Stratigraphy and copper deposits of the Abo Formation, Abo Canyon area, central New Mexico

William O. Hatchell, John W. Blagbrough, and James M. Hill

1982, pp. 249-260. https://doi.org/10.56577/FFC-33.249

in:

Albuquerque Country II, Wells, S. G.; Grambling, J. A.; Callender, J. F.; [eds.], New Mexico Geological Society 33 rd Annual Fall Field Conference Guidebook, 370 p. https://doi.org/10.56577/FFC-33

This page is intentionally left blank to maintain order of facing pages.

STRATIGRAPHY AND COPPER DEPOSITS OF THE ABO FORMATION, ABO CANYON AREA, CENTRAL NEW MEXICO

WILLIAM 0. HATCHELL
Bureau of Geology
Energy and Minerals Department
Santa Fe, New Mexico 87501

JOHN W. BLAGBROUGH
P.O. Box 8063
Albuquerque, New Mexico 87198
and
JAMES M. HILL
Bureau of Geology
Energy and Minerals Department
Santa Fe, New Mexico 87501

INTRODUCTION

Purpose and Scope

The purpose of this report is to describe the stratigraphy of the Abo Formation of Permian age within and adjacent to the type section, as well as to redefine the type section established by Needham and Bates (1943). Lithofacies are identified; supplementary measured sections, sedimentary structures, and fossils are described; and depositional environments are inferred. In addition, the copper deposits and uranium occurrences of the Sholle district, their relationship to Abo stratigraphy, and the history of discovery and copper production are discussed.

The late C. B. Read of the U.S. Geological Survey originally suggested and guided the stratigraphic work needed to redefine the type section, and contributed his knowledge of Permian flora by identifying the fossil plant collection. W. 0. Hatchell measured the stratigraphic sections and described the Abo and its depositional environment. J. W. Blagbrough investigated the copper and uranium occurrences and described the geology of the deposits. The history of mining and the production statistics were compiled by J. M. Hill.

Location and Accessibility

Abo Canyon is located some 80 km southeast of Albuquerque and 16 km west of Mountainair on U.S. Highway 60 (fig. 1). The settlement of Scholle is located at the southern end of the area, near the juncture of Torrance, Valencia, and Socorro counties. Ruins of Abo mission in Salinas National Monument are situated near the eastern extremity. The Scholle mining district is in T2, 3, and 4N, R5E and extends from the Abo mine (sec. 3, T2N, R5E) near Scholle northward to the Copper Girl mine (sec. 28, T4N, R5E).

Mesa-like cuestas and open canyons are characteristic of the topography which has some 90 to 120 m of relief. Accessibility to outcrops and mine workings is good, especially by way of U.S. Highway 60 in Abo Canyon, U.S. Forest Service Road 422 in Cation Salado and Priest Canyon, and State Road 513 to the Abo ruins.

Geologic Setting

The Abo Formation at the type section crops out in a series of cuestas along the northwestern edge of Chupadera Mesa, at the southern end of the Manzano Mountains. Regional dips average about 2° to 3° to the southeast. No major faults or folds have been mapped within the area (fig. 1).

West of the Abo outcrops, the underlying Bursum Formation of Permian age forms a broad valley which is cut by Priest Canyon, Canon Salado, and Canon Arado. To the east, the Meseta Blanca Sandstone Member of the Yeso Formation of Permian age is exposed in mesas and cuestas eastward to Salinas National Monument. Exposures of all stratigraphic units except siltstones and mudstones are good or fair.

STRATIGRAPHY

General Statement

The Abo Formation in the type area is a sequence of dark, reddish brown mudstone and siltstone with subordinate lenses of intercalated red sandstone, arkose, and limestone-pellet conglomerate about 247 m thick. The Abo Formation lies disconformably above the Bursum Formation and is in turn conformably overlain by the Meseta Blanca Sandstone Member of the Yeso Formation. On the basis of stratigraphic relationships (King, 1945; Baars, 1962) and fossil plants (Read and Mamay, 1964), the Abo Formation has been dated as partly Wolfcampian and partly Leonardian in age (fig. 2).

The Bursum Formation was defined by Wilpolt and others (1946) and is a sequence of interbedded purplish shale, arkose, arkosic conglomerate, and gray marine limestone. Only the upper part of the Bursum was measured in this study in order to establish the Abo-Bursum stratigraphic boundary. Gray limestone, nodular argillaceous limestone, thick massive red mudstone and shale, and crossbedded, coarse, red, arkosic sandstone comprise the upper Bursum stratigraphic section.

The contact between the Bursum and the Abo is well exposed in Cation Salado and along U.S. Forest Service Road 422. Reddish mudstone and gray marine limestone of the Bursum lie below arkosic sandstone and conglomerate of the Abo. The contact is sharp and disconformable. The Bursum is lithologically similar to the overlying Abo except for marine limestones that bear early Wolfcampian fusilinids (Wilpolt and others, 1946). However, basal Abo arkosic beds occupy scours cut into the highest Bursum limestones and mudstones and contain limestone clasts derived from the Bursum. Therefore, the base of the Abo is drawn along this disconformity between Abo arkose and Bursum limestone.

Pinkish gray, buff, and light orange, fine-grained sandstone and gypsiferous siltstone comprise the Meseta Blanca Sandstone Member of the Yeso Formation above the Abo type section. A Leonardian age has been established for the Yeso Formation (Needham and Bates, 1943).

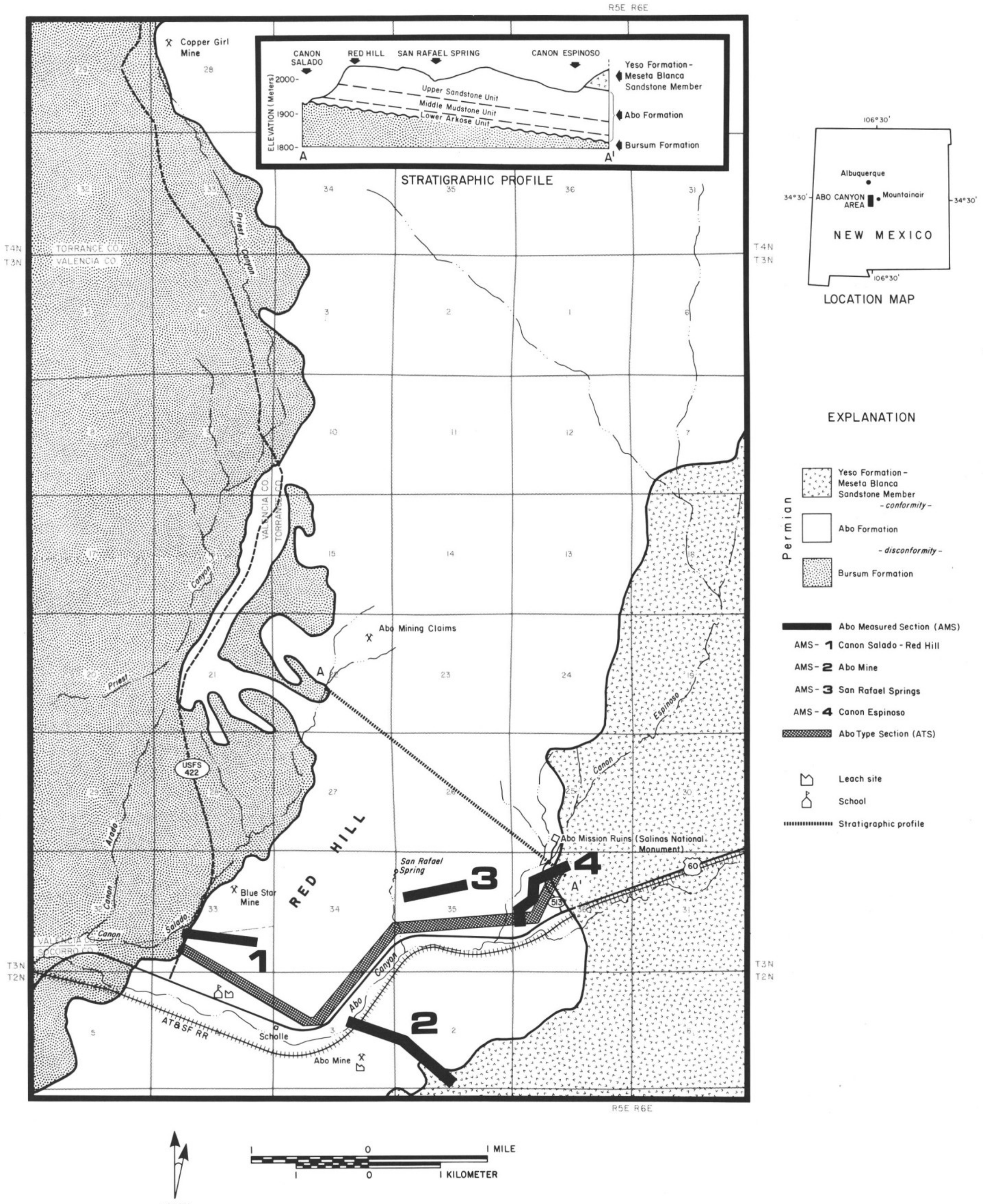

Figure 1. Geologic and location map of Abo Canyon area, New Mexico with stratigraphic profile (geology modified from Myers, 1977). Abo type section and supplementary measured sections as well as copper mines and leach sites are shown.

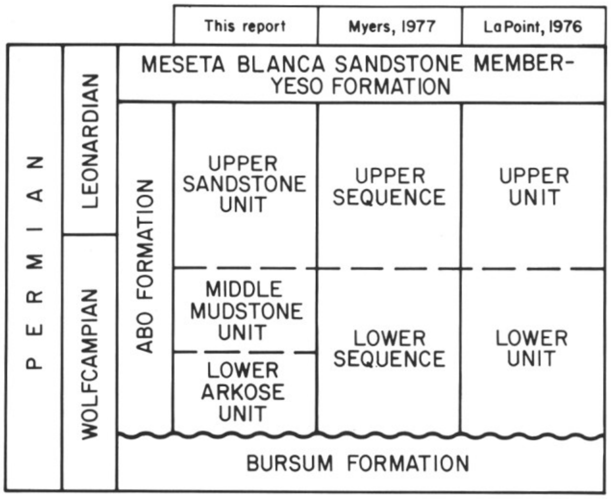

Figure 2. Stratigraphic nomenclature chart of Abo Formation and its informal stratigraphic units.

Northrop and Wood (1946) suggest that the Abo-Yeso contact be drawn below the lowest tangentially crossbedded sandstone of the Meseta Blanca. In this paper, the criterion of Northrop and Wood is regarded as suitable with the stipulation that the presence of gypsum and salt hopper casts in thinly bedded sandstone and siltstone is also an indicator of the transition from Abo to Meseta Blanca lithology. Intertonguing between the Abo and the Yeso may occur as basal Meseta Blanca sandstones are intercalated with reddish mudstones at some localities. The upper Abo sandstones appear to grade into the Meseta Blanca near the contact where colors change from red to reddish orange, light orange, and buff. For this reason, the upper Abo contact is arbitrarily drawn within the transitional zone of intertonguing with the Meseta Blanca.

Abo Formation

History of nomenclature

Lee and Girty (1909) originally named the Abo Formation for exposures in Abo Canyon at the southern end of the Manzano Mountains. They refer to the sequence as both the Abo sandstone and Abo redbeds, and describe it as sandstone, conglomeratic near the base, with subordinate amounts of shale (mudstone). The Abo is stated to vary in thickness from 90 to 245 m with the upper limit placed unconformably upon the Magdalena Group.

Needham and Bates (1943, p. 1656) established the type section for the Abo Formation in Abo Canyon between Scholle and the Abo mission ruins some 34 years after the formation was named by Lee and Girty. The section is located just north of U.S. Highway 60, from the base of the formation in sec. 33, T3N, R5E through secs. 34, 35, 36 and into sec. 25 near the Abo ruins at the Abo-Yeso contact. Needham and Bates included 32 m of the overlying Meseta Blanca Sandstone Member of the Yeso Formation in the Abo section, for a total Abo thickness of 279 m. The stratigraphic error was recognized by Northrop and Wood (1946) through field work in the Nacimiento Mountains in north-central New Mexico. Although Bates and others (1947) mapped the corrected Abo-Yeso contact in the Abo Canyon area, workers continued to state the Abo thickness as 274 to 279 m rather than the adjusted thickness of 247 m (Baars, 1962; Myers, 1977).

Detailed lithologic descriptions of the Abo Formation within the type area have not been published. An adjusted stratigraphic section showing the corrected upper limit of the Abo at the type section is not documented in the literature, although Bates and others (1947) and Myers (1977) delineated the upper contact on geologic maps. The present study was begun in 1965 at the suggestion of C. B. Read in order to adjust the thickness of the type section (appendix, ATS), give a detailed lithologic description, and determine both the lower and upper contact of the Abo Formation.

Recently, the Abo has been subdivided into informal stratigraphic units in the Abo Canyon area. LaPoint (1976) subdivides the formation at the Blue Star mine (sec. 33, T3N, R5E) into a lower and upper unit, defined largely on the basis of copper occurrences in the lower half of the formation. Myers (1977) identifies an upper sequence of fine-grained sandstone and siltstone, and a lower sequence of shale, siltstone, arkosic sandstone, and conglomerate throughout the Scholle 7.5-minute quadrangle.

Lithology

Red mudstone and siltstone are the predominant lithologies within the Abo in the type area, and coarser units such as sandstone, arkosic sandstone, and conglomerate are subordinate. The mudstone-siltstone to sandstone-conglomerate ratio is approximately 4 to 1 for the formation as a whole but is less in the upper 120 m where sandstone predominates. The Abo Formation in this paper is divided into three informal units based on lithologic criteria (fig. 3). All three can be traced throughout the area of Abo and Priest canyons (fig. 4a). Arkose, arkosic sandstone, and arkosic limestone-pebble conglomerate characterize the lower unit. Thick mudstone and siltstone with subordinate lenses of limestone and limestone-pebble conglomerate distinguish the middle unit and sandstone is most common in the upper unit. The lower Abo of LaPoint (1976) and Myers (1977) includes the lower and middle units of this paper; their upper units are the same as the upper unit of this paper (fig. 2).

The lower arkose unit contains dark red and grayish red, fine-to-coarse grained arkose, arkosic micaceous sandstone, and arkosic limestone-pebble conglomerate. These coarse elastic beds are intercalated with reddish-brown mudstone and siltstone, which together erode into a bench along the eastern side of Priest Canyon, Cafion Salado, and Abo Canyon in the vicinity of Scholle. Lithologically, the lower arkose unit is composed of angular, pink orthoclase clasts to 0.6 cm in diameter. Slightly rounded to angular limestone and quartz clasts which range in size from pellets to pebbles occur sporadically throughout the arkosic beds (fig. 4b). All lithologies may be calcareous, although the coarser beds are locally silicified. Trough-type cross stratification is evident in the arkosic beds which are channel deposits ranging from a few meters to more than 90 m wide. Thickness varies from wedge edges to 8 or 9 m near channel axes. Some of the channels are exposed along the lower Abo bench area where they can be viewed in three dimensions. The axial portions of the these channels stand topographically higher than the lateral floodplain and overbank deposits of siltstone and mudstone (fig. 4c). The lower arkose unit grades upward into the middle mudstone unit as sandstones become thinner and less arkosic. The lower unit averages about 40 m thick and ranges from 35 to 47 m.

High-energy alluvial fan and associated piedmont deposition are indicated for the lower Abo (Table 1). The ancestral Pedernal uplift to the northeast was apparently the provenance with deposition on a basin-edge surface of Bursum and older rocks (LaPoint, 1974; McKee and others, 1967; and Kottlowski and Stewart, 1970). Both cross stratification and channel trends observed in this study confirm a northeastern source.

The middle mudstone unit conformably overlies the lower arkose unit, forming a prominent talus covered slope above the lower Abo bench on the eastern side of Cafion Salado and Priest Canyon. This unit is composed of reddish-brown mudstone and siltstone, locally mottled to grayish-green, with sparse limestone lenses, limestone peb-

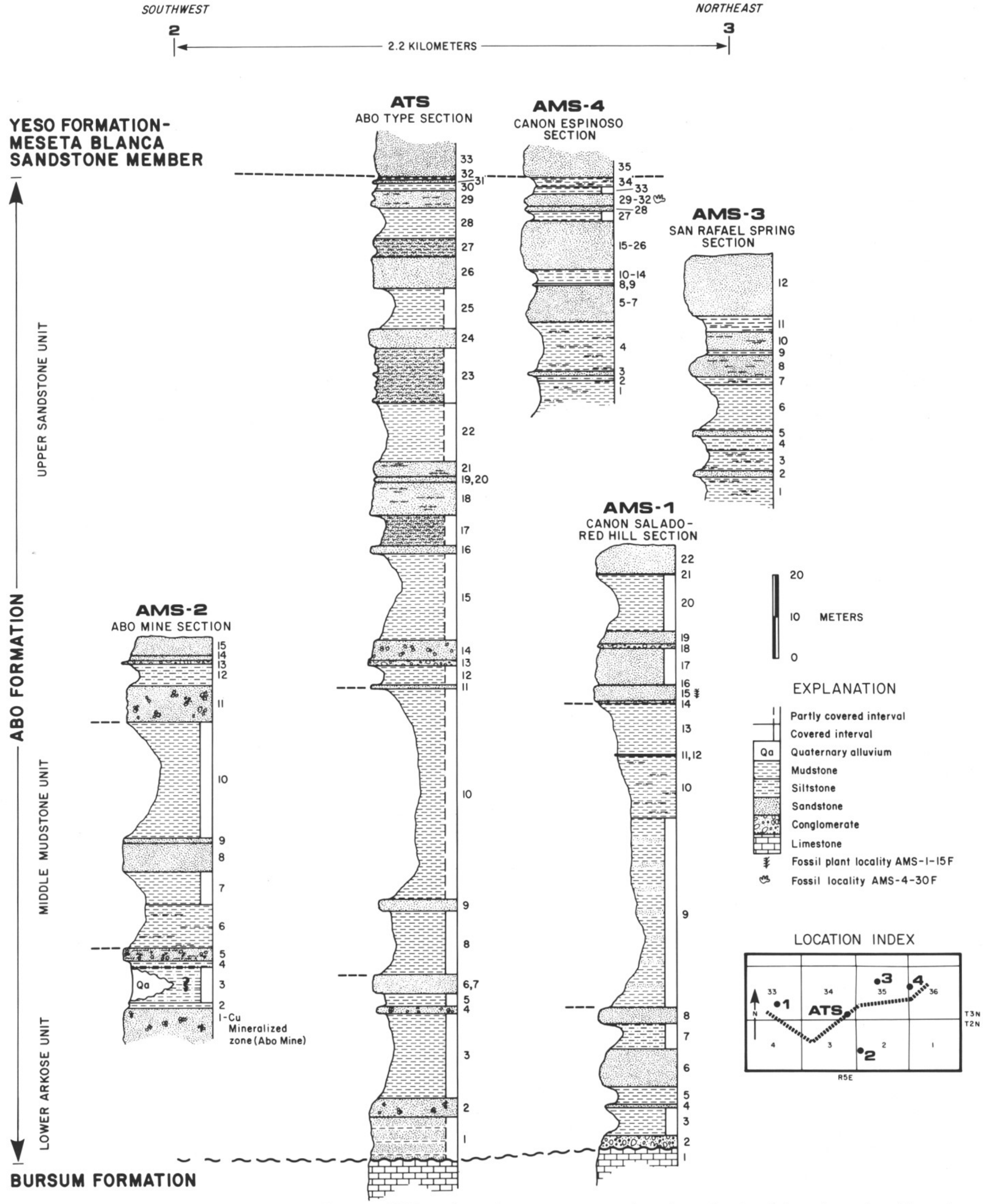

Figure 3. Abo type section (after Needham and Bates, 1943) and supplementary measured sections showing informal stratigraphic units and formational boundaries established in this paper.

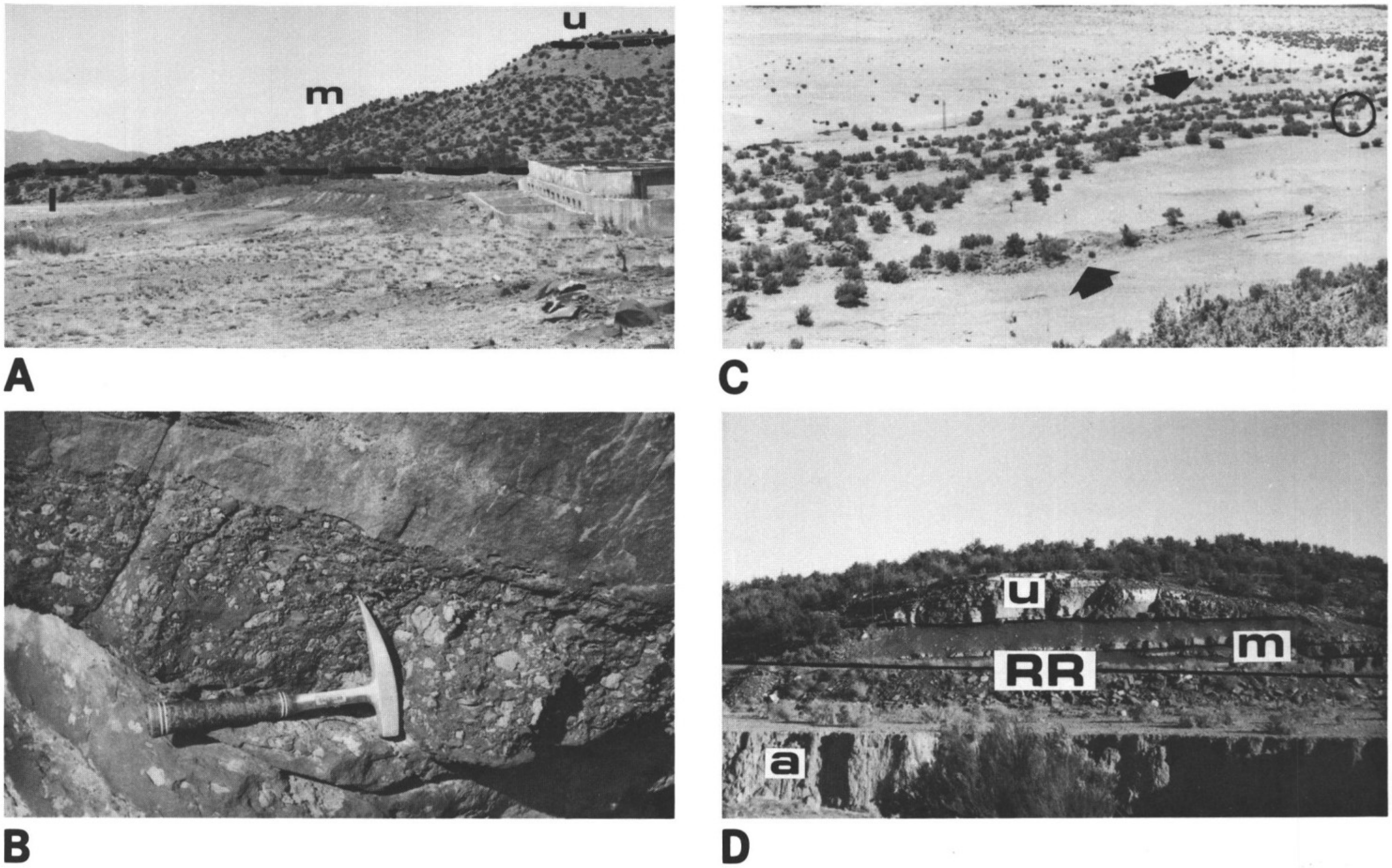

Figure 4. Views of Abo Formation outcrops and lithologic features.

a. Lower arkose (l), middle mudstone (m), and part of upper sandstone (u) units of Abo Formation exposed at Red Hill, SE¼, sec. 33, T3N, R5E (appendix, AMS-1). Cuesta slope has approximately 120 m of relief; concrete precipitate launders at Scholle school in foreground.

b. Close-up of limestone-pebble conglomerate lenses of coarse, arkosic sandstone of lower arkose unit, SE¼, sec. 33, T3N, R5E (appendix, AMS-1, unit 2).

c. Exhumed, arkosic sandstone channels (arrows) in lower arkose unit of Abo Formation at Red Hill, SW¼ NE¼, sec. 33, T3N, R5E. Headframe of Blue Star mine circled; view is to the northwest.

d. Conformable contact between middle mudstone (m) and upper sandstone (u) units exposed in railroad (RR) cut, SW¼, sec. 35, T3N, R5E, 1.6 km northeast of Scholle. Quaternary alluvium (a) exposed in arroyo.

ble-conglomerate, feldspathic to quartzose sandstone, and siltstone. Limestone and siltstone lenses are typically less than 2.5 cm thick but range up to 7.6 cm. Limestone conglomerates are nodular to angular, usually pebble size, reddish-gray in color, and probably intraformational in origin. Sandstones are coarse to fine grained, micaceous, and cross-bedded. All lithologies are calcareous. The middle unit is conformably overlain by and intertongues with the upper sandstone unit throughout the area (fig. 4d). Thickness ranges from 56 to 77 m and averages about 70 m.

A low-energy, fluvial, floodplain and shallow-water lacustrine environment of deposition is indicated for the middle Abo. The middle Abo lithotope was probably that of a coastal plain bordering a more subdued ancestral Pedemal uplift. Small, ephemeral streams cut across the plain in the Abo Canyon area.

The upper sandstone unit forms a prominent bluff which caps the eastern slopes of Priest Canyon and Cafion Salado and is exposed in Abo Canyon between Scholle and Abo ruins. Light and pale red-to-moderade orange-pink, fine-grained, laminar-bedded, ripple-marked sandstone predominates. The base of the upper sandstone contains sparse conglomeratic lenses up to 1 m thick, consisting largely of limestone pellets in sandstone matrix. Mudstone partings up to 2.5 cm in thickness and bedded mudstone units with a maximum thickness of 2.5 m occur throughout. Sandstone beds are thin (15 to 30 cm) and even, with laminar bedding and low-angle, tabular crossbedding usually in laterally continuous units. The sandstone weathers locally into flaggy or thin, platy fragments. Siltstone and mudstone display abundant mud cracks, raindrop imprints, ripple marks, and worm (?) trails and burrows (fig. 5a-d).

Floral impressions with fair to good preservation occur in fine-grained sandstone and siltstone beds of the upper unit along the eastern rim of Cation Salado (fig. 6a-c). These include *Walchia pimformis* of the *Callipteris* floral zone, and *Supaia thinnfeldioides,* and *Brachyphyllum* sp. which belong to the *Supaia* floral zone. The *Callipteris-Supaia* association indicates that the upper part of the Abo is correlative with the Hermit Shale of northern Arizona (C. B. Read, personal commun., 1966). Read and Mamay (1964) show *Wakhia piniformis* to be indicative of Wolfcampian and *Supaia thinnfeldioides* and *Brachyphyllum* sp. to be representative of the early to middle Leonardian Series. Tetrapod tracks occur in a siltstone in the upper unit along Calton Espinoso, 0.4 km southwest of the ruins of Abo mission (fig. 7). These tracks and trails are notable as no faunal evidence has been reported previously from the Abo Formation in the type area.

Table 1. Summary of stratigraphic and sedimentologic features showing depositional environments of the Abo Formation in the type area at Abo Canyon, New Mexico.

Informal Abo Stratigraphic Unit	Lithology	Dominant Stratification Type and Features	Average Bedding Thickness	Fossils	Depositional Environment
		(Meseta Blanca Sandstone Member-Yeso Formation)			
		Conformable-Intertonguing Contact			
Upper Sandstone Unit	Fine to medium grained, well-sorted sandstone and siltstone; minor mudstone beds and partings.	Low angle planar cross stratification, flat laminar sets, interference-ripple marks, mudcracks.	15 cm to 30 cm	*Callipteris* and *Supaia* spp.; tetrapod tracks and trails; invertebrate burrows and trails locally abundant.	Low to moderate energy, near-marine fluvial, deltaic and tidal flat.
		Conformable Sandstone-Mudstone Contact			
Middle Mudstone Unit	Massive mudstone and siltstone with intercalated lenses of limestone, sandstone, and minor conglomerate.	Flat, laminar and cross-beds; sparse crossbedded sandstone and intraformational conglomerate.	30 cm to 60 cm	Sparse unidentified plant impressions (probably float from upper unit).	Low-energy fluvial, flood-plain and shallow-water lacustrine plain with small ephemeral streams.
		Conformable Mudstone-Sandstone Contact			
Lower Arkose Unit	Coarse, arkosic sandstone and conglomerate lenses and channels; minor mudstone beds.	Scour and fill, trough cross stratification; great lateral lithic heterogeneity.	0 to 9 m (crossbed sets)	Sparse except for macerated plant debris associated with channels especially near copper deposits.	High-energy alluvial fan and associated piedmont, near-source pediment, and basin-edge.
		Disconformity			
		(Bursum Formation)			

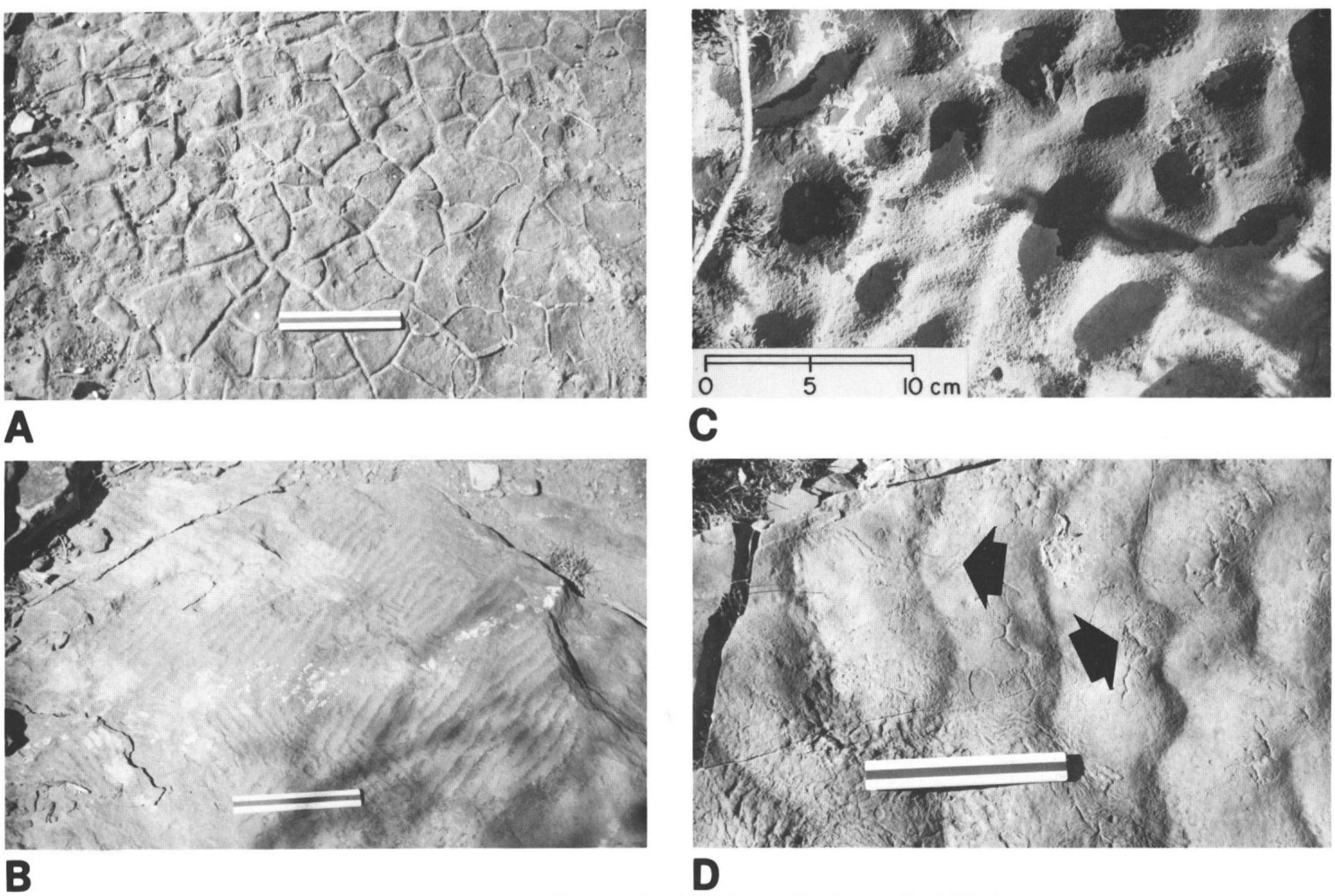

Figure 5. Sedimentary structures and features in upper sandstone unit of Abo Formation (appendix, AMS-4).
a. Close-up of mudcracks on argillaceous siltstone exposed in Cañon Espinoso, SE¼ NE¼, sec. 35, T3N, R5E. Scale is 15 cm.
b. Interference-type ripple marks on fine-grained sandstone in Cañon Espinoso, NE¼ NE¼, sec. 36, T3N, R5E. Scale is 15 cm.
c. Cusp-type ripple marks on fine-grained sandstone in Cañon Espinoso, NE¼ NE¼, sec. 36, T3N, R5E.
d. Unidentified trails and burrows in ripple-marked, fine-to-medium-grained sandstone, NE¼ SE¼, sec. 3, T2N, R5E. Scale is 15 cm.

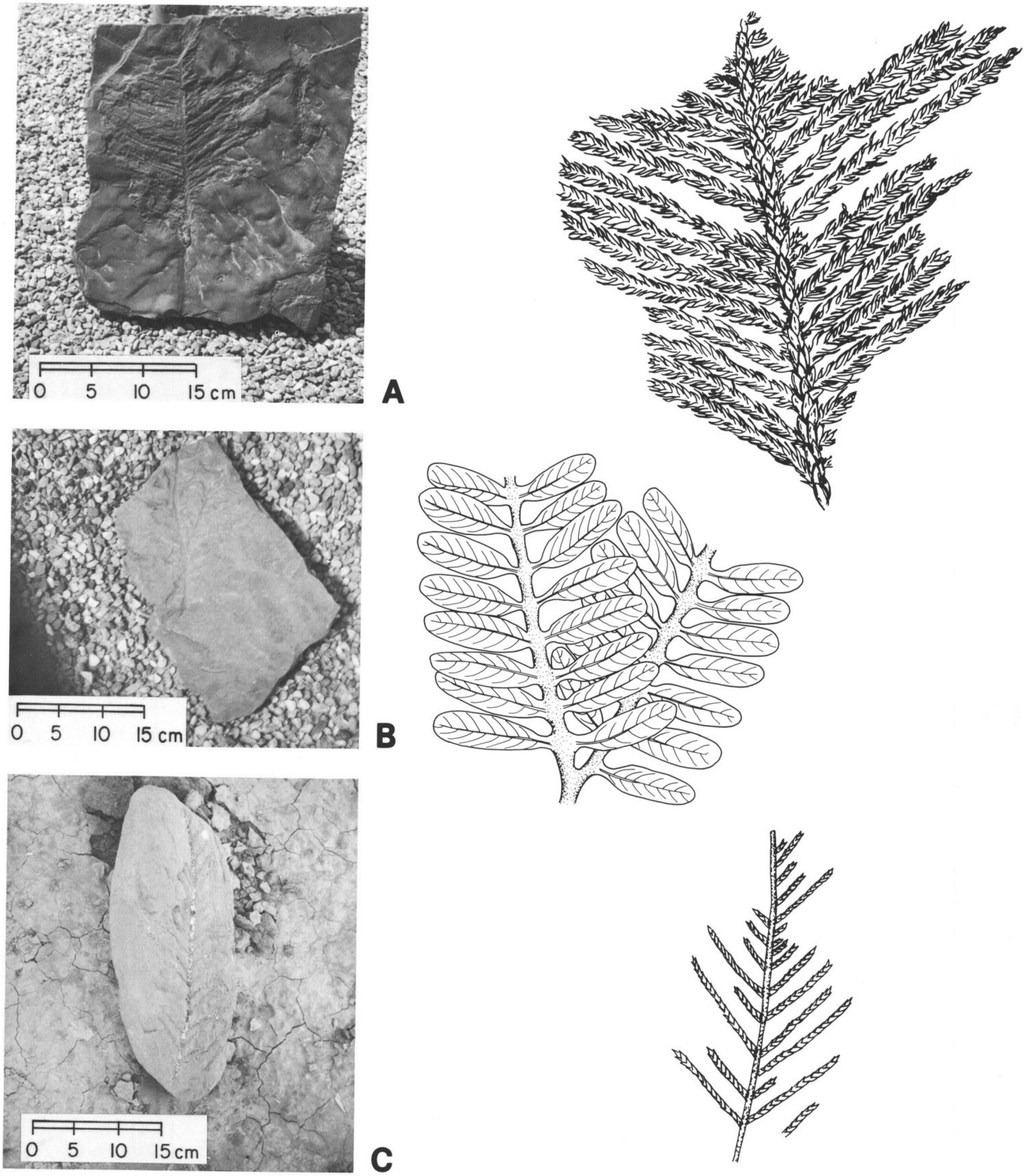

Figure 6. Callipteris *and* Supaia *floral impressions at fossil locality AMS-1-15F in the upper sandstone unit, NW¼ SE¼, sec. 33, T3N, R5E (appendix, AMS-1, unit 15).*

a. Walchia piniformis, Callipteris *floral zone (Wolfcampian) showing a branch with smaller branchlets of sheathed, needlelike leaves.*

b. Supaia thinnfeldioides, Supaia *floral zone (early or middle Leonardian) showing a dichotomous rachis of obliquely set pinnules.*

c. Brachyphyllum *sp.,* Supaia *floral zone (early or middle Leonardian) showing branching twigs which (although not visible in photograph) are sheathed with scalelike leaves.*

Figure 7. Tetrapod tracks and trails at fossil locality AMS-4-30F in fine-grained sandstone bed or upper sandstone unit exposed in Cañon Espinoso, NE¼ NW¼, sec. 36, T3N, R5E (appendix, AMS-4, unit 30). Scale is 15 cm.

The upper sandstone unit of the Abo grades into the overlying Meseta Blanca Sandstone Member of the Yeso Formation along a conformable contact which shows evidence of intertonguing. Total measured thickness of the upper unit is 129 m in the adjusted type section of Needham and Bates (1943). A near-marine, fluvial, deltaic, and tidal-flat depositional regime began to dominate during latest Abo time. The environment was transitional with that of the littoral Meseta Blanca. Fossil plants of the *Callipteris* and *Supaia* association indicate the upper Abc to be latest Wolfcampian and Leonardian in age, and to have beer deposited in a vigorous, middle-latitude climatic zone (Read and Mo- rnay, 1964, p. K17).

COPPER DEPOSITS AND URANIUM OCCURRENCES

The Scholle mining district is at the juncture of Socorro, Torrance and Valencia counties. Most of the production has come from Torrance County but some of the mining operations were in Socorro and Valencie counties. In addition to being called Scholle, the district has beer referred to as Carocito, Carricito, Caracita, and Abo in some reports The Abo mine is located 1.2 km southeast of Scholle and is one of the largest in the district (fig. 1). Most of the other important producirq localities are along the eastern edge of Cation Salado and Priest Canyon in a belt extending for about 14.5 km north of Scholle.

Copper deposits were known in the area as early as 1904 and wen noted by Emmons in 1905. Between 1949 and 1955, the area wa! intensely prospected for uranium but no economic deposits were dis. covered. Many claims have been located both for copper and uranium and there is some difficulty in assigning proper names to mines anc prospects due to the complex history of unpatented claim ownership.

Production

Mining in the Scholle district commenced in 1915 when at least 5 operations were engaged in exploration and development work. The district produced 263,721 kg of copper and 137,538 g of silver from 1915 through 1919, a period of activity which accounts for 55 percent of total production (Table 2). Significant amounts of ore were mined sporadically between 1922 and 1943, with the level of activity apparently related to the fluctuating price of copper. No production was reported between 1944 and 1955. Mining operations commenced again in 1956, and 31,484 kg were produced in 1957. The district has been inactive since 1961.

All of the production for the Scholle district is assigned to Torrance County in official reports. Because the district spans parts of three counties, some of the production may be credited to Valencia and Socorro counties rather than to the Scholle district. Available information indicates that total production for the district is approximately 12,340 metric tons of ore which contained 265,340 g of silver and 474,912 kg of copper.

Mining and Milling

All of the deposits which were exploited are near the surface and were mined by surface and underground methods. Open pits and trenches generally are less than 3 m deep. Adits and inclines have maximum lengths of about 21 to 30 m, and shafts are 3 to 23 m deep. The most extensive underground workings are at the Abo, Blue Star, and Copper Girl mines.

Most of the recovered ore was not concentrated except by hand-cobbing. Ore was shipped to the copper smelter of the American Smelting and Refining Company in El Paso, Texas. Several small heap-leaching plants were built at various times but were reported as unsuccessful. The leaching solvent was sulfuric acid; this resulted in excessive acid consumption due to the high calcium-carbonate content

Table 2. Summary of production in the Scholle mining district 1915-1961; NP denotes no production; asterisk indicates estimated production (U.S. Bureau of Mines, 1932-1979 and U.S. Geological Survey, 1914-1931).

Year	Deposits	Ore (metric ton)	Silver (g)	Copper (kg)
1915	5	171	3,857	11,390
1916	13	2,877	80,868	150,158
1917	14	1,967	40,807	90,884
1918	7	578	11,228	8,812
1919	2	68	778	2,477
1920-21	NP			
1922	1	15	404	788
1923	2	54	466	2,934
1924-27	NP			
1928	7	1,762	60,713	84,749
1929	4	1,814	43,948	72,707
1930	2	109	1,773	4,077
1931-32	NP			
1933	1	51	529	906
1934-35	NP			
1936	1	23	156	680
1937	NP			
1938	1	43	12,597	2,129
1939-42	NP			
1943	2	199	4,199	8,607
1944-55	NP			
1956			498*	2,085
1957	2	2,608	2,519	31,484
1958-60	NP			
1961	1	1*		45*
1962-79	NP			
Total		12,340	265,340	474,912

of the host rock. The ruins of one plant are directly north of the Scholle school. Leach pads and precipitate launders were of concrete construction. Another leach plant was built in 1956 and is located at the Abo mine.

Description

The copper deposits of the Scholle district are described by Soule (1956), Anderson (1957), and LaPoint (1976). All of the major producing mines are in the lower arkose unit of the Abo Formation. The mineralization usually is associated with organic material in coarse- to medium-grained, arkosic sandstone and conglomerate that represent small channel deposits as well as in underlying carbonaceous mudstone and siltstone. The ore in the channels is concentrated near channel flanks where carbonaceous debris is abundant. Host rocks for the copper are light gray to light brown. Many of the mineralized sandstones appear red due to red-stained feldspar where their matrices are gray or light brown.

The primary mineralization consists of chalcocite that has replaced carbonaceous debris in siltstone and arkosic sandstone, chalcocite that occurs as nodules in organic-rich gray mudstone, and chalcocite which has replaced limestone fragments and nodules. The oxidation of the primary minerals has resulted in the dissemination of secondary copper minerals. Malachite and azurite occur along bedding planes in mudstone and siltstone, as cement in sandstone, as a halo around chalcocite, and along fractures in sandstone.

The ore-bearing beds are nearly flat, with dips of 2° to 3° to the southeast. At many localities they are cut by joints and vertical faults of small displacement. The ore zones vary in thickness from 0.3 to 3.6 m, averaging about 0.6 m. Mineralization is very irregular, and concentrations are scattered and of insufficient value to be minable. Ore beds are small but often high grade. Samples from several mines in the district range between 0.58 and 5.72 percent copper and indicate the approximate grade range of the ore (Soule, 1956, p. 61).

Uranium mineralization has been reported in several mines and prospects in the Scholle district (Gibson, 1952; Gott and Erickson, 1952; Finch, 1967; and Hilpert, 1969). Among the more important localities are the Abo mine (sec. 3, T2N, R5E), the Abo mining claims (sec. 22, T3N, R5E), and the Copper Girl mine (sec. 28, T4N, R5E), all of which were worked for copper. A large area of low-grade radioactive sandstone and siltstone cut by a small seam of carnotite is about 5 km north of Scholle (Lovering, 1956).

Uranium minerals are disseminated in arkosic sandstone and conglomerate, siltstone, and mudstone, and also occur as a coating on joint surfaces. The grade is usually low; chemical assays range from a trace in most samples up to 13 percent L130„ in one select sample. Autunite, meta-autunite, torbernite, metatorbernite, uranophane, and carnotite have been identified in samples from the district. The uranium usually occurs in close association with copper mineralization, but the highest levels of radioactivity do not necessarily correspond to the richest copper concentrations. Radioactive zones are small pods 0.3 to 0.6 m thick with diameters less than 1.5 m. Economic uranium deposits have not been developed due to the low grade of the mineralization and the small size of the pods.

Origin

Organic material in the permeable channels and in underlying siltstone and mudstone is the most important factor in controlling the mineralization. Both copper and uranium minerals were deposited around carbonaceous debris, which created the reducing environment necessary for precipitation of the two metals from solution. Oxidation of primary copper minerals has resulted in the dissemination of malachite and azurite in coarse channel sandstones. A similar process apparently has taken place in mudstones and siltstones underlying channels, but to a lesser extent.

LaPoint (1974) postulates that erosion of mineral deposits or rocks with a high copper content in the ancestral Pedernal uplift may be the source of the copper in the deposits at Scholle. Arkosic conglomerate at the base of the Abo indicates uplift and erosion of the highland during deposition of the lower unit. Mobilization of copper is attributed to the breakdown of sulfides and mafic silicate minerals during diagenesis and the formation of sedimentary beds. Copper was transported downdip in alkaline, oxidizing ground waters along porous channels at the base of the Abo, until it precipitated around carbonaceous debris.

Uranium also may have been derived from the erosion of Precambrian rocks exposed in the ancestral Pedernal uplift. Fischer and Stewart (1961) point out that igneous rocks can be a source for both copper and uranium in ore deposits in first-generation sandstones. Both metals are dispersed in igneous rocks and occur in hydrothermal veins. The principal copper minerals and some uranium minerals in igneous rocks and veins oxidize readily to a higher valence when subjected to weathering. The metals are mobilized and transported by surface and ground waters, and metals are available to circulate in porous sediments derived from the weathering of an igneous terrane. Copper and uranium can be precipitated from the mobile, high-valence state in a reducing environment around carbonaceous debris in the sediments.

REFERENCES

Anderson, E. C., 1957, The metal resources of New Mexico and their economic features through 1954: New Mexico Bureau of Mines and Mineral Resources Bulletin 39, 183 p.

Baars, D. L., 1962, Permian System of the Colorado Plateau: American Association of Petroleum Geologists Bulletin, v. 46, p. 149-218.

Bates, R. L., Wilpolt, R. H., MacAlpin, A. J., and Vorbe, G., 1947, Geology of the Gran Quivira quadrangle, New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 26, 52 p.

Emmons, S. F., 1905, Copper in the redbeds of the Colorado Plateau region: U.S. Geological Survey Bulletin 260, P. 221-232.

Finch, W. I., 1967, Geology of epigenetic uranium deposits in sandstone in the United States: U.S. Geological Survey Professional Paper 538, 121 p.

Fischer, R. P. and Stewart, J. H., 1961, Copper, vanadium, and uranium deposits in sandstone-their distribution and geochemical cycles: Economic Geology, v. 56, p. 509-520.

Gibson, R., 1952, Reconnaissance of some redbed copper deposits in southwestern United States: U.S. Atomic Energy Commission Report RMO-890, 78 p.

Gott, G. B. and Erickson, R. L., 1952, Reconnaissance of uranium and copper deposits in part of New Mexico, Colorado, Utah, Idaho, and Wyoming: U.S. Geological Survey Circular 219, 16 p.

Hilpert, L. S., 1969, Uranium resources of northwestern New Mexico: U.S. Geological Survey Professional Paper 603, 166 p.

King, R. E., 1945, Stratigraphy and oil-producing zones of pre-San Andres formations of southeastern New Mexico: New Mexico Bureau of Mines and Mineral Resources Bulletin 23, 34 p.

Kottlowski, F. E. and Stewart, W. J., 1970, The Wolfcampian Joyita uplift in central New Mexico: New Mexico Bureau of Mines and Mineral Resources Memoir 23, part I, p. 1-31.

LaPoint, D. J., 1974, Genesis of sandstone-type copper deposits of the Scholle district, central New Mexico: Geological Society of American Abstracts with Programs, v. 5, p. 451-452.

, 1976, A comparison of selected sandstone copper deposits in New Mexico: Oklahoma Geological Survey Circular 77, p. 80-96.

Lee, W. and Girty, G. H., 1909, The Manzano Group of the Rio Grande Valley, New Mexico: U.S. Geological Survey Bulletin 389, 141 p.

Lovering, T. G., 1956, Radioactive deposits in New Mexico: U.S. Geological Survey Bulletin 1009-L, p. 315-390.

McKee, E. D. and others, 1967, Paleotectonic investigations of the Permian System in the United States: U.S. Geological Survey Professional Paper 515, 271 p.

Myers, D. A., 1977, Geologic map of the Scholle quadrangle, Socorro, Valencia, and Torrance Counties, New Mexico: U.S. Geological Survey Geologic, Quadrangle Map GQ-1412.

Needham, C. E. and Bates, R. L., 1943, Permian type sections in central New Mexico: Geological Society of American Bulletin, v. 54, p. 1653-1667.

Northrop, S. A. and Wood, G. H., 1946, Geology of Nacimiento Mountains, San Pedro Mountain, and adjacent plateaus in parts of Sandoval and Rio Arriba Counties, New Mexico: U.S. Geological Survey Oil and Gas Preliminary Investigations Map 57.

Read, C. B. and Mamay, S. H., 1964, Upper Paleozoic floral zones and floral provinces of the United States: U.S. Geological Survey Professional Paper 454-K, p. KI-K35.

Sou16, J. H., 1956, Reconnaissance of the "red bed" copper deposits in southeastern Colorado and New Mexico: U.S. Bureau of Mines Information Circular 7740, 74 p.

U.S. Bureau of Mines, 1932-1979, Minerals yearbook, v. II: U.S. Bureau of Mines, Washington, D.C.

U.S. Geological Survey, 1914-1931, Mineral resources of the United States, part 1: U.S. Geological Survey, Washington, D.C.

Wilpolt, R. H., MacAlpin, A. J., Bates, R. L., and Vorbe, G., 1946, Geological map and stratigraphic sections of Paleozoic rocks of Joyita Hills, Los Pinos Mountains, and northern Chupadera Mesa, Valencia, Torrance, and Socorro Counties, New Mexico: U.S. Geological Survey Oil and Gas Preliminary Investigations Map 61.

APPENDIX

ABO FORMATION TYPE SECTION (ATS)

(secs. 33, 34, 35, 36, and 25, T3N, R5E, Socorro and Torrance counties, New Mexico)

Type section of Abo Formation measured just north of U.S. Highway 60 at Scholle from the base of the formation in Calton Salado, along the north side of Abo Canyon to the top of the formation near Abo mission ruins in Salinas National Monument. Measured by Needham and Bates in 1943. Adjusted formational top, informal stratigraphic units within the Abo, and metric-unit conversions added as part of this report.

	Thickness (meters)
PERMIAN-YESO FORMATION (MESETA BLANCA SANDSTONE MEMBER)	
Unit 40. Sandstone: white, one massive bed; upper part weathers limy	1.8
Unit 39. Sandstone: pink, medium grained, in beds of medium thickness	13.1
Unit 38. Sandstone: light colored, coarse	0.9
Unit 37. Shale: pink, sandy, with sandstone parting	2.1
Unit 36. Sandstone: light colored, coarse	1.7
Unit 35. Sandstone: pink and buff, with shale partings	6.4
Unit 34. Sandstone: red	2.1
Unit 33. Sandstone: pink, shaly; and sandy shale	3.7
Gradational Contact	
PERMIAN-ABO FORMATION	0.9
Unit 32. Shale: red	
Unit 31. Sandstone: light pink, medium grained	0.6
Unit 30. Shale: pink	2.4
Unit 29. Sandstone: buff, thin bedded and shaly, fine grained	5.5
Unit 28. Shale: red	7.6
Unit 27. Sandstone and shale: buff	4.6
Unit 26. Sandstone: pink, medium grained, thin bedded in lower part, massive in upper	7.6
Unit 25. Shale: buff, partly covered	9.8
Unit 24. Sandstone: pink, medium to heavy bedded; caps mesa	4.9
Base of Upper Sandstone Unit; Top of Middle Mudstone Unit	
Unit 23. Sandstone and shale: pink and red, interbedded; partly coyered	13.7
Unit 22. Shale: red, partly covered	14.6
Unit 21. Sandstone: red, shaly	3.7
Unit 20. Sandstone: red, medium bedded, medium grained, crossbedded; weathers blocky. This bed and No. 21 cap a wide prominent cuesta	1.4
Unit 19. Shale: yellow-gray	0.3
Unit 18. Sandstone: red, fine, shaly, extremely crossbedded	8.2
Unit 17. Shale and sandstone: red, partly covered	7.9
Unit 16. Sandstone: red, medium bedded, medium grained, crossbedded	1.8
Unit 15. Shale: red, partly covered	21.3
Unit 14. Sandstone: red, coarse, crossbedded; carries conglomerate lenses	4.9
Unit 13. Conglomerate: limestone pebbles in red sandstone	1.5
Unit 12. Shale: red, partly covered	4.9
Unit 11. Sandstone: red, slabby	0.9
Unit 10. Mostly covered: some red sandy shale	52.4
Unit 9. Sandstone and arkose: dark red, coarse	3.0
Unit 8. Covered: probably red shale	15.9
Base of Middle Mudstone Unit; Top of Lower Arkose Unit	
Unit 7. Sandstone: red, arkosic, coarse; forms ledge	1.8
Unit 6. Sandstone: red, shaly, arkosic	3.0
Unit 5. Covered: probably red shale	3.4
Unit 4. Sandstone: red-brown, coarse, arkosic, conglomerate	1.8
Unit 3. Covered: probably red shale	21.3
Unit 2. Arkose and sandstone: red-brown, thick bedded, with fragments of limestone	4.6
Unit 1. Sandstone and shale: interbedded, partly covered	10.7
Total thickness of Abo formation	278.7
Disconformity	
PERMIAN-BURSUM FORMATION	

CANON SALADO-RED HILL SECTION (AMS-1)

(sec. 33, T3N, R5E, Valencia and Socorro counties, New Mexico)

Measured from Abo-Bursum contact in Cafion Salado at U.S. Forest Service Road 422, 0.8 km north of U.S. Highway 60 to top of Red Hill above Scholle school. Measured by W. 0. Hatchell, April, 1965.

PERMIAN-ABO FORMATION	Thickness (meters)
Erosional Surface	
Unit 22. Sandstone: moderate red, fine to medium blocky, massive; irregularly shaped, bleached, grayish pink spots	6.7
Unit 21. Conglomerate: like units 14 and 12	0.2
Unit 20. Covered interval: mudstone (?)	14.0
Unit 19. Sandstone: reddish brown, medium to coarse, very arkosic (weathered feldspars); lenticular; crossbedded	3.0
Unit 18. Conglomerate: like unit 14	0.9
Unit 17. Covered interval: blocks of fine to medium, crossbedded sandstone (as unit 16) ranging to 0.8 m in diameter	9.1
Unit 16. Sandstone: grayish pink, fine; grades into covered interval above	0.1
Unit 15. Sandstone: moderate red, fine to very fine, micaceous fine laminar crossbedding; sporadic lenses of fine to medium, arkosic sandstone averaging 13 cm thick; good to fair floral impressions. Fossil plant locality AMS-I-15F with imprints of *Callipteris* and *Supaia* flora as follows: *Walchia piniformis, Supaia thinnfeldioides,* and *Brachyphyllum* sp.	3.7
Unit 14. Conglomerate: pale red, coarse; angular limestone fragments range to 8 cm diameter; coarse crystalline calcium-carbonate matrix	0.6
Base of Upper Sandstone Unit; Top of Middle Mudstone Unit	
Unit 13. Mudstone: grayish red	13.4
Unit 12. Conglomerate: grayish red; limestone-pellet conglomerate; quartz detritus to 0.6 cm diameter; calcareous matrix	0.2
Unit 11. Siltstone: grayish red, silty, blocky; ledge former	0.2
Unit 10. Mudstone: grayish red, silty, massive, blocky; mottled stringers and spots, light brownish gray	15.9
Unit 9. Covered interval: sandstone and mudstones (?)	47.3
Base of Middle Sandstone Unit; Top of Lower Arkose Unit	
Unit 8. Sandstone: grayish red, medium grained, micaceous, crossbedded, medium bedding. Sandstone: grayish red, fine, flaggy, thin bedded	4.0
Unit 7. Covered interval: siltstone (?)	6.7
Unit 6. Sandstone: grayish red, fine to medium; slightly micaceous. Sandstone: grayish red, coarse, arkosic; crossbedded. Sandstone: grayish brown to pale brown, medium, arkosic, micaceous; flaggy; medium bedded	9.6

Unit 5. Mudstone: light brownish gray to pinkish gray, fine, massive, blocky; irregularly mottled to light brownish gray	4.4
Unit 4. Sandstone: grayish red, coarse, arkosic; crossbedded	0.5
Unit 3. Covered interval: mudstone (?); forms low bench	6.9
Unit 2. Conglomerate: grayish red; limestone-pellet conglomerate with quartz and feldspar detritus; sharp but conformable lithologic break with underlying Bursum limestone. Conglomerate: as above but very dark red, arkosic; quartz pebbles range to 2.5 cm diameter	3.0
Total Abo Measured	150.4

Disconformity

PERMIAN-BURSUM FORMATION

Unit I. Limestone: pale reddish purple, massive, microcrystalline; mottled to light olive gray; calcite stringers; no fossils noted; upper 1.5 m exposed	1.5

Base not exposed

Total Bursum Exposed	1.5

ABO MINE SECTION (AMS-2)
(secs. 2 and 3, T2N, R5E, Torrance County, New Mexico)

Measured from arroyo below Abo Mine, 1.2 km southeast of Scholle, up cuesta on south rim of Abo Canyon. Measured by W. 0. Hatchell, April, 1965.

PERMIAN-ABO FORMATION	Thickness (meters)
Erosional Surface	
Unit 15. Sandstone: moderate orange pink, fine, massive, non-micaceous, small-scale crossbedding; interference ripple marks; color ranges to light brown	4.6
Unit 14. Sandstone: very pale orange to grayish red, fine to medium, thin bedded; laminar crossbedding; interference (cross type) ripple marks; worm (?) burrows	1.4
Unit 13. Conglomerate: pinkish gray; limestone pebbles range to 8 cm diameter, subangular to subrounded	0.5
Unit 12. Siltstone: moderate reddish brown, blocky, friable; poorly exposed	5.5
Unit 11. Sandstone: pale red to very pale orange, fine to coarse, massive, lenticular bodies of limestone conglomerate ranging to maximum thickness of 1 m; crossbedded; current ripple marks along some bedding planes; mudcracks in fine, evenly bedded phase	9.1
Unit 10. Covered interval: mudstone or siltstone (?); a few fragments of plant imprints on siltstone talus	29.0
Unit 9. Sandstone: pale reddish brown, fine to very fine, thin bedded, flaggy on outcrop; small-scale crossbedding	1.2
Unit 8. Sandstone: pale reddish brown to grayish orange-pink, fine, slightly micaceous, thick bedded, crossbedded; cross-type ripple marks	7.0
Unit 7. Covered interval: mudstone (?); slope former	8.2
Unit 6. Mudstone: grayish red, silty, non-micaceous, massive; irregular lenses of siltstone; mottled, grayish orange-pink	11.0
Base of Middle Mudstone Unit; Top of Lower Arkose Unit	
Unit 5. Sandstone: grayish red; interbedded siltstone and conglomcrate; sandstone fine to medium; limestone-pellet conglomerate, calcium-carbonate cement; calcite stringers throughout; unit 5 comprises zone of copper mineralization at Abo Mine	3.0
Unit 4. Siltstone: pale red brown; interbedded sandstone and mudstone; mudstone mottled to grayish green, silty	1.5
Unit 3. Covered interval: (Quaternary alluvium)	10.4
Unit 2. Mudstone: grayish red, silty, non-micaceous; mottled stringers, light brown gray, orientated parallel to bedding (?)	1.5
Unit 1. Sandstone: grayish red, massive; lentils of limestone conglomerate, pebbles range to 1 in diameter; sandstone fine to coarse; forms resistant ledge in bed of arroyo below railroad grade	3.2
Quaternary Alluvium	
Total Abo Measured	97.1

SAN RAFAEL SPRING SECTION (AMS-3)
(sec. 35, T3N, R5E, Torrance County, New Mexico)

Measured from below San Rafael Spring north of U.S. Highway 60 to exposures above springline. Measured by W. 0. Hatchell, April, 1965.

PERMIAN-ABO FORMATION	Thickness (meters)
Erosional Surface	
Unit 12. Sandstone: moderate brown to pinkish gray, fine to medium; thin to medium bedding; crossbedded; ripple marks, mudcracks	14.3
Unit 11. Mudstone: moderate reddish brown, silty, massive, mottled	3.8
Unit 10. Sandstone: pale reddish brown to pale red, fine to medium, thin to medium bedding; mudstone partings average 8 cm to 16 cm thick	4.6
Unit 9. Mudstone: grayish red, silty; lenticular zones of silty nodules; mottling to light gray	1.0
Unit 8. Sandstone: grayish red, fine to medium, massive, crossbedded; thin, lenticular partings of mudstone	5.5
Base of Upper Sandstone Unit; Top of Middle Mudstone Unit	
Unit 7. Mudstone: moderate reddish brown, silty; siltstone lenses ranging to 8 cm thick; mottled irregularly	1.8
Unit 6. Mudstone: poor exposure; forms floor of valley	11.6
Unit 5. Sandstone: moderate reddish brown, fine to medium grained; massive; crossbedded	1.2
Unit 4. Siltstone: moderate reddish brown, sandy, micaceous, thin bedded	3.5
Unit 3. Mudstone: pale reddish brown to grayish red, silty, massive; mottled in masses ranging to 30 cm diameter; micaceous	5.0
Unit 2. Sandstone: grayish red to yellowish gray near the top of exposure; fine to very fine, slightly micaceous; mottled as mudstone below; quartz-lined vugs range to 3 cm diameter	0.3
Unit 1. Mudstone: pale red-brown, silty, massive; irregularly mottled to light greenish gray in upper 1 m	1.0
Total Abo Measured	53.6

CANON ESPINOSO SECTION (AMS-4)
(secs. 35 and 36, T3N, R5E, Torrance County, New Mexico)

Measured from north roadcuts on U.S. Highway 60, up Cation Espinoso, across State Road 513 and up hill above Abo mission ruins in Salinas National Monument. Measured by W. 0. Hatchell, April, 1965.

PERMIAN-YESO FORMATION (MESETA BLANCA SANDSTONE MEMBER)	Thickness (meters)
Unit 35. Sandstone: light brown, fine to medium, gypsiferous; moderately sorted; interbedded with very light gray, gypsiferous siltstone; thin, evenly bedded. Symmetrical current ripple marks abundant on bedding planes; salt hoppers; entire unit flaggy on outcrop	1.7
Base of Yeso Formation (Meseta Blanca Sandstone Member)	
Gradational Contact	
PERMIAN-ABO FORMATION	
Unit 34. Mudstone: grayish red, silty, thinly bedded, slightly micaceous; mottled along bedding planes to grayish yellow-green especially in upper 15 cm	2.6
Unit 33. Covered interval: mudstone (?)	1.5
Unit 32. Sandstone: grayish red, fine, very thinly bedded, symmetrical and cross-type ripple marks	0.6
Siltstone: dark reddish brown, very thinly bedded, fissile	0.5
Unit 31. Sandstone: pale red to pinkish gray, fine, thin bedded, 5-to-8-cm thick fissile mudstone partings; cusp-shaped ripple marks	0.9
Unit 30. Sandstone: pale red to grayish red, fine to medium-fine, thin bedded, flaggy; small-scale crossbedding, asymmetrical ripple marks; 3-to-5-cm thick fissile mudstone partings abundant; unidentified tetrapod tracks and trails; fossil locality AMS-4-30F	0.6

Unit 29. Sandstone: pale red to grayish red, fine, massive	1.1
Unit 28. Sandstone: pale red, fine, thin bedded, Baggy	0.9
Unit 27. Covered interval: mudstone (?)	2.4
Unit 26. Sandstone: moderate reddish brown, fine, thin bedded; small-scale crossbedding; interbedded silty partings averaging 20 cm thick	15
Unit 25. Sandstone: very pale orange, fine; thin laminae range to 0.5 cm thick	0.6
Unit 24. Siltstone: moderate reddish brown, fissile; occasional fine, sandy lenses	2.1
Unit 23. Sandstone: pale red, fine to medium-fine, thin bedded	0.6
Unit 22. Sandstone: moderate reddish brown, arkosic, fine to medium, crossbedded	15
Unit 21. Sandstone: gray orange-pink, fine, massive	03
Unit 20. Sandstone: pale reddish brown, fine, medium bedded laminar bedding	1.8
Unit 19. Sandstone: medium orange-pink, massive, crossbedded	0.6
Unit 18. Siltstone: pale reddish brown to pale yellow-orange, medium bedded in laminar sets	0.9
Unit 17. Sandstone: pale red, fine to medium-fine, thin bedded	09
Unit 16. Sandstone: light brown to grayish orange-pink, fine to medium; very thinly bedded; flaggy on outcrop	05
Unit 15. Sandstone: pale red, fine to medium-fine, medium bedded; siltstone partings ranging to 15 cm thick	1.8
Unit 14. Mudstone: grayish red, thin bedded with siltstone partings ranging to 0.5 cm thick; mottled to greenish gray near top	0.5
Unit 13. Siltstone: light greenish gray	0.5
Unit 12. Mudstone: grayish red, silty, fissile, massive	1.5
Unit 11. Siltstone: pale reddish brown, fissile, massive	0.6
Unit 10. Mudstone: dark reddish brown, silty, fissile, massive; mottled	3.4
Unit 9. Sandstone: grayish red, fine, massive	0.5
Unit 8. Mudstone: moderate reddish brown, massive, silty, fissile	0.5
Unit 7. Sandstone: moderate reddish brown to pale reddish brown, fine, medium bedded; small-scale crossbedding; mudcracks; upper 0.5 cm light gray	3.7
Unit 6. Sandstone: pale reddish brown; interbedded mudstone and siltstone partings; fine, even bedded; mudcracks abundant in mudstone and siltstone partings	3.0
Unit 5. Sandstone: pale reddish brown, fine, massive; crossbedded; mudcracks exposed on siltstone partings	1.5
Base of Upper Sandstone Unit; Top of Middle Mudstone Unit	
Unit 4. Mudstone: grayish red, massive, fissile, silty; irregularly mottled to greenish gray	12.2
Unit 3. Sandstone: moderate reddish brown, fine, massive, mottled	0.9
Unit 2. Siltstone: moderate reddish brown; nodular, greenish gray mottling	0.9
Unit 1. Mudstone: dark reddish brown, silty, massive; weathers into blocky masses; mottled to light greenish gray; paper-thin calcite veins	1.7
Total Abo Measured	57.3