section in the intervening Peloncillo Mountains of western New Mexico (Gillerman, 1958). Schumacher (1978) traced these shallow-water carbonates more than 100 km farther west in Arizona, into the Mescal and Santa Catalina Mountains (Fig. 1). In the most western sections, the shales that underlie these carbonates are gradually replaced by sandstones, suggesting increasing proximity to a shoreline in this direction.

Comparable shallow-water, upper Famennian carbonates may extend slightly northeast of the Big Hatchet Mountains. In the Klondike Hills, the nodular Box Member of the Percha Formation is overlain by at least 10 m of Upper Devonian carbonates that are overlain by the base of the Escabrosa Group (Armstrong et al., 1980). Farther east, in the Florida Mountains, the Percha is represented only by dark shales. North of the Big Hatchet Mountains, in the Santa Rita area (Fig. 1), the Box Member contains abundant carbonate nodules and layers that have yielded moderately diverse megafaunal collections (Stainbrook, 1947).

At Bear Mountain, northwest of Silver City, a conodont fauna that includes *Palmatolepis perlobata postera, P. gracilis sigmoidalis, Polygnathus experplexus*, and *Pelekysgnathus inclinatus* was recovered from carbonate nodules in the upper 16 m of the Box Member (Fig. 4). This association is characteristic of the late Famennian Lower and Middle *expansa* Zones. The upper part of the Box at Bear Mountain appears to be approximately the same age as the upper limestone member of the Percha in the Big Hatchet Mountains. The Bear Mountain conodont fauna most closely resembles the polygnathid–icriodid biofacies of Sandberg (1976) and is considered to be typical of the moderately shallow water conditions of the outer cratonic shelf, farther offshore than the polygnathid–"icriodid" conodont biofacies that is present in the Big Hatchet Mountains. Farther east, near Santa Rita, Sandberg (1976) reported a comparable fauna association from the Box Member.

From these sparse data, it is possible to reconstruct some aspects of Late Devonian depositional history and paleogeography in southwestern New Mexico. During the late Famennian (*expansa* Zone?), the supply of terrigenous clastics into the region decreased such that carbonate environments began to develop. A shallow-water carbonate platform area formed in eastern Arizona and extreme southwestern New Mexico. As best as can be determined, the edge of this platform area ran approximately north to south along the western margin of New Mexico, parallel to what later would be the margin of the Escabrosa Shelf (Fig. 1). Eastward, deeper water environments existed, in which nodular carbonates accumulated in dominately terrigenous clastic environments. Whether or not a comparable uppermost Devonian carbonate complex existed in central New Mexico at this time is uncertain. At most sections the Box Member of the Percha Formation is the youngest Devonian unit preserved (Bowsher, 1967). However, at Rhodes Canyon in the San Andres Mountains, a 2.75-m unit of oolitic grainstone yielded a *Polygnathus–Palmatolepis* fauna that is latest Devonian (*expansa* Zone) in age (De Keyser et al., 1985). This small outlier could represent a fragment of an uppermost Devonian carbonate platform that was largely removed by erosion during the earliest Mississippian.

Armstrong and Mamet (1978b) and Armstrong et al. (1980) presented a series of cross sections and paleogeographic and lithofacies maps that depict Mississippian stratigraphic relationships in eastern Arizona and southwestern New Mexico. Primary biostratigraphic control was provided through the use of the microfossil (largely foraminifera) zonation of Mamet although in some instances conodonts and macrofossil zones were used. Basal strata of the Keating Formation (Bugle Member) of the Escabrosa Group fall in the pre-Zone 7 interval of Mamet's zonation, which is shown to be pre-Osagean in age (Armstrong and Mamet, 1978b; Armstrong et al., 1980).

Norby (1971) described conodont faunas from the Escabrosa Group in Arizona that more accurately date the base of the Mississippian succession. At Blue Mountain in the Chiricahua Mountains, the type section of the Escabrosa Group, the lower 20 m of the Bugle Member are coarse-grained pelmatozoan grainstone like that found at the Mescal Canyon section in the Big Hatchet Mountains. The basal three meters of the Bugle Member bear a conodont fauna of latest Kinderhookian age (*Siphonodella isosticha* and *S. obsoleta*, Norby, 1971, fig. 6). The upper 30 m of the Bugle Member at Blue Mountain consist of dark-gray, fine-grained carbonates that contain only minor amounts of fine terrigenous clastics. This upper interval is largely barren of conodonts but includes one form, *Gnathodus* cf. *G. semiglaber*, the illustrated specimens of which appear to be elements of *G. punctatus* (Norby, 1971, pl. 5, figs. 11 and 16). *Gnathodus punctatus* occurs in the dark argillaceous carbonates of Unit 2 of the Bugle at Mescal Canyon, and the upper carbonates of the Bugle at Blue Mountain and Mescal Canyon appear to be the same age although slightly different lithofacies are present in the two sections. Armstrong et al. (1980, fig. 5) indicate a similar correlation based on macrofossil zones.

The conodont fauna of the Witch Member at Blue Mountain is strikingly similar to that of the Witch Member at Mescal Canyon. At the base of the Witch Member at Blue Mountain (Norby, 1971), elements of *Polygnathus communis* became abundant and lesser numbers of *Pseudopolygnathus multistriatus* and *Gnathodus* species are present. As is the case at Mescal Canyon, the base of the Witch Member at Blue Mountain can be assigned to the Lower *typicus* Zone. Higher in the Witch Member, fewer conodonts occur, and the sparse faunas continue to be dominated by elements of *P.communis*.

Armstrong et al. (1980, fig. 7) illustrated how Mississippian strata of the Escabrosa Shelf might be correlated with strata of the Lake Valley Shelf. Relatively little biostratigraphic control for the lower units is indi- ☞

cated on their figure. Beds of the Andrecito and Alamogordo Members of the Lake Valley Formation were shown to contain a pre-Zone 7 microfossil assemblage, and the Tierra Blanca Member at Bear Mountain yielded a Zone 7 assemblage. However, considerable biostratigraphic information for the Lake Valley Shelf exists in the form of conodont faunas.

The Andrecito Member of the Lake Valley Formation in the Sacramento Mountains (Lane, 1974, 1982), the San Andres Mountains (De Keyser et al., 1985), and the Cooke's Range (Moore, 1984) ranges from the upper part of the upper Kinderhookian *isosticha*–Upper *crenulata* Zone into the lower Osagean Lower *typicus* Zone. The Alamogordo Member contains conodont faunas of the Lower *typicus* Zone in the areas cited above but locally ranges into the Upper *typicus* Zone in some sections in the southern part of the Sacramento Mountains (Lane, 1982). The carbonate mounds of the Sacramento Mountains are of an equivalent age, ranging from the Lower *typicus* Zone through the Upper *typicus* Zone, and possibly as high as the middle Osagean *anchoralis–latus* Zone (Lane, 1982).

Correlations based on conodonts between the Escabrosa Shelf and the Lake Valley Shelf confirm most aspects of the correlation proposed by Armstrong et al. (1980). The most significant correlation is the apparent equivalence of the lower part of the Witch Member of the Keating Formation with the Alamogordo Member of the Lake Valley Formation. The base of each unit lies within the Lower *typicus* Zone, and the two units possess similar lithologic attributes. Both units comprise dark-gray, cherty carbonate mudstones to packstones that form cliffs to steep slopes in outcrop. The widespread distribution of this distinctive lithofacies over both shelf regions is probably a reflection of the regional Osagean transgressive event that flooded most of the North American craton during Early Mississippian time (Lane, 1982). The maximum of this transgressive event in the western United States was achieved during the time represented by the *anchoralis–latus* Zone, in the middle Osagean (Sandberg et al., 1983).

Interpretation of the more diverse lithofacies represented by strata below the Witch–Alamogordo interval is more difficult. The Andrecito Member of the Lake Valley Formation is equivalent in age to the Bugle Member of the Keating Formation. The Andrecito Member comprises a relatively heterogeneous association of argillaceous gray carbonates, typically mudstones to packstones and calcareous shales and siltstones. In contrast, the Bugle Member at Blue Mountain and Mescal Canyon consists of two lithofacies, a lower shallow-water pelmatozoan grainstone and an upper deeper-water interval of carbonate mudstones and wackestones that are argillaceous at the Mescal Canyon section. The lithologic sequence at Mescal Canyon, where the slope-forming argillaceous beds of the upper Bugle grade abruptly into the ledge-forming cherty carbonates of the basal Witch Member, strongly resembles the upper Andrecito–Alamogordo sequence

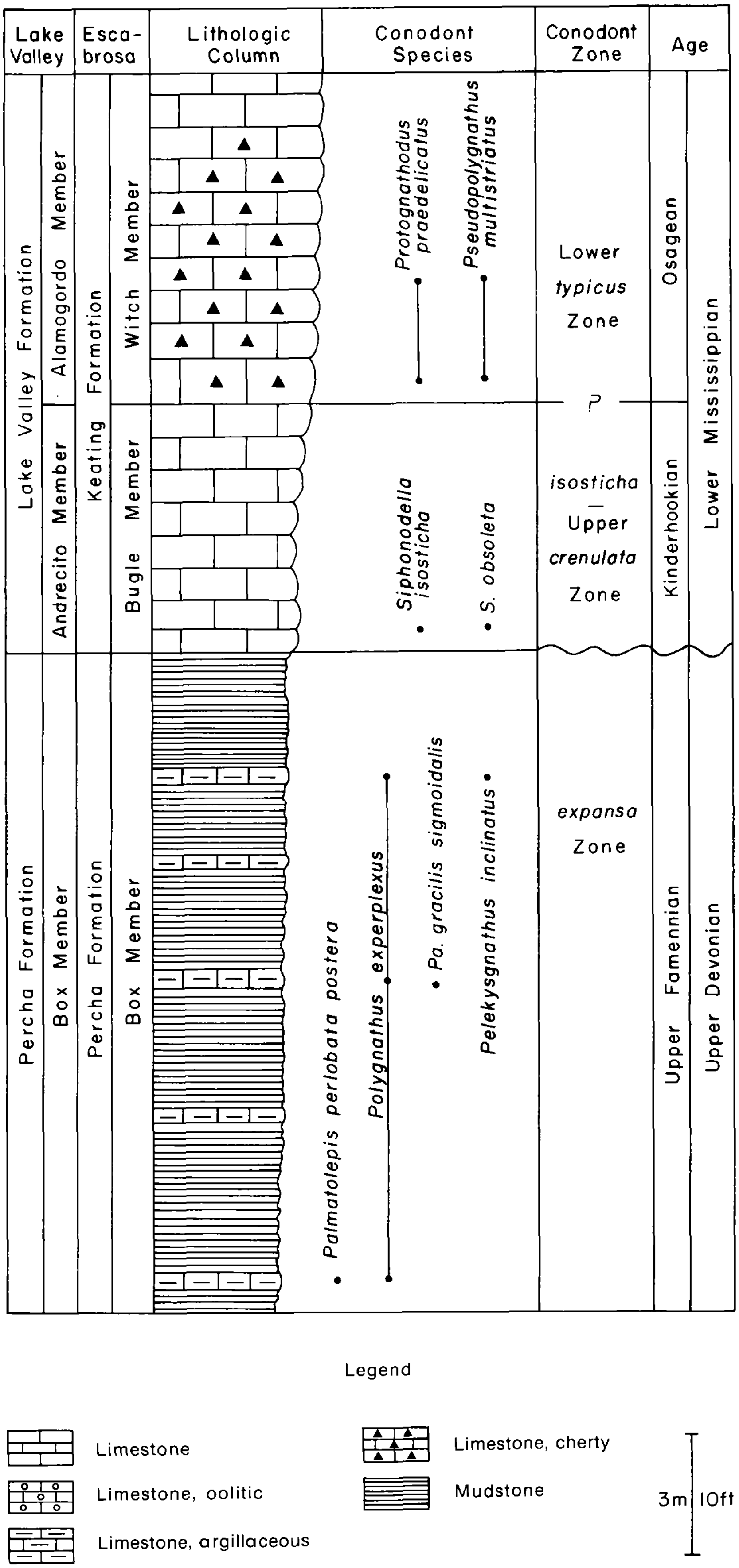

FIGURE 4—Stratigraphic column of Upper Devonian and Lower Mississippian strata at the Bear Mountain section (SE1/4 sec. 11, T17S, R15W) northwest of Silver City. "Lake Valley" and "Escabrosa" refer to Lake Valley and Escabrosa Shelf stratigraphic nomenclature, respectively. Ranges of important conodont species are shown as are ages inferred from conodont distribution.

on the Lake Valley Shelf. Locally, grainstones do occur at the base of the Andrecito Member, such as at San Andres Canyon in the San Andres Mountains (De Keyser et al., 1985) and south of Alamo Canyon in the Sacramento Mountains (Lane, 1982). In both instances, the basal grainstones of the Andrecito occur near where the shelf margin is more clearly indicated by the facies patterns in overlying units. The locations of these Osagean shelf margins are thought to have been determined largely by topography developed on the underlying Devonian surface (Lane 1982; De Keyser, 1983). It is conceivable that the existence of the basal grainstone facies of the Bugle Member is similarly related to the development and subsequent preservation of the upper Devonian carbonate shelf that occupied southwestern New Mexico and adjacent Arizona.

Because of the discontinuous outcrop pattern, it is difficult to determine how strata of the basal part of the Lake Valley Shelf might have merged into strata of the Escabrosa Shelf. In south-central New Mexico, there is good evidence that a starved-basin setting existed in the vicinity of the Florida Mountains during the Early Mississippian. There Kinderhookian and lower Osagean strata are absent, and the basal beds of the Mississippian carbonate section contain middle Osagean conodonts (*anchoralis–latus* Zone) apparently transported off the edge of an adjacent carbonate shelf (Armstrong and Mamet, 1978b; Moore, 1984).

To the northwest, in the Silver City area, the section at Bear Mountain possesses some attributes of the stratigraphic successions of both the Lake Valley and Escabrosa Shelves (Fig. 4). Resting unconformably on the nodular carbonates of the Box Member of the Percha Formation is a 5–6-m unit of light-gray, wavy-bedded skeletal grainstones with intercalated thin argillaceous layers. Near the base of the unit occur conodonts of the late Kinderhookian *isosticha*–Upper *crenulata* Zone. Massive dark-gray carbonate wackestones rest with a knife-sharp contact on the lower grainstone interval. The lower few meters of the upper unit form a prominent ledge and lack significant amounts of chert. Higher in the section, chert becomes abundant and the unit erodes into more of a slope exposure, as illustrated by Armstrong et al. (1980, fig. 7). Conodonts obtained from the lower 2 m of the upper unit appear to represent a Lower *typicus* Zone fauna although the collections are not completely diagnostic (Fig. 4).

In their monographic work on the strata of the Lake Valley Shelf, Laudon and Bowsher (1949) assigned the lower grainstone unit to the Andrecito Member and the upper dark carbonates to the Alamogordo Member of the Lake Valley Formation. Most subsequent workers (e.g., Armstrong et al., 1980), have followed this nomenclatural assignment. However, the stratigraphic subdivisions of the Escabrosa Shelf can also be applied to the Bear Mountain section. The lower grainstone interval at Bear Mountain can be assigned to Unit 1 of the Bugle Member of the Keating Formation (Fig. 4). The sharp contact between the grainstones and the overlying dark carbonates at Bear Mountain is identical with that found between Units 1 and 2 of the Bugle at the Mescal Canyon section and could represent the same depositional event. Like the contact at Mescal Canyon, this sharp lithologic contact separates conodonts of the *isosticha*–Upper *crenulata* Zone from those of the Lower *typicus* Zone. Lithologically, the ledge-forming dark carbonates at the base of the upper unit at Bear Mountain more strongly resemble the upper Bugle Member at the Blue Mountain section. The base of the Witch Member of the Keating Formation can be picked up at the level where abundant cherts appear, approximately 20 m above the base, as it was chosen at the Blue Mountain section by Armstrong and Mamet (1978b).

At the present time, there is not sufficient information available to evaluate further the lithologic succession of the Bear Mountain section relative to the Lake Valley and Escabrosa sequences. Regardless of the proper application of stratigraphic nomenclature, the Lower Mississippian sections in the Silver City area, including Bear Mountain, appear to represent the transitional area between the Lake Valley and Escabrosa Shelves. Only 30 km farther east, near Santa Rita, a Lake Valley section is present that includes a more typical development of the Andrecito Member at its base (Laudon and Bowsher, 1949, fig. 43). The closest outcrop of the Keating Formation of the Escabrosa Group lies more than 100 km to the southwest, in the Peloncillo Mountains (Armstrong et al., 1980, fig. 5). Unless additional lithofacies and biostratigraphic information can be obtained in this region, the sections of the Bear Mountain area may be the only source of information for making a detailed reconstruction of the latest Kinderhookian and the earliest Osagean at the juncture of the two shelf regions.

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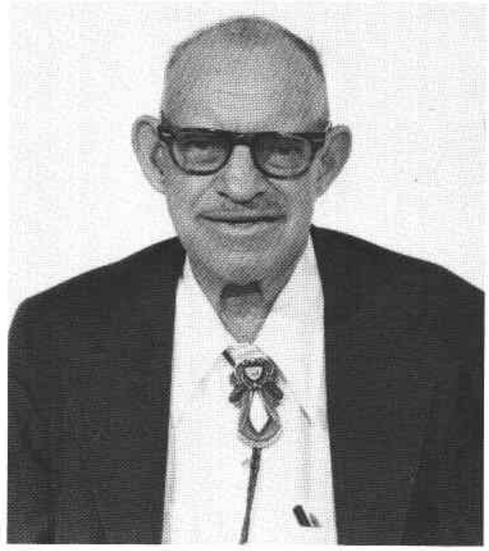
Rousseau Haynor Flower (1913–1988)



Rousseau Haynor Flower was born on March 21, 1913 at the family home near Troy, New York. He was the son of Franklin Rousseau and Ethna Haynor Flower. Rousseau attended elementary school in a one-room schoolhouse, where his aunt Lilian taught, and high school in Troy, New York. In high school, Rousseau found the compound microscope and a love of science, and the cello. He entered Cornell University in 1930, earning a tuition scholarship and majoring in entomology. He completed his undergraduate degree in 1934 and an MA degree in 1935 under Dr. J. G. Needham. His thesis dealt with the venation pattern of dragonfly wings; a portion of the terminology he developed was incorporated in Needham and Westfall's *Dragonflies of North America*, published in 1955. Rousseau's introduction to fossils came through a course in historical geology that he took in his final undergraduate year, and he continued to study paleontology as a minor for his graduate degree. He intended to complete a PhD in entomology, but a collecting trip to the Gulf Coast Tertiary in 1936 altered the direction of his career.

In 1936–37, Rousseau studied paleontology at the University of Indiana under E. R. Cummings, but family health concerns forced him to return to New York. In his free time he became increasingly engrossed in the collection and study of fossil cephalopods, and he received encouragement from the distinguished paleontologist Rudolph Ruedemann. By 1938, Rousseau's dear friend and teacher Kenneth Caster managed to get him support at the University of Cincinnati where Rousseau completed his PhD in June 1939. His dissertation, *Study of the Pseudorthoceratidae,* was later published by the Paleontological Research Institution. Rousseau was unemployed until September 1940—the effects of the depression were still felt in the sciences—when he became a curator at the University of Cincinnati. He held that position until 1944 when he left to teach at Bryn Mawr. At year's end he became Assistant State Paleontologist, a position he held until coming to New Mexico in 1951.

In 1951, Rousseau married Margaret (Peg) and accepted a position as Stratigraphic Geologist at the New Mexico Bureau of Mines and Mineral Resources offered to him by Dr. Eugene Callaghan, then the Bureau's director. His title was later changed to Senior Paleontologist. Although technically retired from the Bureau in March 1978, Rousseau remained active to the end, despite a progressively frail constitution.

Rousseau was an internationally renowned paleontologist. His interest in fossils took him to every continent except Africa and Antarctica. He was known and respected by paleontologists wherever he went, and he brought a great deal of distinction to New Mexico Tech. His scientific accomplishments are evident through his publications that include almost 200 papers, many of them monographs of substantial length, and the fact that he described approximately 100 new genera and more than 400 new species. Although he was completely engrossed in the study of fossil cephalopods, he made important contributions to our understanding of New Mexico stratigraphy, fossil corals, graptolites, and other groups.

Rousseau's love of the opera and classical music is well known. For many years he contributed reviews of musical productions to the Defensor Chieftain, Socorro's newspaper. He had a love of literature and classical film as well.

Rousseau was a complicated and colorful individual. Flower stories abound among paleontologists, and almost all have a germ of truth—in many ways, he was bigger than life. Rousseau died suddenly on February 27, 1988 at his home with his beloved Peg at his side. In addition to Peg, he is survived by his son John Flower and daughter Peg Rushing, both of Las Cruces, and brother Donald of Syracuse, New York. It was my privilege to know Rousseau for almost ten years; his kind will not soon be seen again and we will all miss him.

—Donald L. Wolberg