

# Stromatolites of the Mescal Limestone (Apache Group, middle Proterozoic, central Arizona): Taxonomy, biostratigraphy, and paleoenvironments

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## ABSTRACT

The 25- to 30-m-thick Algal Member of the Mescal Limestone (middle Proterozoic Apache Group) contains two distinct stromatolitic units: at the base, a 2- to 3-m-thick unit composed of columnar stromatolites and above, a thicker unit of stratiform and pseudocolumnar stromatolites. Columnar forms from the first unit belong to the Group *Tungussia*, and two new forms are described: *T. mescalita* and *T. chrysofila*. Among the pseudocolumnar stromatolites of the thicker unit, one distinctive new taxon, *Apachina henryi*, is described. Because of the low stromatolite diversity, the biostratigraphic value of this assemblage is limited. The presence of *Tungussia* is consistent with the generally accepted isotopic age for the Apache Group of 1200 to 1100 Ma. The Mescal stromatolites do not closely resemble any other known Proterozoic stromatolites in the southwestern United States or northwestern Mexico.

Analyses of sedimentary features and stromatolite growth forms suggest deposition on a stable, flat, shallow, subtidal protected platform during phases of *Tungussia* growth. Current action probably influenced the development of columns, pseudocolumns, and elongate stromatolitic ridges; these conditions alternated with phases of relatively quiet water characterized by nonoriented stromatolitic domes and stratiform stromatolites. Stable conditions favorable for development of the Mescal stromatolites were short-lived and did not permit the development of thick, stromatolite-bearing units such as those characteristic of many Proterozoic sequences elsewhere.

## INTRODUCTION

Proterozoic interregional stromatolite correlation remains a somewhat neglected area of research in the United States. Compared with other regions, the United States is not particularly rich in middle and late Proterozoic stromatolite-bearing sequences—the time interval for which there is a great deal of biostratigraphic information available (Bertrand-Sarfati and Walter, 1981). Although Americans figured prominently in the development of stromatolite research (Walcott, 1914; Fenton and Fenton, 1931; Cloud, 1942; Rezak, 1957; Ginsburg, 1960), the development of stromatolite biostratigraphy was a Soviet contribution (Keller and others, 1960) that was largely ignored by American researchers until 1969 (Cloud and Semikhatov, 1969).

Of the approximately 12 stromatolite-containing regions in the United States (southeastern California; the Belt Basin, Montana; east-central Idaho; Medicine Bow Mountains, Wyoming; Hartville uplift, Wyoming; east-central Alaska; Grand Canyon, Arizona; West Texas; Upper Peninsula of Michigan; northeastern Minnesota; Adirondacks of New York; and central Arizona), only stromatolites of the Belt (see Horodyski, 1989) and Hartville uplift, Wyoming (Hofmann and Snyder, 1985), have been studied in detail. We report here new information and taxonomic descriptions of stromatolites from the middle Proterozoic Mescal Limestone of central Arizona, and we compare them to other stromatolites in the southwestern United States and northwestern Mexico.

The Mescal Limestone contains a conspicuous 20- to 25-m-thick stromatolitic unit termed the Algal Member (Shride, 1967; Fig. 1). In describing weathered surfaces of outcrops expos-

ing what are now known to be stromatolites, Ransome (1916, p. 138) referred to the Mescal's "... gnarled banding that is its most characteristic feature." Wilson (1928) recognized the stromatolites, considered them to be an important stratigraphic marker, and first used the term "algal member" for the unit.

Although the Mescal stromatolites have been known for some time, the identification of morphologically distinctive stromatolites proceeded slowly. The pseudocolumnar stromatolite *Collenia frequens* Walcott 1914 was identified by Rezak (*in Shride*, 1967, p. 32, Fig. 9). Cloud and Semikhatov (1969) mentioned the presence of *Conophyton* cf. *garganicum* and illustrated its microstructure. They also identified and described the branching columnar stromatolite *Tungussia* form indeterminate. McConnell (1972, 1975) provided additional information on *Tungussia* and provisionally identified *Baicalia* cf. *baicalica* and *Parmites* fm. Aside from Cloud and Semikhatov (1969), however, the identification of stromatolite taxa in the Mescal was apparently based on appearance in outcrop and hand specimen and not on the serial sectioning of samples, graphical reconstruction of three-dimensional morphology, and thin-section analysis of microstructure, which are critical for proper taxonomic identifications.

Attempts at using Mescal stromatolites to aid interregional correlations include Darton's (1925) comparison of the Mescal to the Bass Limestone in the Grand Canyon, Arizona. Shride (1967) used the Mescal stromatolites as well as other stratigraphic similarities to suggest possible correlation of the Mescal with the Crystal Spring Formation (Pahrump Group of southeastern California) and the Castner Marble (Franklin Mountains, Texas), as well as the Bass Limestone.

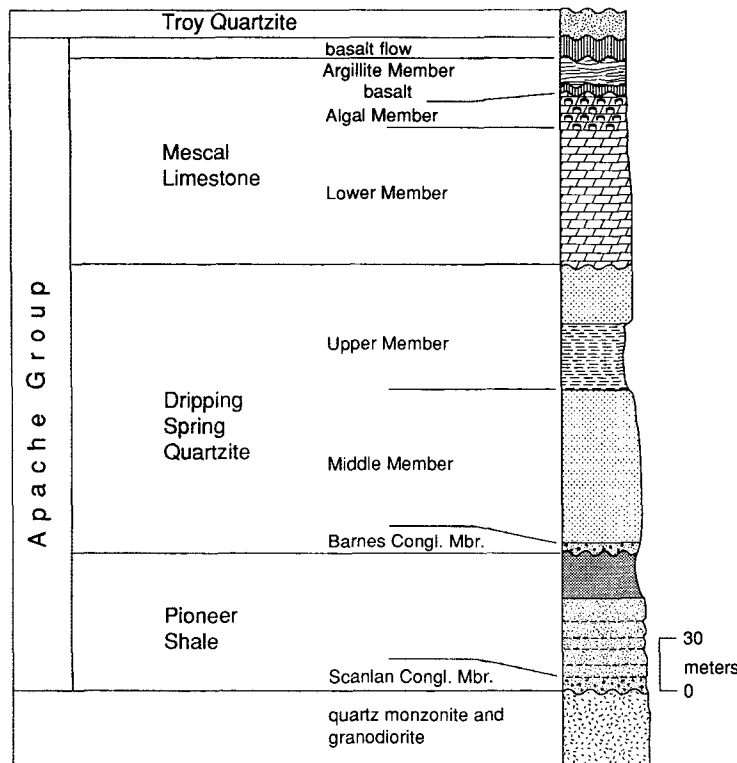


Figure 1. Generalized stratigraphic section of the Apache Group (redrawn from McConnell, 1975, with modifications from Wrucke, 1989).

## STRATIGRAPHY AND AGE OF THE MESCAL LIMESTONE

The Apache Group crops out over ~42,000 km<sup>2</sup> of central Arizona and ranges in thickness from ~380 to 850 m (less the diabase sills; Shride, 1967; McConnell, 1975; Wrucke, 1989). Three formations, each separated by an unconformity, make up the Apache Group (Fig. 1); in ascending order, they are the Pioneer Shale (45 to 155 m thick), the Dripping Spring Quartzite (140 to 215 m thick), and the Mescal Limestone (75 to 130 m thick) (Wrucke, 1989). The Mescal is subdivided into Lower, Algal, and Argillite Members (Shride, 1967). An erosional unconformity occurs between the Algal and Argillite Members (Shride, 1967). The Algal and Lower Members are separated by a sharp contact (Shride, 1967). Basalt flows, 0 to 125 m thick, occur at two stratigraphic levels. One, of regional extent, separates the Upper Member from the overlying Troy Quartzite. The other, which is known locally from three regions and is as much as 35 m thick, separates the Algal Member from the Argillite Member (Shride, 1967). Paleosols developed on upper Mescal units when the limestone was subaerially exposed and eroded (Beeunas and Knauth, 1985).

In their paper on the Proterozoic geochronol-

ogy of central Arizona, Livingston and Damon (1968) provided the following summary. The Apache Group overlies the Ruin Granite (Quartz Monzonite) with a Rb-Sr isochron/biotite K-Ar age of 1420 Ma. The Ruin is intruded by diabase sills dated at 1120 Ma by means of U-Pb isotopic dating on zircons (Silver, 1978, p. 162). Magnetostratigraphic correlations indicate that the Mescal Limestone correlates with the lower Dox Sandstone of the Unkar Group, Grand Canyon, and with the lower part of the middle Keweenaw Supergroup of the Lake Superior region, radiometrically dated at ca. 1145 Ma (see Link and others, in press). The top of the Unkar Group is radiometrically dated as 1070 ± 70 Ma (Link and others, in press). The middle Riphean age (1350–1050 Ma) suggested by some of the stromatolites (McConnell, 1975) agrees with these radiometric and magnetostratigraphic results.

## THE STROMATOLITE SUCCESSIONS

Stromatolites of the Algal Member were collected and studied from several different localities (Fig. 2). Most of our field work was concentrated on exposed sections in the McFadden Peak quadrangle and at a chrysotile mine in the Blue House Mountain quadrangle. Addi-

tional sections were studied along Walnut Creek (Young quadrangle), along Arizona Highway 288 south of Roosevelt Dam, and at Salt River along U.S. Highway 60.

## McFadden Peak Quadrangle Succession

This succession is ~25 m thick and is best exposed in the immediate vicinity of Bench Mark 5083 (Section 11, T. 7 N., R. 15 E., McFadden Peak quadrangle). Five different types of stromatolites are organized into five distinctive layers. Each type of stromatolite intergrades vertically with the type characterizing the overlying layer (Fig. 3A). A biostrome composed of dense clusters of *Tungussia mescalita* constitutes the basal 1.2 m of the succession (layer 1). The *T. mescalita* columns, which grade vertically into larger columns (layer 2) with more conical laminae (no axial zone) and diffuse lateral boundaries, closely resemble *T. chrysotila* (Fig. 3A). The uppermost columns of layer 2 are more bridged and ramified than those in lower portions of the same layer. Layer 3 is composed of undulate laminae (with moderate to high inheritance) organized into parallel ridges. Layer 4 contains subcylindrical pseudocolumnar stromatolites that are organized into complex ridges as well as the predominantly pseudocolumnar stromatolite *Apachina henryi*. Finally, wavy laminae and low domes that have been called *Collenia frequens* Walcott 1914 (Shride, 1967; see Fig. 13b below) compose layer 5. All of these types and layers appear to be distributed over a large area in the vicinity of Bench Mark 5083. Stratiform stromatolites and fascicles of *T. mescalita* and *T. chrysotila* occur throughout sections visited in McFadden Peak quadrangle; however, *Apachina* has been observed at one locality.

## Chrysotile Mine Road Succession (Blue House Mountain Quadrangle)

This succession is exposed along the west side of the gravel road to the abandoned mine site of Chrysotile, 3.6 km northwest of the intersection with U.S. Highway 60, 5.5 km south of Seneca, Arizona (Blue House Mountain quadrangle; Fig. 1). At the base of the Algal Member, discrete, globular-shaped examples of *Tungussia* have developed from laminated dolostone, forming a 2-m-thick biostrome (Fig. 3B). Although composed of dolomite, the representatives of *Tungussia* are enclosed in an argillaceous carbonate (metamorphism has altered it to argillaceous limestone) that commonly weathers recessively, leaving isolated mushroom-shaped stromatolites. The stromatolites have conical laminae and, in outcrop, exhibit pseudoramifications

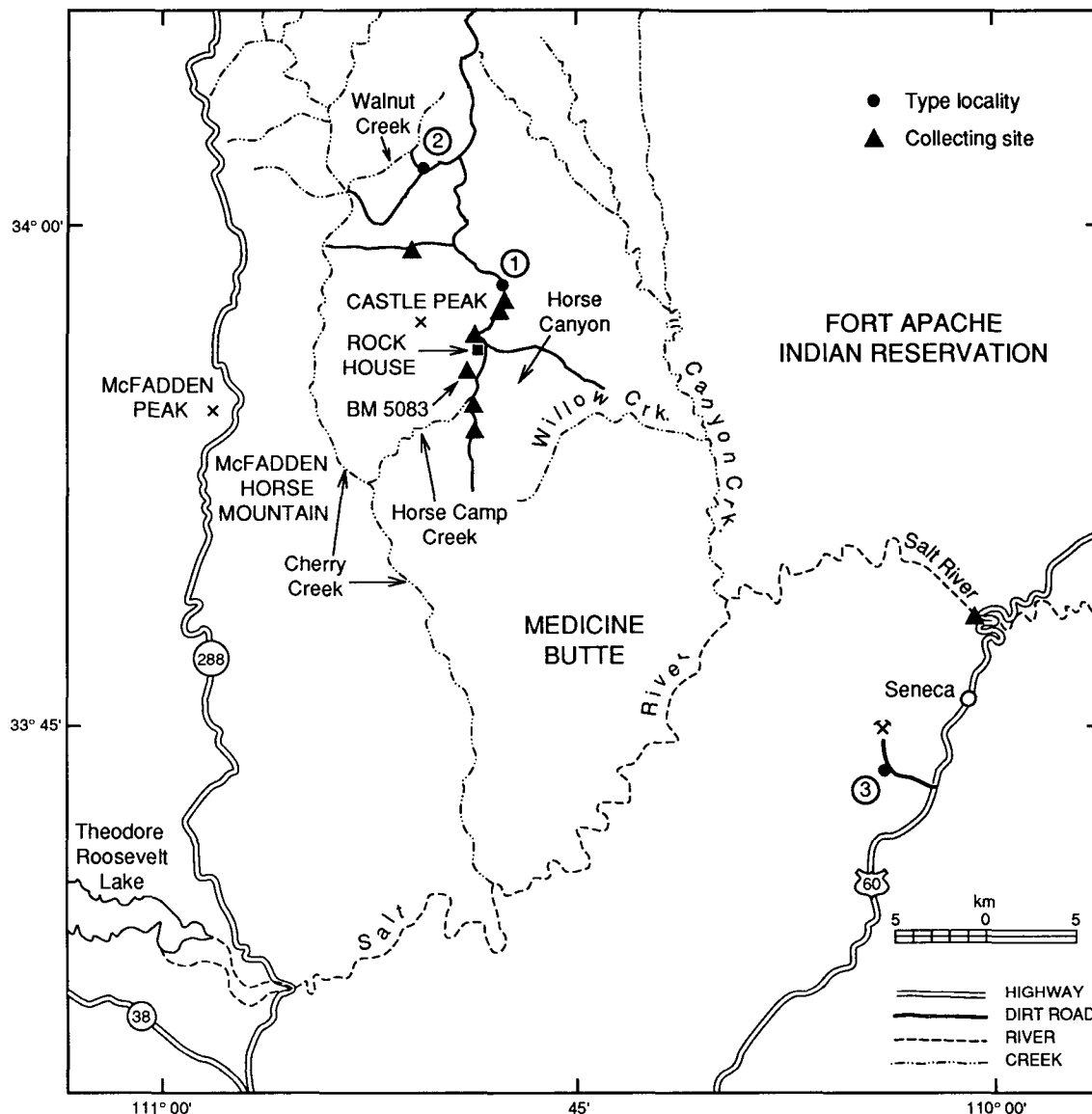


Figure 2. Map showing outcrop localities where stromatolites were collected (map adapted from Mesa and Holbrook 1:250,000 sheets). Type localities are numbered (refer to text); other localities are indicated by triangles.

produced by deep fissures into the columns. These structures are overlain by laminated (?stratiform stromatolites) carbonate followed by a 4- to 5-m-thick layer of ramified, tall bushes of *Tungussia chrysofila*. The tops of the *T. chrysofila* columns have caps of short conical laminations. Above *Tungussia*, stratiform stromatolites begin abruptly.

#### SYSTEMATIC DESCRIPTION OF STROMATOLITES

Three taxa are described from two localities: one new Group, *Apachina*, and two new Forms of *Tungussia*. *Collenia frequens* Walcott 1914

was not examined, and *Conophyton* was not observed in the field. Holotypes are housed at the Centre Géologique et Géophysique, Montpellier, France, and paratypes are on deposit in the Type Collection of the Preston Cloud Research Laboratory, University of California, Santa Barbara, California.

#### *Apachina* new Group

*Type form*: *Apachina henryi* new Form

*Etymology*: Named after the Apache Indian Nation.

*Diagnosis*: Complex laminated structure consisting of pseudocolumns and columns radiating

in a perpendicular fashion from a central elongate ridge.

*Comparisons*: The pseudocolumnar portions resemble *Omachtenia* Nuzhnov 1967, and some of the columnar portions resemble some elongate examples of *Kussiella* Krylov 1963. Otherwise, this stromatolite resembles no other taxa.

#### *Apachina henryi* new Form (Figs. 4a-4e, Figs. 5a-5c)

*Etymology*: Named in honor of Henry Pollak of the University of California, Santa Barbara, field assistant and naturalist.

*Material*: Three specimens from one outcrop.

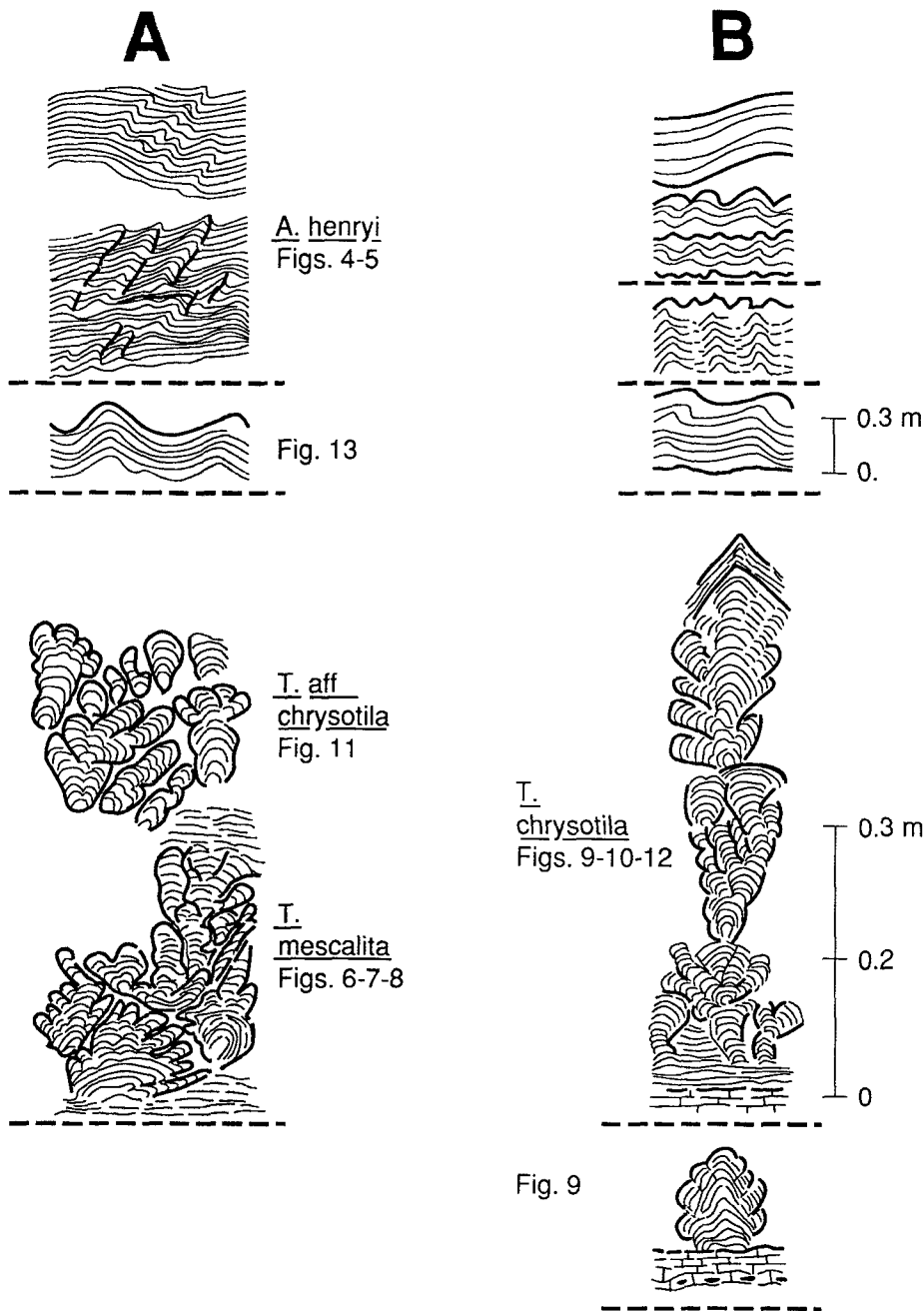


Figure 3. Schematic successions of stromatolites through the Mescal Algal Member at Bench Mark 5083 (A) and chrysotile mine (B) localities. Drawings of the columnar stromatolite layer show the relationship between clusters; drawings of the stratiform stromatolites above illustrate some of the most striking features. See figures noted at sides of drawings for additional illustrations.

*Holotype:* Sample e of 1 of 5/14/79.

*Type locality:* Outcrop located ~3.5 km north of Rock House (Bench Mark 5083, Section 11 T. 7 N., R. 15 E., McFadden Peak quadrangle, Arizona; locality 1 in Fig. 2).

*Diagnosis:* Complex, subcylindrical to later-

ally elongate pseudocolumns and columns that radiate in a perpendicular fashion from a central ridge. Pseudocolumns grade vertically into short, true columns. Laminae are shaped convex to conical and are asymmetrical.

*Mode of occurrence:* *A. henryi* occurs as one

or two complex structures within stratiform stromatolitic biostromes composed in part of parallel, asymmetric ridges. Because of the limited outcrop available, lateral extensions of the stromatolite have not been observed. On the exposed surface that best displays the stromatolite (Figs. 4b–4c), the ridges are oriented parallel to one another (approximately N132°E) and the elongate columns issuing from the ridges are almost perpendicular to the ridges (approximately N15°E).

*Column shape and branching:* Pseudocolumns initiate from a low ridge (Fig. 4). The initial pseudocolumns grew on, and perpendicular to, the flank of the ridge. As the pseudocolumns grew, they curved up to become normal to bedding. Linkage between pseudocolumns becomes less frequent away from ridge and results in true columns. Columns situated toward the ridge crest are short and straight (Fig. 4a). Columns do not branch; however, they originate at different levels from a common pseudocolumnar base. The surface of the outcrop shows subcircular, discrete cross sections of columns near the crest and at the flanks, coalescing, elongate, asymmetric cross sections of pseudocolumns (Figs. 4e and 5a).

*Laminae shape and lateral surface:* Laminae are predominantly conical, but without an axial zone, in both the pseudocolumnar and columnar stromatolites but vary from gently convex to conical. The conical part of the column is short, only 2 to 3 cm thick, usually symmetrical in columns and asymmetrical in pseudocolumns. In the pseudocolumns, the laminae abruptly plunge into the interspace area. Interspace areas are filled with clear, equigranular dolomite crystals.

*Microstructure:* The microstructure is poorly preserved; recrystallization has obscured original features of the laminae (Fig. 5c). Dark dolomicrosparite laminae are interrupted by stylolites. Clear laminae are discontinuous and contain numerous voids and cavities, and they are irregularly filled by acicular crystals.

*Comparison:* The pseudocolumnar nature of columns is roughly similar to *Omachtenia* Nuzhnov 1967 and some elongate parallel sections of *Kussiella* Krylov 1963. These two Groups, however, do not contain conical laminae nor do they or any other Group exhibit the overall complex morphology and mode of occurrence found in *Apachina*. We know of no other stromatolite with this morphology.

*Stratigraphic occurrence and age:* Algal Member of the Mescal Limestone (Apache Group), central Arizona. Middle Proterozoic, between 1,200 and 1,100 m.y. old (middle Riphean).

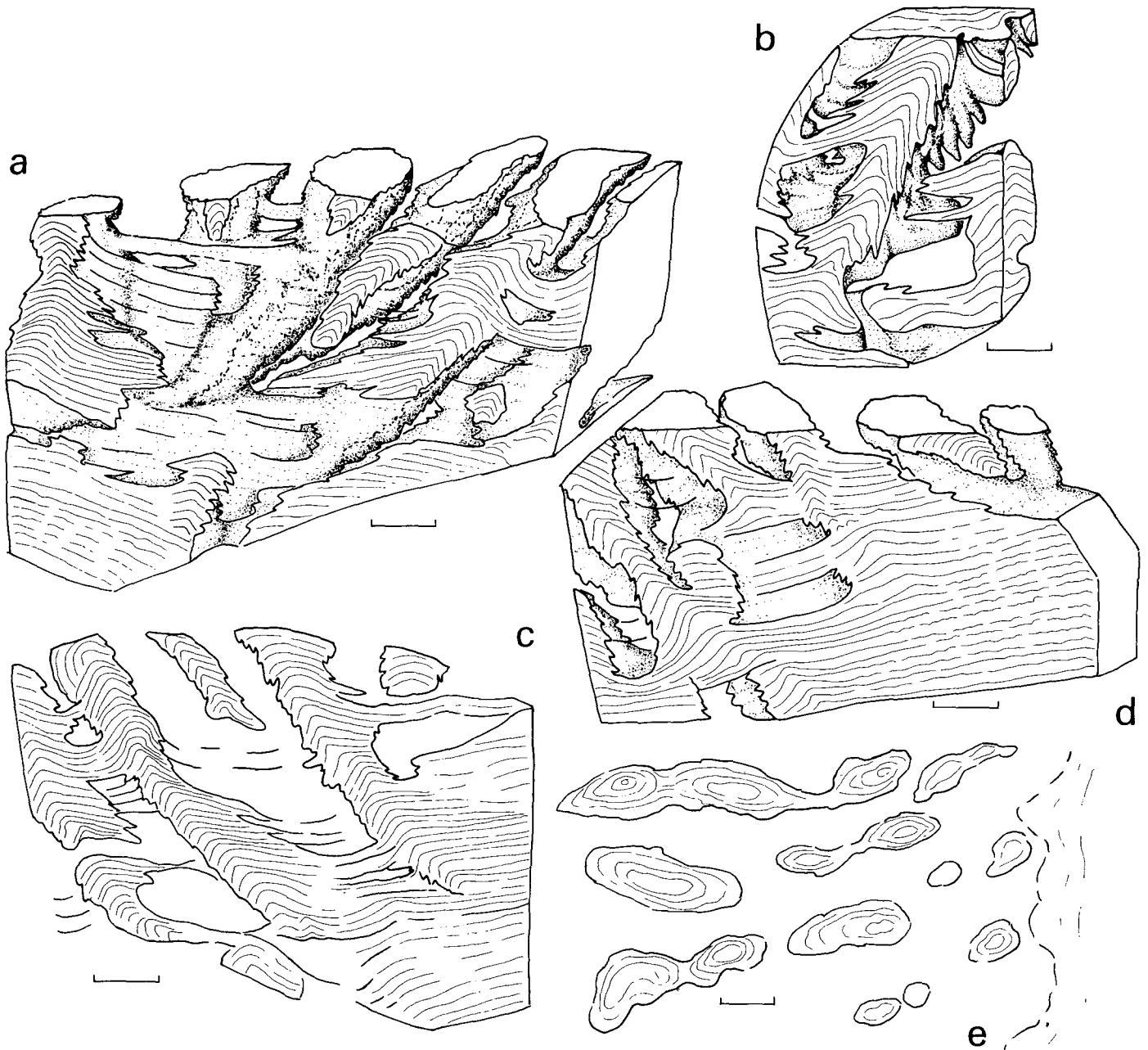


Figure 4. *Apachina henryi* new Group, new Form. Bar scale = 3 cm in all drawings. (a and d) Drawings of views on each side of the central ridge showing the columns and pseudocolumns growing and expanding outward from the ridge. Based on holotype (sample e of 1 of 5/14/79). (b) Pseudocolumns similar to *Apachina* from the road to Horse Camp Creek. Sample 3 of 5/13/79. (c) Section of the holotype showing asymmetric laminae. (e) Cross-sectional view of part of *Apachina*; to the right, the upper part of the ridge; to the far left, cross sections of subcircular, elongated pseudocolumnar stromatolites with elongation perpendicular to axis of the ridge. From part of the field photograph shown in Figure 5a.

*Tungussia* Semikhatov 1962

*Type form:* *Tungussia nodosa* Semikhatov 1962, p. 205–207, Plate VI, 3–6; Plate VII, 1, 2.

*Diagnosis:* For a translation of the diagnosis of Group *Tungussia* Semikhatov 1962, see Walter and others, 1979, p. 279.

*Content:* Group *Tungussia* has had 32 Forms

described for it, and these are listed in Table 1.

*Age:* Late Aphebian to Vendian; predominantly middle and late Riphean.

*Tungussia mescalita* new Form  
(Figs. 6a–6g; 7a–7c; 8a–8c)

*Tungussia* sp. Cloud and Semikhatov 1969,

p. 1058, Fig. 15, Plate 5, Fig. 1. *Parmites* sp. McConnell 1975, p. 320, Fig. 3E. *Baicalia* aff. *baicalica* McConnell, 1975, p. 321, Fig. 4D. *Tungussia* sp. McConnell 1975, p. 321, Figs. 4B and 4C.

*Etymology:* Named after the Mescal Limestone.

*Material:* Five specimens from outcrops south-

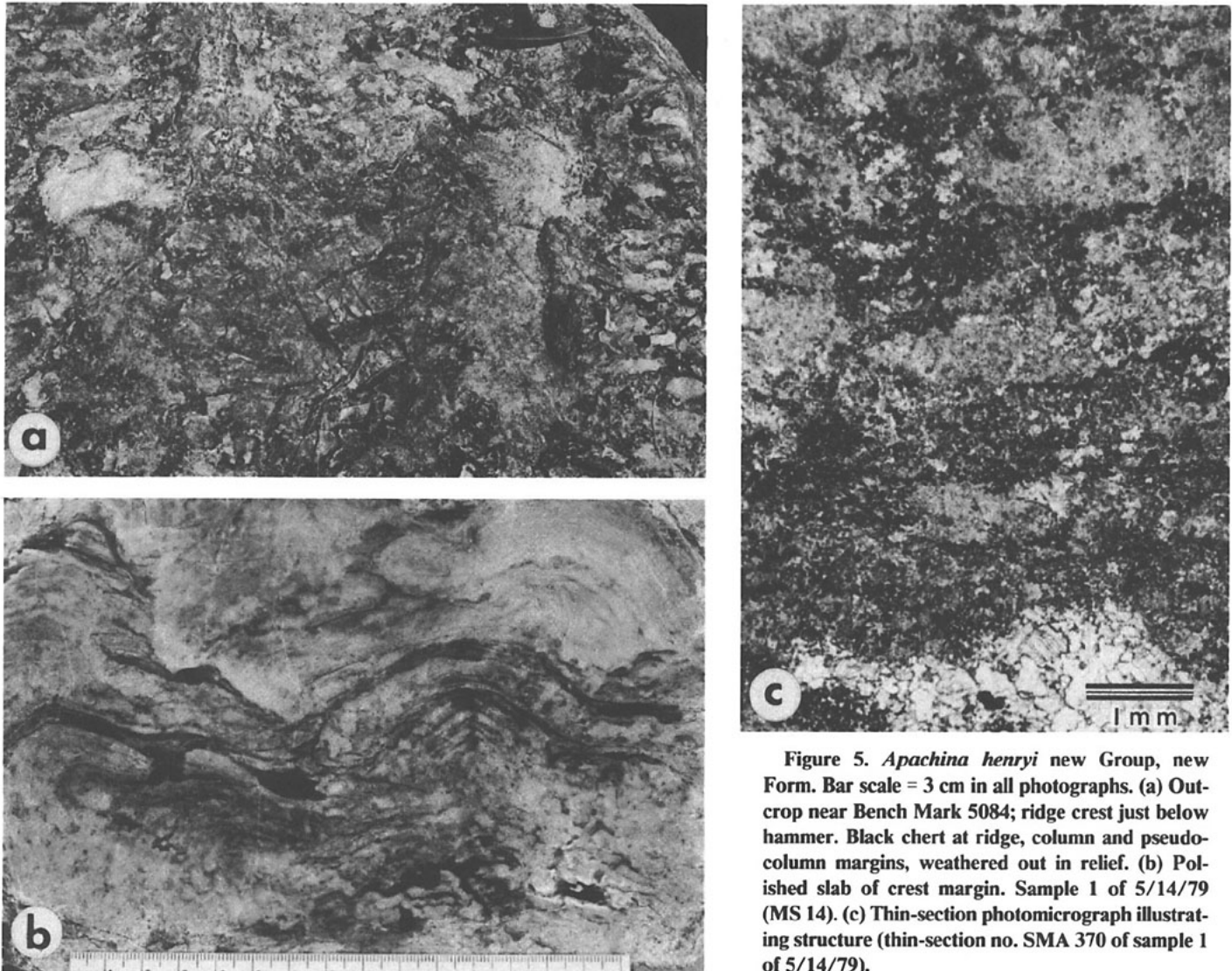


Figure 5. *Apachina henryi* new Group, new Form. Bar scale = 3 cm in all photographs. (a) Outcrop near Bench Mark 5084; ridge crest just below hammer. Black chert at ridge, column and pseudo-column margins, weathered out in relief. (b) Polished slab of crest margin. Sample 1 of 5/14/79 (MS 14). (c) Thin-section photomicrograph illustrating structure (thin-section no. SMA 370 of sample 1 of 5/14/79).

east of Walnut Creek (southeast corner of Section 19, T. 8 N., R. 15 E.; Young quadrangle) and from the northeastern part of McFadden Peak quadrangle above Horse Camp Creek, south of Rock House at Bench Mark 5083.

**Holotype:** Specimen 2 of 5/14/79; Walnut Creek locality (locality 2 in Fig. 2).

**Diagnosis:** *Tungussia* with turbinate, frequently ramified columns, and laterally persistent, elongate columns; all are closely packed into a fascicle. Lamina profile of low relief.

**Mode of occurrence:** In biostromes, a basal, 2- to 3-cm-thick layer of flat to slightly undulating laminae forms the base of the biostrome (Fig. 3A), and small columns develop from this basal layer. The columns expand quickly and branch (Fig. 6d), forming erect ramified bushes (low, branched stromatolites that arise from or near their base) of *T. mescalita*. The lower or basal columns remain oblique and elongate

(Figs. 6a and 6b) and are an understory of the erect bushes. This complex structure, which is composed of ramified turbinate columns organized into erect bushes with elongate columns, form what is termed a fascicle (see Grey, 1984). These clusters of *T. mescalita* columns are as much as 1.5 m across and as much as 2 m high. We use the term "fascicle" instead of "bioherm," because they are discrete structures within a biostrome. Similar architectures have been described as "massifs" by Bertrand-Sarfati (1972). The fascicles are isolated, never connected to one another, and show no morphological differentiation at the periphery.

**Column shape and branching:** The bushes are composed of straight to slightly curved columns that rapidly enlarge from their region of branching. The tops of the bushes have smaller columns (Fig. 8a). Branching is slightly divergent and delimits a narrow interspace area. The size of col-

umns varies from 2 to 3 cm to 10 cm in diameter. The lateral, oblique columns (Fig. 7c) expand laterally from the base of the bushes, giving rise to a niche-like style of branching. Cross sections of the bushes show the complex shape of the columns within a fascicle (Fig. 7d); in particular, (a) overall complexity of an individual bush, (b) subcircular cross sections of the uppermost columns of a bush, and (c) asymmetric laminae in an elongate section of the oblique connecting columns. The cross sections never show polygonal outlines of columns. There is no preferred orientation of the ramifications.

**Laminae shape and lateral surface:** Laminae shape in the columns are usually symmetrical with low relief ( $h/w = 1/5$  to  $1/6$ ). Laminae plunge quickly at column edges and terminate. The lateral surface of columns is smooth with low-amplitude bumps. Oblique columns have an asymmetrical laminae shape and a ragged

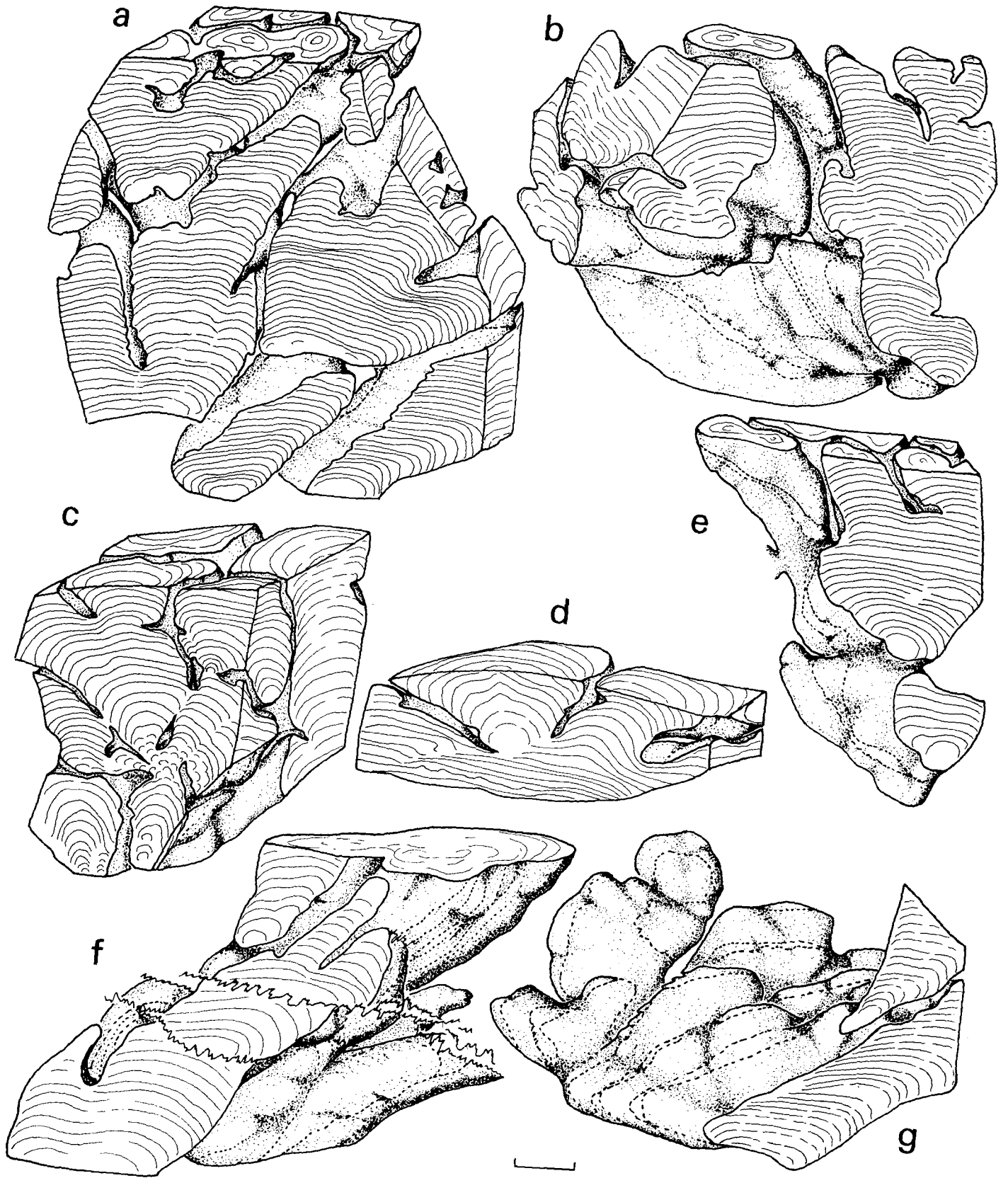


Figure 6. *Tungussia mescalita* new Form. (a) Part of a fascicle; the columns ramify vertically with a divergent mode of branching (bushes), and laterally, the columns greatly expand. Holotype: sample 2 of 5/14/79, Walnut Creek locality. (b) Part of fascicle showing relationship between straight and oblique columns; sample 1 of 5/14/79. (c) Central part of fascicle showing ramifications of three branches from one region (sample 4 of 5/13/79, from the road to Horse Camp Creek). (d) Base of *T. mescalita* bioherm; columns expanded rapidly, preventing growth of the adjacent columns (sample 1 of 5/14/79 at BM 5083 locality). (e) Straight branching columns from a portion of one fascicle; divergent branching columns and small projections in niches. Holotype: sample 2 of 5/14/79. (f) Lateral part of a fascicle; elongate columns with niche-like branching and oval cross section (sample 5 of 5/13/79, above Horse Camp Creek). (g) Lateral part of a fascicle with connections between the columns. Fascicle is elongated in two directions and illustrates the formation of vertical projections, which give rise to the erect bushes whenever space is available (sample 2 of 5/14/79).

surface along margins facing the interior of the bush. Laminae are broadly convex, almost flat at the tops of the columns, and abruptly plunge at column margins.

**Microstructure:** It is poorly preserved (Fig. 8d) and is composed of alternating clear and dark layers. The dark dolomicrosparite layer is discontinuous and is rich in iron oxide and pyrite, with talc and chrysotile when close to a diabase intrusion. Clear layers are composed of acicular crystals, which can cross 3 to 4 laminae, especially where laminae plunge over

and partially envelop the edge of columns. In some places, thick striations pass through the acicular crystals, giving rise to a quadratic network.

**Comparison:** The niche-like branching and straight bushes are similar to some *Inzeria* Krylov 1963, particularly *I. groenlandica* Bertrand-Sarfati & Caby 1976; however, *Inzeria* columns are less turbinate and more erect without bushes, connecting columns, and regular clusters. *Eleonora* Bertrand-Sarfati & Caby 1976 has branching somewhat similar to the

bushes, but it has branches that are less turbinate and longer. *Nouatila* Bertrand-Sarfati 1972, *Serizia* Bertrand-Sarfati 1972, and *Acaciella* Walter 1972 have hemispherical clusters, but they differ in column shape. Parts of *T. mescalita* resemble *Archaeozoon acadense* Matthew 1890 (see Hofmann, 1974, Figs. 4 and 5); however, *T. mescalita* does not have conical laminae, and the fascicles radiate more than is apparent for *A. acadense*. As first recognized by Cloud and Semikhatov (1969) for these Mescal stromatolites, the distinctive column shape of this form places it in the Group *Tungussia*. We consider the oblique, elongate columns that give rise to the straight bushes a variation of the general *Tungussia* shape that serves to distinguish the Mescal Form from *T. confusa* and *T. nodosa* Semikhatov 1962. *T. erecta* and *T. inna* Walter 1972 have straighter, more variable columns and lack oblique columns as do *T. etina* Preiss 1972 and *T. globulosa* Bertrand-Sarfati 1972. These latter two Forms of *Tungussia* have bushes with rapidly expanding columns similar to *T. mescalita* but never form clusters. The microstructure of *T. mescalita* is too poorly preserved for detailed comparisons.

**Stratigraphic occurrence and age:** Algal Member of the Mescal Limestone (Apache Group), central Arizona. Middle Proterozoic,

TABLE 1. GROUP *TUNGUSSIA*: FORM CONTENT AND DIAGNOSTIC CHARACTERISTICS

Form	Author and year	Age	Diagnostic characteristics
<i>T. arbora</i> *	Semikhatov†	..	..
<i>T. aryanitoca</i> §	Schapovalova†	Middle Riphean	..
<i>T. bassa</i>	Krylov, 1967	Vendian	Large horizontal branches and numerous small columnar ramifications
<i>T. colcima</i>	Raaben, 1972	Late Riphean	Laminae distinctly banded; filmy-jagged, ribboned microstructure
<i>T. confusa</i>	Semikhatov, 1962	Middle to late Riphean	Few horizontal columns; laminae banded but disrupted; ribboned microstructure
<i>T. cumata</i>	Bertrand-Sarfati, 1972	Late Riphean	Widening-upward columns; conical layering in places; irregular, tussocky microstructure
<i>T. enpiggenni</i>	Raaben, 1969*	Late Riphean	Microstructure is even-textured, clearly banded, with globulous clots
<i>T. erecta</i>	Walter, 1972	Late Riphean	Gnarled tuberos, mostly erect, subparallel, walled columns; at base, columns are horizontal and inclined; indistinct laminae
<i>T. etina</i>	Preiss, 1974	Late Riphean	Wide variation of branching style from subparallel to markedly divergent; thick, wavy laminae that pinch and swell
<i>T. florimacula</i>	Zhang and Wang, 1980††	Middle Riphean	Well-developed wall; spotted microstructure
<i>T. golovanovi</i>	Raaben, 1972	Late Riphean	Fine-grained, clearly laminated, filmy microstructure
<i>T. globulosa</i>	Bertrand-Sarfati, 1972	Late Riphean	Flared, globular columns; tussocky microstructure
<i>T. grata</i>	Schapovalova and Krylov, 1976	Late Riphean	Clotted microstructure
<i>T. heterostroma</i>	Preiss, 1976	Late Apebbian	Multilaminar wall; laminae in center of columns indistinct and of granular texture§§
<i>T. (?) indica</i>	Raaben, 1972	Late Riphean	Fascicular, long-fibered, layered microstructure
<i>T. inna</i>	Walter, 1972	Vendian	Crooked, bumpy columns, frequently coalescing and branching; almost continuous, multilaminar wall; bridging and wavy laminae occur independently
<i>T. julia</i>	Walter and Krylov, 1979***	Vendian	Highly variable lamina shape; laminae markedly wavy; streaky microstructure
<i>T. kunlunensis</i>	Gao, 1985†††	Late Riphean	Branching resembles a tuning fork
<i>T. laqueusa</i>	Golovanov, 1966	Middle Riphean	Clotted, layered microstructure
<i>T. nebulosa</i>	Bertrand-Sarfati, 1972	Late Riphean	Oblique columns rare; nebulous wall around columns; elongate clots in microstructure
<i>T. nodosa</i>	Semikhatov, 1962	Late Riphean	Numerous horizontal and slightly oblique columns; no walls; interrupted ribboned microstructure
<i>T. nuzhonovi</i>	Raaben, 1972	Late Riphean	Distinct lamination; globular clots in microstructure forming irregular "wool ball"
<i>T. parietia</i>	Zhao and others, 1989	Late Riphean	Markedly divergent branches; false wall; distinct banded microstructure
<i>T. parmensis</i>	Raaben, 1972	Late Riphean	Irregularly and thinly laminated; filmy microstructure (reticulation, mesh work, latticed)
<i>T. perforata</i>	Raaben and Komar, 1982	Late Riphean	Perforated microstructure composed of clear carbonate grains
<i>T. russa</i>	Raaben, 1969**	Vendian	Clotted, banded microstructure
<i>T. sibirica</i>	Nuzhinov, 1967	Late Riphean	Lens-like and lens-laminated layers with hemispherical and compressed bulges
<i>T. spongiosa</i>	Golovanov, 1966§§§	Late Riphean	Spongy-pelletal microstructure
<i>T. striata</i>	Raaben, 1972	Middle Riphean?	Small columns; finely and regularly (parallel) laminated
<i>T. striolata</i>	Zhu and others, 1987****	Apebbian	Finely banded microstructure
<i>T. wilkatanna</i>	Preiss, 1974	Middle Riphean	Columns smooth to gently bumpy, subcylindrical to tuberos, frequently walled; markedly divergent multiple branching; continuous, thinly banded hemispherical laminae
<i>T. ukka</i> ††††	Raaben, 1972	Late Riphean	Ornamented, filmy microstructure

\*Mentioned in Zhu and others (1987); †reference to type not found; §mentioned in Krylov (1975); \*\*in Raaben and Zabrodin (1969); †† in Zhang and others (1980); §§Grey (1984) placed the small columns into *Naberubia tooloensis*; \*\*\*\* in Walter and others (1979); ††† in Liang and others (1985); §§§ in Golovanov and Zlobin (1966); \*\*\*\*\* in Zhu and others (1987); †††† Raaben (1972) synonymized *Linella ukka* Krylov 1967 into *T. ukka* based on microstructure (*Linella ukka* Krylov continues to be recognized).



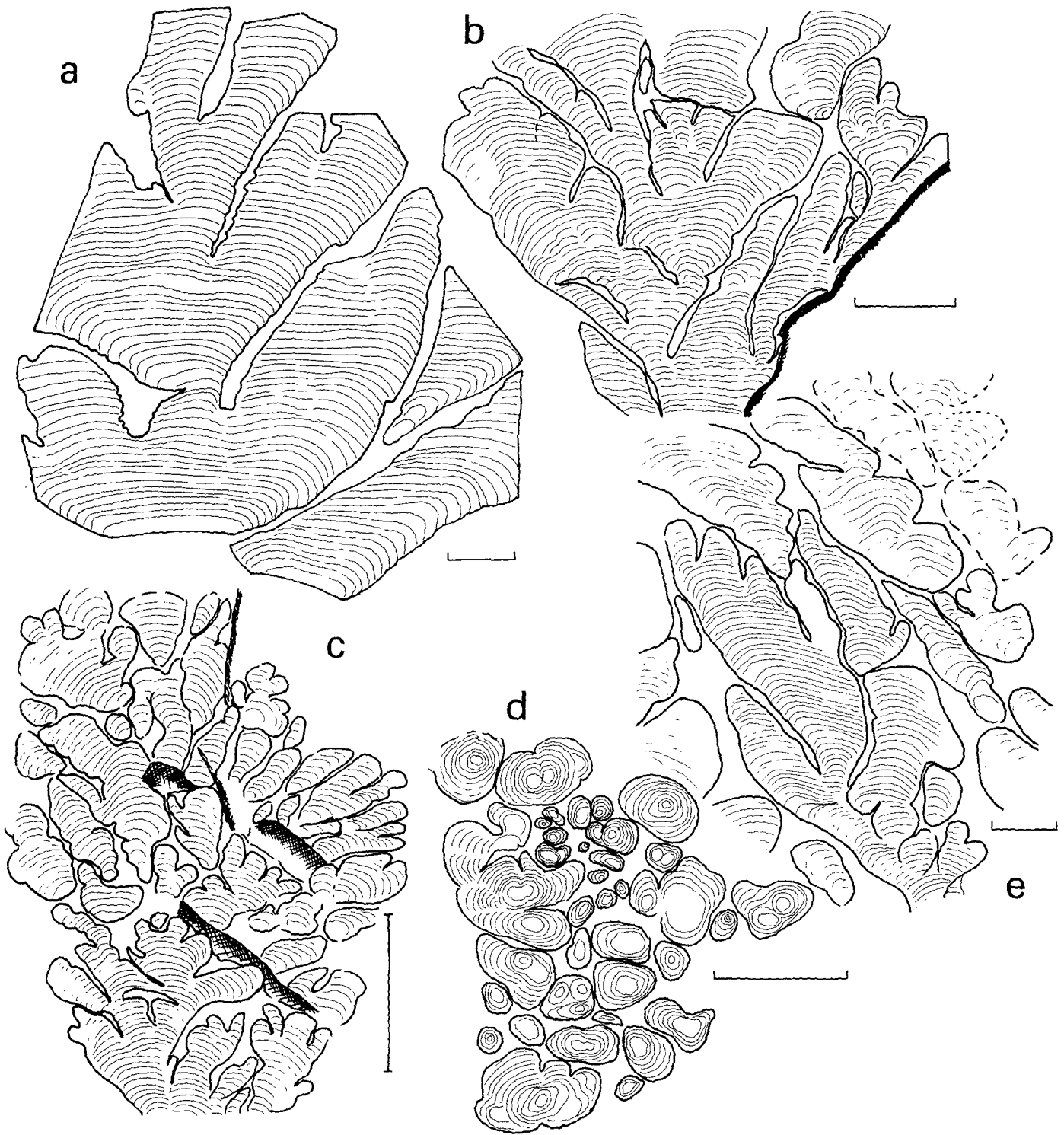


Figure 7. *Tungussia mescalita* new Form. (a) Section of the holotype (2 of 5/14/79); on the right, asymmetric laminae; toward the top, nearly symmetrical laminae. Bar scale = 3 cm. (b) Part of a fascicle cut along the axis of symmetry showing the repeated bushes (drawing from a field photograph, outcrop north of Walnut Creek). Bar scale = 15 cm. (c) Another symmetrical fascicle; only the top shows different types of columns (see Fig. 11; from a field photograph; locality north of Horse Camp Creek). Bar scale = 17 cm. (d) Plan view of fascicle showing the different sizes and shapes of columns (from a field photograph; locality on road to Horse Camp Creek). Bar scale = 17 cm. (e) Fascicle cut tangentially, showing inclined columns (from field photograph; locality along Walnut Creek). Bar scale = 8 cm.

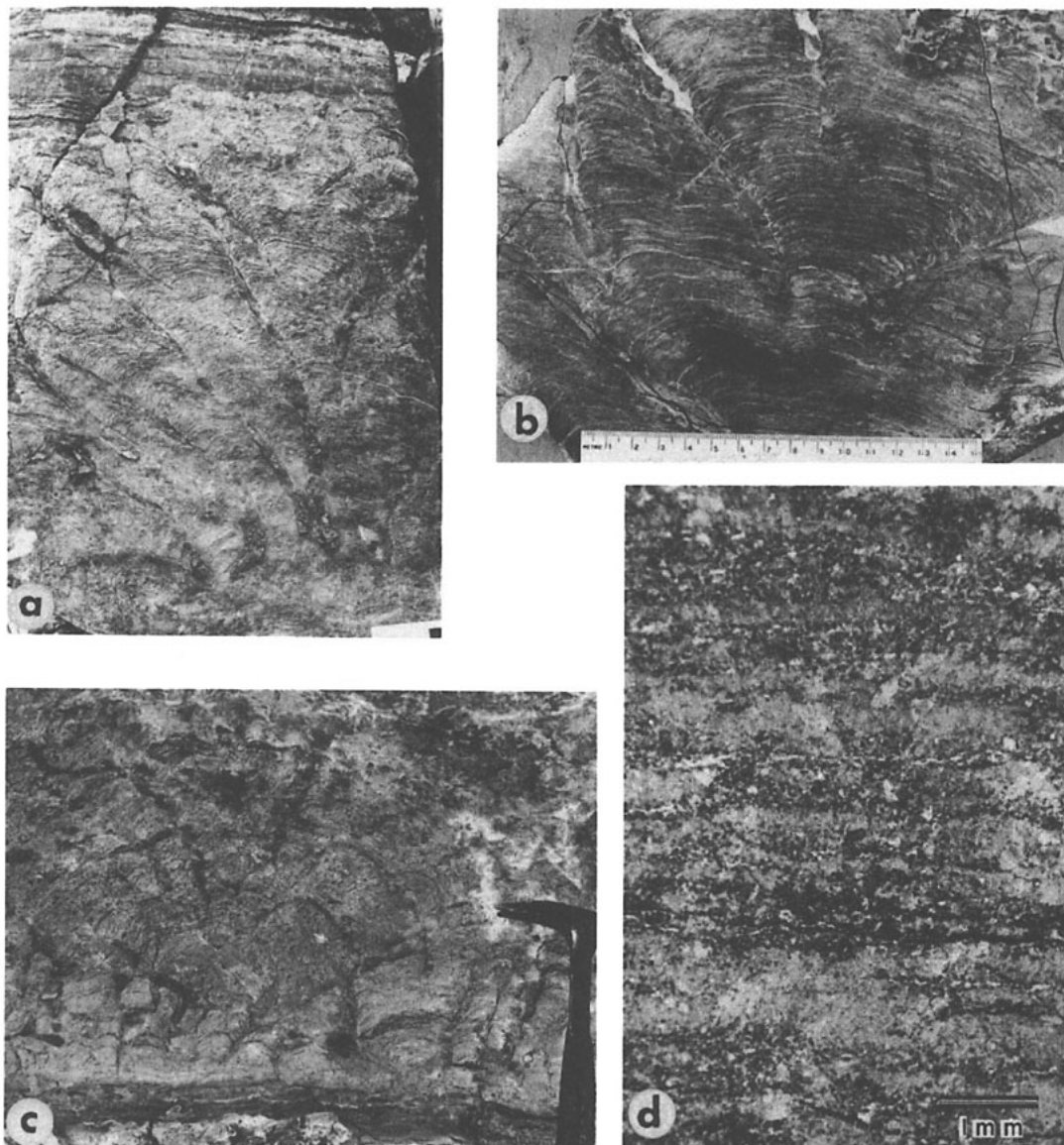


Figure 8. *Tungussia mescalita* new Form. (a) Outcrop showing branching patterns southeast of Wilson Creek, R. 15 E., T. 8 N., Section 31. (b) Ramifying columns of *T. mescalita*. Holotype: sample 2 of 5/14/79 (MS 15); Walnut Creek locality. (c) Outcrop of *T. mescalita*; Wilson Creek locality. (d) Photomicrograph of thin section illustrating microstructure (thin-section no. SMA 371 of sample 2 of 5/14/79).

between 1,200 and 1,100 m.y. old (middle Riphean).

*Tungussia chrysofila* new Form  
(Figs. 9a, 9c, 10a, 10b, 11b, 12a–12d)

**Etymology:** Named after its type locality at the abandoned chrysotile mine.

**Material:** Three specimens from the chrysotile mine locality.

**Holotype:** Slab b from sample 2 of 5/15/79.

**Type locality:** West side of gravel road to old mine site of Chrysotile, 3.6 km northwest from intersection with U.S. Highway 60, 5.5 km south of Seneca, Arizona (Blue House Mountain quadrangle; locality 3 in Fig. 2).

**Diagnosis:** Turbinate to cumulate form, variable with numerous projections and niche-like

depressions between branches. High-relief conical laminae.

**Mode of occurrence:** Big columns are grouped in a biostrome with an exposed lateral extent of several meters. Fascicles are never formed, but columns are roughly parallel in their distribution in the biostrome (Fig. 9c).

**Column shape and branching:** Two different growth modes are found in *T. chrysofila*: (1) erect columns with numerous projections, bridges, and peaks growing on a globular head (Fig. 9a) and (2) one column that has developed more than others, crowding out adjacent columns and forming a large head. This head is characterized by deep, narrow depressions that do not give rise to any branching, but that produce regular grooves at the periphery of the column (Fig. 10b). At the top of the biostrome the

heads are capped by conical, cumulate columns. Globular heads similar to *T. chrysofila* (Fig. 10c) are found at the base of these columnar stromatolites. Stromatolite heads have the same high conical laminae and narrow depressions simulating branching as do the erect columns. Branching that occurs as small projections or in slightly divergent columns of equal size is found in the region between the globular heads.

**Laminae shape and lateral surface:** Laminae relief is high in all the columns ( $h/w = 2/3$  to 1). Laminae are predominantly conical without axial zone and are symmetrical. Columnar margins are often ragged with peaks and ridges.

**Microstructure:** The microstructure is poorly preserved (Fig. 12d) and consists of alternating clear and dark laminae. Dark dolomicrosparite laminae are discontinuous, forming only a line

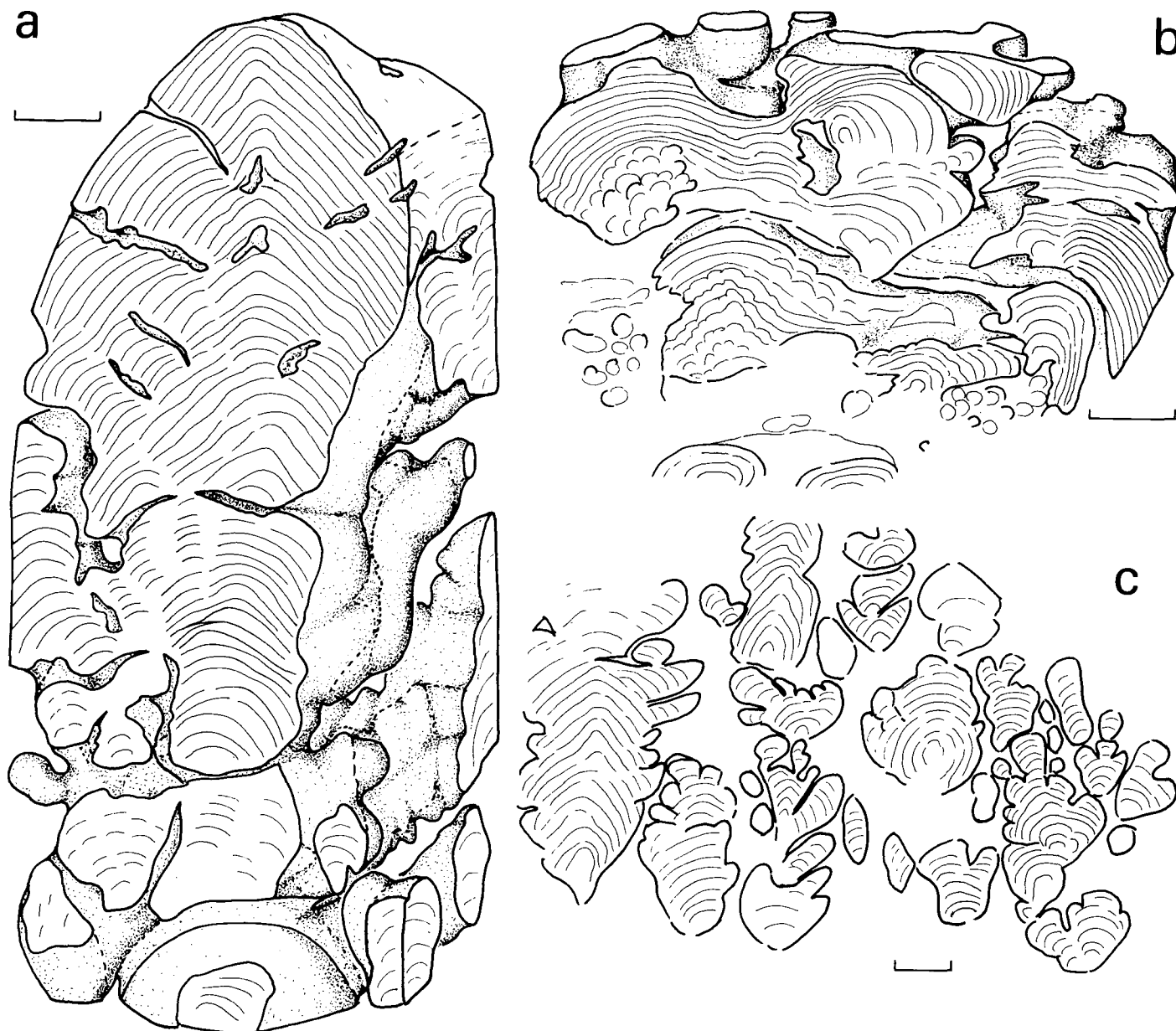


Figure 9. *Tungussia chrysofila* new Form. (a) Reconstruction showing the ramified part in the center capped by a conical head with pseudobranching. Holotype: sample b of 2 of 2/5/79; road to chrysofile mine. Bar scale = 3 cm. (b) Unnamed stromatolite from top of a biostrome of *Tungussia mescalita* (at BM 5083). Bar scale = 3 cm. (c) Drawing from outcrop of *T. chrysofila* showing parallelism of the columns (from field photograph, road to chrysofile mine). Bar scale = 9 cm.

of dots or patches of dots. In the upper parts of capping columns, the dark layers of the central conical area are composed of small hemispherical cushions and contain small voids filled by chert. The clear layer is everywhere crystallized with acicular crystals cutting across three to four adjacent laminae; this is more pronounced in narrow depressions.

**Comparison:** The conical shape of laminae and the radiating branching superficially resem-

ble *Jacutophyton* Schapovalova 1968 or *Georginia* Walter 1972, but these stromatolites have a persistent, differentiated axial zone. *Garadakia* Bertrand-Sarfati & Siedlecka 1980 has long, subcylindrical, oblique branches with no globular heads or pseudoramifications. Superficially, *Archaeozoon acadense* Matthew 1890 (see Hofmann, 1974) resembles *T. chrysofila*; however, the Canadian form is partially walled with smooth margins and lacks globular head devel-

opment. *A. acadense* columns are imbricated in a closely packed manner (Hofmann, 1974, his Fig. 3). *T. chrysofila* columns are more or less parallel, and they have small branches included in niches within the columns but remain almost parallel to the parent column (compare Fig. 9a with Fig. 9 in Hofmann, 1974). It was Hofmann's opinion that *Tungussia* Semikhatov 1962 might be a junior synonym of *Archaeozoon* Matthew 1890 based on the overall sim-

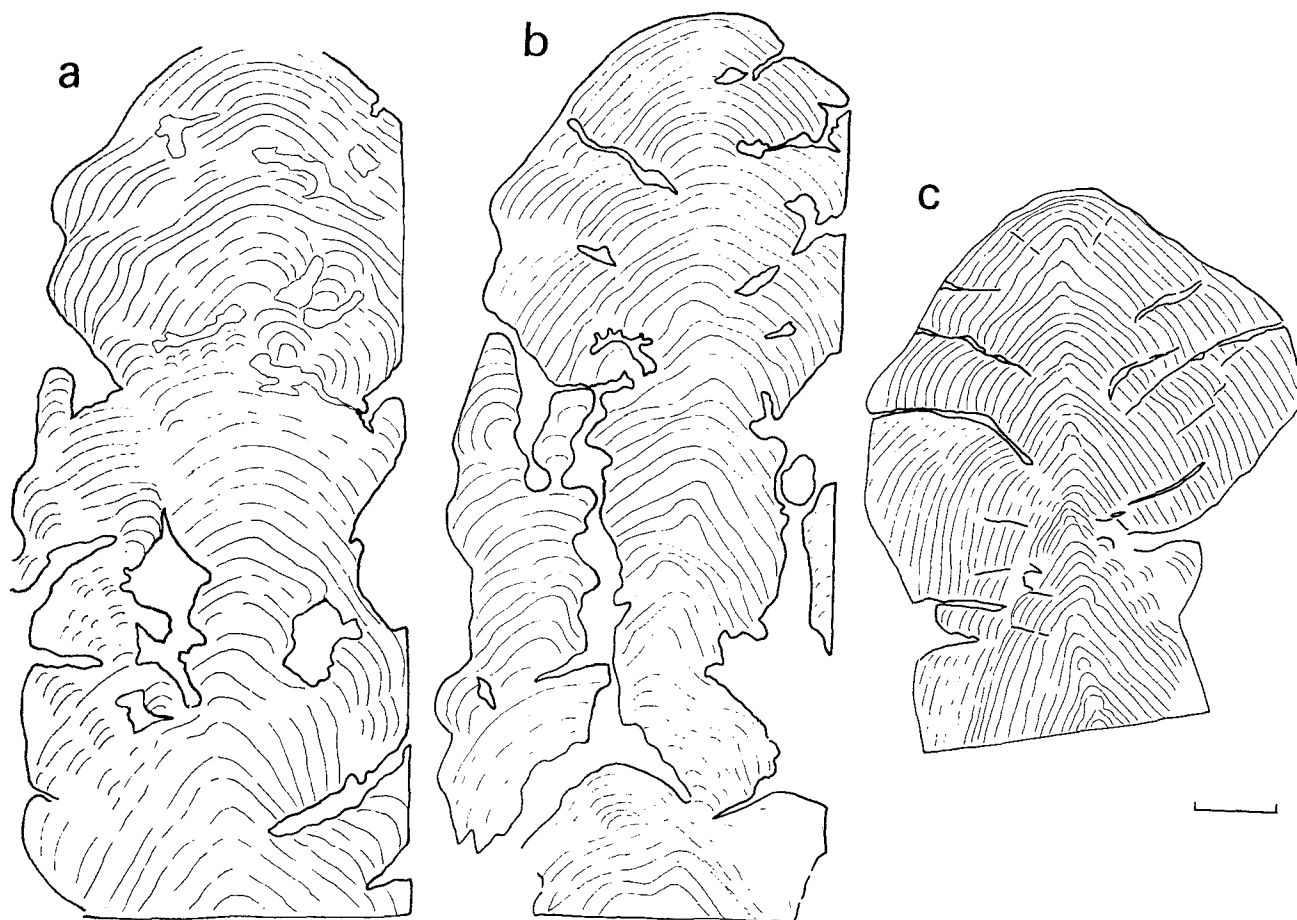


Figure 10. *Tungussia chrysofila* new Form. Bar scale = 3 cm for all drawings. (a and b) Two sections from the holotype specimen (2 of 5/15/79): (a) edge of the columnar structure and (b) through the axis of symmetry showing conical laminae. The axis of symmetry changes from the base of column in a to the top in b. (c) Small conical bioherm from the base of chrysofile mine road section that contains stromatolites resembling *T. chrysofila*.

ilarity of morphology and the rule of priority (Hofmann, 1974, p. 1105–1106). He suggested, however, that both names be retained until a revision of *Tungussia* is carried out. It is our opinion that *T. chrysofila* belongs to Group *Tungussia* as currently defined.

*T. mescalita* differs from all described Forms of *Tungussia* (Table 1), including *T. mescalita*, by the more conical shape of laminae and the development of globular heads with pseudo-branching. In growth habit, *T. chrysofila* does not form the fascicles characteristic of *T. mescalita* and lacks the oblique columns in the bushes. In *T. mescalita* biostromes, the columns above the fascicles have a strong resemblance to *T. chrysofila* (Fig. 11).

**Stratigraphic occurrence and age:** Algal Member of the Mescal Limestone (Apache Group), central Arizona. Middle Proterozoic, between 1,200 and 1,100 m.y. old (middle Riphean).

## GENERAL CONSIDERATIONS OF THE MESCAL STROMATOLITES

### Comparison of the Stromatolites from the Two Successions

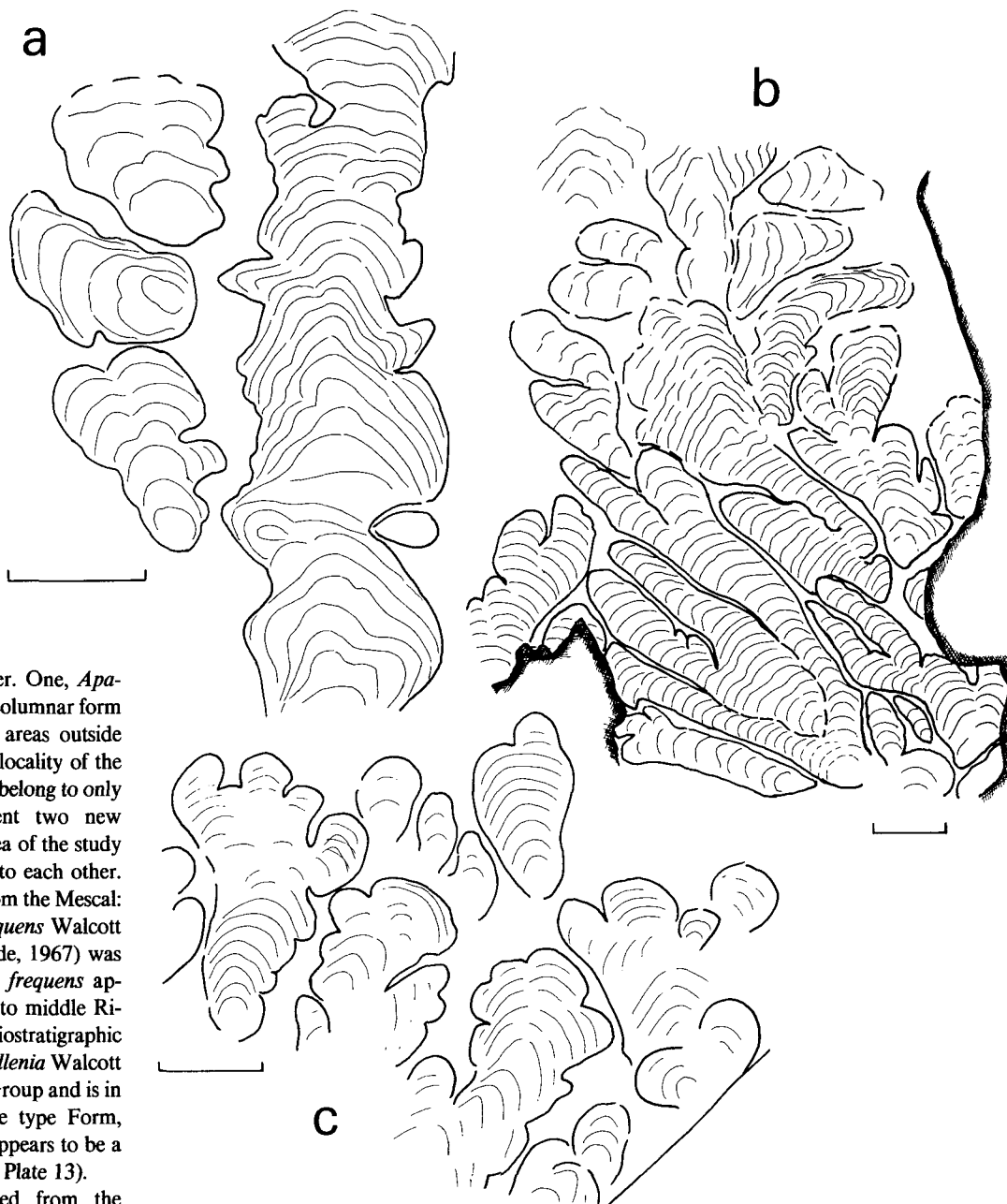
In all areas visited in the McFadden Peak quadrangle, the base of the Algal Member is built by *Tungussia mescalita*. In the chrysofile mine area, the discrete heads of *T. chrysofila*-like stromatolites form the base of the Algal Member. The large columns that grew from *T. mescalita* are quite similar to those forming the main layer of *T. chrysofila* at the chrysofile mine locality. We found that *T. chrysofila* is present at all localities visited. *T. mescalita* and *Apachina henryi* are only known from the McFadden Peak quadrangle. Both successions contain planar to stratiform stromatolites that have not been formally described. No oncolites have been found.

The microstructure of the stromatolites from both areas, although strongly recrystallized and poorly preserved, shows the same general alternation of dark dolomicrosparite laminae and clear laminae composed of acicular crystals. Few differences were noted. Despite recrystallization, the persistence of acicular crystals restricted to clear laminae probably reflects an original character of the lamination. Rare hemispherical cushions in the tops of *T. chrysofila* can be compared with caution to the tussocky microstructure described by Bertrand-Sarfati (1976). Probably, *T. mescalita* and *T. chrysofila* are closely related; possibly they are morphological end members of a *Tungussia* form.

### Biostratigraphic Value of the Assemblage

Pseudocolumnar, domical, columnar, and columnar-branching stromatolites are not diverse in the Mescal Limestone; only three types

Figure 11. *Tungussia* aff. *chrysotila*. Bar scale = 3 cm for each drawing. (a) Columnar structure showing lateral columnar projections; from locality along the road cut at Salt River Canyon. (b) *T. chrysotila* above *T. mescalita* clusters; locality along Walnut Creek. (c) Large columns of similar shape from the top of *T. mescalita* on road to Horse Camp Creek. All drawings from field photographs.



have been identified in this paper. One, *Apachina*, is predominantly a pseudocolumnar form that has not been recognized in areas outside Arizona and is known from one locality of the Mescal Limestone. The other two belong to only one Group, *Tungussia*; represent two new Forms distributed over a large area of the study region; and are probably related to each other. Other stromatolites are known from the Mescal: the pseudocolumnar *Collenia frequens* Walcott 1914 identified by Rezak in Shride, 1967) was not studied (Fig. 13b). *Collenia frequens* appears to range in age from early to middle Riphean (1650 to 1050 Ma). Its biostratigraphic utility is uncertain. The Group *Collenia* Walcott 1914 is not a rigorously defined Group and is in need of taxonomic revision. The type Form, *Collenia undosa* Walcott 1914, appears to be a large oncolite (see Walcott, 1914, Plate 13).

*Conophyton*, although reported from the Mescal by Cloud and Semikhatov (1969), was not observed by us in the field. Examination of the thin section illustrated in Cloud and Semikhatov (1969, their Plate 2, Fig. 3) from *Conophyton* indicates a microstructure quite different from the microstructure of *Tungussia* (*T. chrysotila* and *Apachina* have conical laminae). The presence of *Conophyton* in the Mescal needs confirmation.

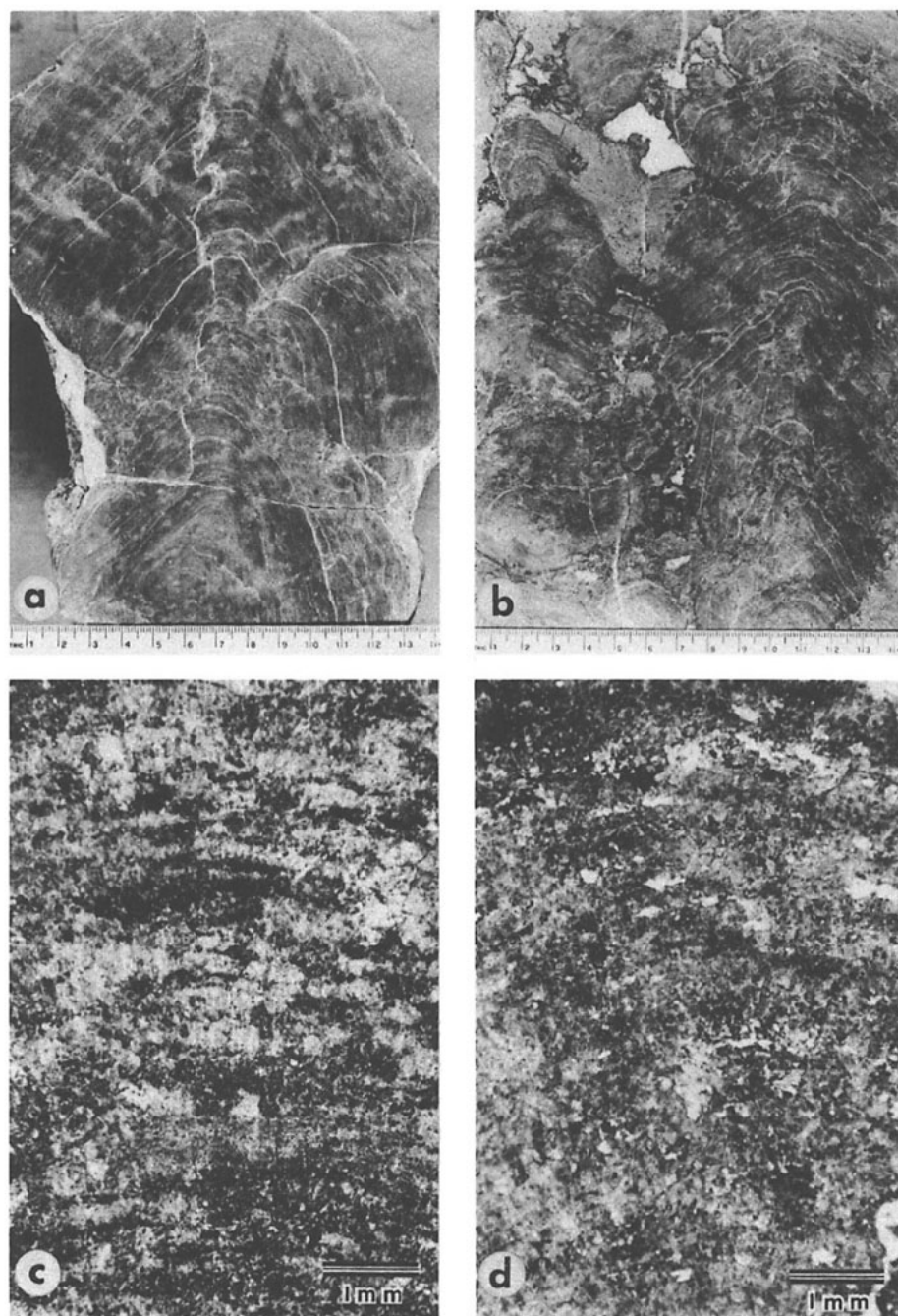
We conclude that the stromatolites of the Mescal Limestone are not sufficiently diverse in terms of columnar stromatolites to comprise a distinctive or representative assemblage that can be confidently compared to stromatolite assemblages that elsewhere define biostratigraphic time intervals.

Well-known middle Riphean assemblages from Russia, Australia, Africa, and Greenland contain numerous Forms of *Tungussia*; however, other Groups, such as *Conophyton*, *Jacutophyton*, and *Baicalia*, also occur, forming distinctive and diverse assemblages. The Mescal assemblage contains only two forms of one distinctive columnar Group, *Tungussia*. *Apachina* is known only from the Mescal and is of no current biostratigraphic use. Based on *Tungussia* and the lack of other typical Riphean stromatolite Groups, this low diversity assemblage can be considered only suggestive of a middle Riphean age (1350 to 1050 Ma), which is the most

common age of *Tungussia* Forms. This middle Riphean stromatolite "age" is nonetheless consistent with the 1200 to 1100 Ma age assigned to the Mescal Limestone (Link and others, in press).

#### Environment of Deposition

Shride (1967) interpreted the Apache Group to have been deposited on a stable continental shelf, because the units are remarkably consistent in lithology and other features throughout the large region of exposure. Wrucke (1989) envisaged an intracratonic basin for the deposi-



**Figure 12.** *Tungussia chrysofila* new Form. (a) Section through sample 2a of 5/15/79 (MS 17) from base of bioherm at the chrysotile mine road locality (see Fig. 10c). (b) Section through sample MS 19 from near the top of a massive columnar stromatolite showing small projections; chrysotile mine road locality (see Figs. 10a and 10b). (c) Photomicrograph of thin section (SMA 372 of sample 2 of 5/14/79) illustrating microstructure of a. (d) Photomicrograph of thin section (SMA 373 of sample MS 19), illustrating microstructure of b.

tional setting. Burke (1980), however, postulated that the Apache Group was deposited in a rift graben. The major conglomerate-bearing unit, the Scanlan Conglomerate, is interpreted to have been deposited as an alluvial fan/proximal

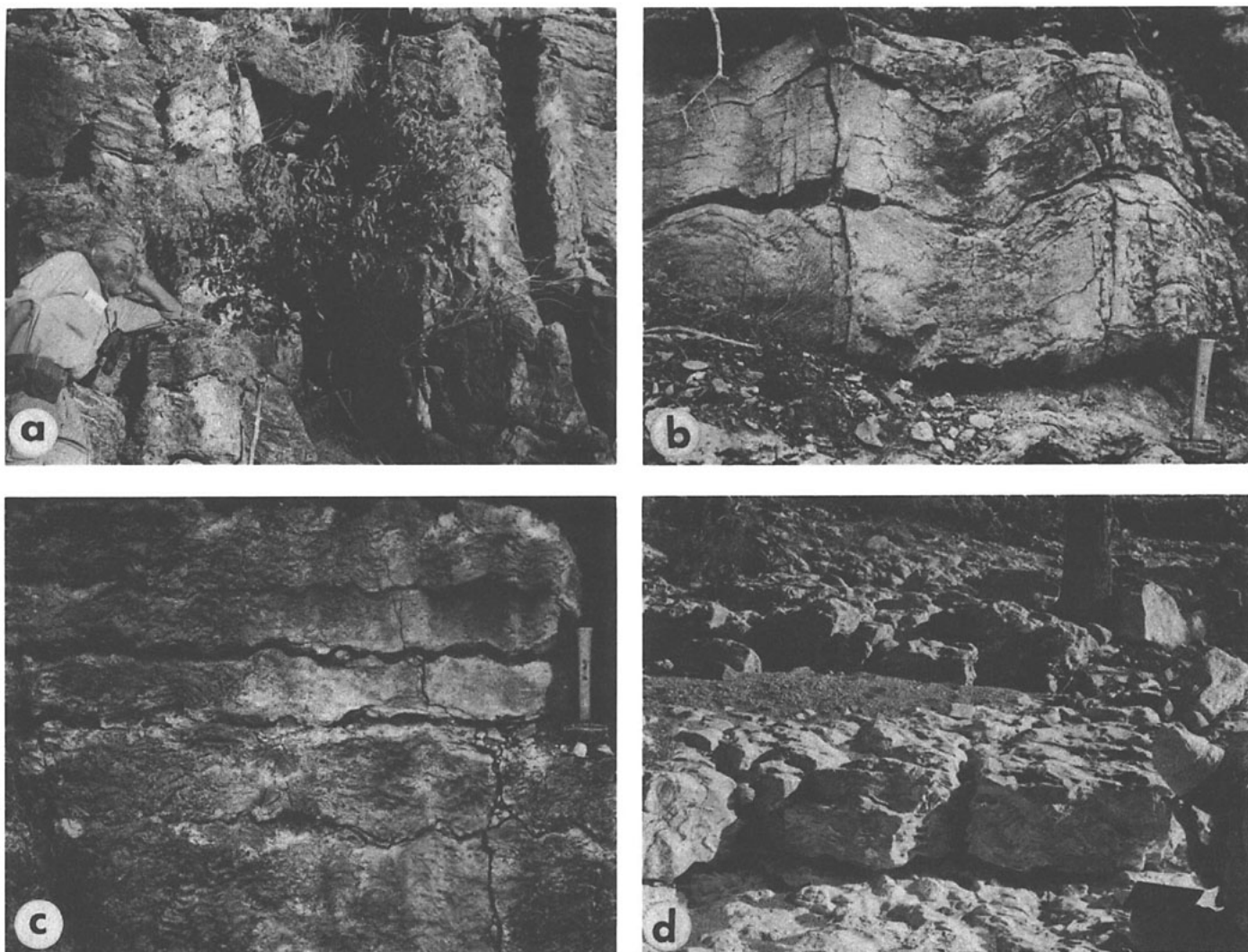
braided-stream complex of syntectonic origin (Middleton and Trujillo, 1984). Wrucke (1989) pointed out that the thickness of the Apache Group (as much as 850 m) is much less than that in well-documented intracratonic basins in

North America. The overall stratigraphy and sedimentology (especially the uniformity of lithology and other features) support a stable, continental-shelf environment as envisaged by Shride.

As reported by McConnell (1972), the predominantly dolomitic Lower Member of the Mescal Limestone contains ripple marks as well as other structures consistent with its interpretation as an intertidal-supratidal deposit: alternating intraclastic-laminated dolostone, birdseye structures, mud cracks, micrite chips and flakes, and possibly halite molds in chert. Gypsum pseudomorphs in the dolostone (Beeunas and Knauth, 1985) and collapse breccias (Shride, 1967) also suggest an evaporite environment. For the depositional environment of the Algal Member, McConnell (1972, 1975) relied on comparisons with modern stromatolite environments, in particular the Shark Bay model of Logan (1961), to conclude that the stromatolites formed in an intertidal to supratidal setting. In Shark Bay, columnar stromatolites are now forming in subtidal settings (Playford and Cockbain, 1976; Awramik and Vanyo, 1986), and columnar stromatolites also are forming in subtidal settings in the Bahamas (Dravis, 1983; Dill and others, 1986). In addition, most of the Proterozoic conical, columnar, and columnar-branching stromatolites probably formed in subtidal settings (Serebryakov, 1976; Awramik and Semikhatov, 1979; Bertrand-Sarfati and Mousine-Pouchkine, 1988). In all fairness to McConnell, at the time of his research, stromatolites were considered to be diagnostic of intertidal to supratidal settings. We see no evidence for an intertidal-supratidal depositional environment for the Algal Member.

The columns near the base of the Algal Member grew on 2 to 3 cm of stratiform stromatolitic laminae lacking any desiccation features such as mud chips or other features characteristic of periodic exposure. Fascicles of *T. mescalita* lack clastic infillings; laminae are not disrupted or eroded. No sedimentary features indicative of current influence or tidal action are registered in, or associated with, the clusters. This suggests to us that these stromatolites grew in a nonturbulent, subtidal, possibly protected environment. The higher relief (synoptic profile) of *T. chrysofila* compared to *T. mescalita* could be due to a slight increase in water depth, although we see no differences in sedimentary structures or of the character of the sediment to invoke a substantially different environmental setting.

The undulatory stratiform stromatolites that occur above the columnar stromatolites are characterized by oriented ridges and elongate domes (Fig. 13) or pseudocolumns. The "crenu-



**Figure 13. Stratiform stromatolites above the columnar layer (see Fig. 3). (a) Rock House Creek: conical, linked stromatolites with a very high inheritance of laminae. (b) Road to Rock House, BM 5083: low, pseudocolumnar stromatolites with gently convex to conical laminae and good inheritance. Probably representative of *Collenia frequens* Walcott 1914, mentioned in Shride (1967). (c) Chrysotile mine road locality: stratiform stromatolite with discontinuous wavy laminations; note changes in shape and convexity of the laminae. (d) Rock House Creek: more or less continuous stromatolite ridges corresponding to deeply convex crests of the linked pseudocolumns of stromatolites.**

lation" in this stratiform, stromatolite-dominated sequence has an orientation (north-northwest strike) similar to the rippled surface of the dolostone below the Algal Member (McConnell, 1975). This is in stark contrast to the lack of any evidence of current activity in the intervening columnar stromatolite biostromes.

The low ridges of *Apachina henryi* are oriented N132°E (south-southeast), similar to the strike of the "crenulations." *Apachina* pseudocolumns are normal to the ridges. The closest modern example of this bidirectionality of stromatolite shape is found in the intertidal settings of Shark Bay, Western Australia. Playford and Cockbain (1976) described stromatolite

ridges approximately parallel to prevailing wind direction with longitudinally oriented stromatolites growing at an angle of about 50° to the ridges (see also Playford, 1980). Mescal stromatolite ridges and *Apachina* at Bench Mark 5083 do not contain any detrital infilling, channeling, mud chips, or other desiccation features characteristic of periodic exposure.

We conclude that the Algal Member of the Mescal Limestone formed in a broad, flat, shallow, subtidal platform-like area that at times was subjected to constant currents of uncertain origin, possibly due to wind or tidal current, resulting in stratiform stromatolites with domes and ridges. *Tungussia* developed when this sub-

tidal area was protected from the influence of currents.

#### COMPARISONS OF THE MESCAL STROMATOLITES WITH STROMATOLITES FROM OTHER REGIONS IN THE SOUTHWESTERN UNITED STATES AND NORTHWESTERN MEXICO

Proterozoic stromatolites are known in only seven regions in the southwestern United States and northwestern Mexico: (1) Death Valley and adjacent regions in eastern California; (2) White-Inyo Mountains of California; (3) San

Bernardino Mountains, California; (4) Grand Canyon, Arizona; (5) West Texas; (6) Caborca in Sonora, Mexico; and (7) central Arizona. Table 2 presents information on the stromatolites that have been named from these regions. The Mescal stromatolites, cf. *Baicalia* from the Crystal Spring Formation, and the Caborca stromatolites have been studied in some detail. Stromatolites from the other regions have not been properly studied and their identifications (Table 2) were based primarily on their appearance in outcrop. Without serial sectioning and graphical reconstruction of the stromatolites to elucidate morphology and petrographic thin sections to study microstructure, details are insufficient for confident identification of stromatolite taxa.

### Death Valley and Eastern California

At least five Proterozoic formations in the Death Valley region contain stromatolites: Crystal Spring Formation, Beck Spring Dolomite, Kingston Peak Formation, Noonday Dolomite, and the Johnnie Formation. The Crystal Spring Formation, Beck Spring Dolomite, and Kingston Peak Formation compose the Pahrump Group. Only the stromatolites of the Crystal Spring, Beck Spring, and Johnnie Formations have been named; however, not all have been treated taxonomically.

Shride (1967) noted the stratigraphic similarities between the Apache and Pahrump Groups. In particular, he noted that the upper part of the Crystal Spring Formation has many features in common with the Mescal Limestone, including the stromatolite beds, but commented, "It would be presumptuous, however, to suggest any correlation of the Apache Group and the Pahrump Series at this time" (Shride, 1967, p. 82). Cloud and others (1969) reached the conclusion that the Apache and Pahrump Groups are probably correlative based on similarities in lithology and geologic setting of the intrusive diabase sills found in both regions. Chemically and petrographically, the diabase sills in the two areas are very similar (Wrucke and Shride, 1972; Hammond, 1983).

Aside from stromatolites identified as *Conophyton*, no other stromatolites are in common with the Mescal. Earlier reports indicated otherwise. (1) McConnell (1975) provisionally recognized cf. *Baicalia baicalica* (= *Tungussia mescalita* herein described) from the Mescal, which he suggested can be compared to, and correlated with, the Crystal Springs cf. *Baicalia* described by Howell (1971). (2) Pierce and Cloud (1979) concluded that the Crystal Spring and Mescal stromatolites are similar and probably correlative.

TABLE 2. PROTEROZOIC STROMATOLITES REPORTED FROM THE SOUTHWESTERN UNITED STATES AND NORTHWESTERN MEXICO

Area	Formation	Age (Ma)	Stromatolites	Reference
1. Death Valley and eastern California	Johnnie	> C < 700	<i>Boxonia</i> aff. <i>B. gracilis</i> <i>Linella</i> aff. <i>L. ukka</i> <i>Paniscollenia</i>	Cloud and Semikhatov (1969) Cloud and Semikhatov (1969) Cloud and others (1969)
	Beck Spring Dolomite	900-825	<i>Conophyton</i> cf. <i>garganicum</i> cf. <i>Baicalia</i> <i>Stratifera</i>	Marian (1979) Marian (1979) Marian (1979)
	Crystal Spring	1150-1100	<i>Baicalia</i> cf. <i>Jacutophyton</i> <i>Conophyton</i>	Howell (1971) Howell (1971) Howell (1971)
2. White-Inyo Mtns., California	Wyman	>C	"Cryptozoa"	Kirk (1918)
3. San Bernardino Mtns., California	Greenspot	>700	cf. <i>Conophyton</i>	McMenamin (1982)
4. Grand Canyon, Arizona	Kwagunt	ca. 850	<i>Boxonia</i> <i>Baicalia</i>	Ford and Breed (1973) Cloud (1988)
	Galeros	ca. 875	<i>Inzeria</i> <i>Baicalia</i> aff. <i>B. rara</i> <i>Stratifera</i> <i>Collenia occidentale</i>	Ford and Breed (1973) Ford and Breed (1973) Elston (1989) Walcott (1914)
	Bass Limestone	ca. 1225	<i>Collenia undosa</i> <i>Collenia symmetrica</i> cf. <i>Collenia frequens</i>	Dalton (1972) in Beus and others (1974) Dalton (1972) in Beus and others (1974) Dalton (1972) in Beus and others (1974)
5. West Texas	Allamoore	ca. 1140	cf. <i>Conophyton</i>	Toomey and Babcock (1983)
	Castner Marble	>1000	cf. <i>Conophyton</i>	Toomey and Babcock (1983)
6. Caborca, Mexico	Gamuza	>600	<i>Conophyton</i> <i>Jacutophyton</i> <i>Platella</i>	Weber and others (1979) Weber and others (1979) Weber and others (1979)
7. Central Arizona	Mescal Limestone	1200-1100	<i>Collenia frequens</i>	Shride (1967)
			<i>Conophyton</i> cf. <i>garganicum</i>	Cloud and Semikhatov (1969)
			<i>Apachina henryi</i>	Bertrand-Sarfati and Awramik (this paper)
			<i>Tungussia chrysoitila</i> <i>Tungussia mescalita</i>	Bertrand-Sarfati and Awramik (this paper) Bertrand-Sarfati and Awramik (this paper)

We do not see that any satisfactory comparisons can be made at this time between the Mescal stromatolites and stromatolites of the Pahrump Group. *Tungussia* is a distinctive taxon that is relatively easy to recognize in outcrop and is very different from the stromatolites known by us from the Crystal Spring and Beck Spring Formations. *Conophyton* from the Mescal was reported on, and laminae were illustrated by, Cloud and Semikhatov (1969, Plate 2, Fig. 3); however, we did not find *Conophyton* in the Mescal during our field studies. Examination of the thin section illustrated by Cloud and Semikhatov (1969, Plate 2, Fig. 3) indicates that the laminae and microstructure are different from known conical stromatolites of eastern California and are unlike those of the Mescal stromatolites we studied. The specimen mentioned in Cloud and Semikhatov (1969) was also examined, and, although it is a conical portion of a stromatolite, no axial zone (diagnostic of *Conophyton*, Komar and others, 1965) is present. The identification of *Conophyton* is questionable.

Unfortunately, *Conophyton* has often been used to compare and to correlate stratigraphic sections in the localities listed in Table 2. *Conophyton* is a long-ranging taxon; it ranges from early Proterozoic to Vendian time. A high degree of diversity exists in *Conophyton* with at least 40 different Forms taxonomically described. Without precise identification of *Conophyton* (a cylindrical conical stromatolite with a

well-defined axial zone) down to the Form level (and this includes analysis of the microstructure and requires good preservation), any suggestion of correlation using one long-ranging stromatolite identified at the Group level can be misleading.

### White-Inyo Mountains, California

Stromatolites are known from the Wyman Formation (Kirk, 1918, mentioned the presence of Cryptozoa = *Cryptozoon*); however, they have not been studied in any detail. Columnar branching and conical stromatolites have not been reported. No comparisons can yet be made of the stromatolites of this region to the Mescal and other regions.

### San Bernardino Mountains, California

Although the units are metamorphosed and often structurally altered, stromatolites are known from the Greenspot Formation (Cameron, 1982). These include conical (McMenamin, 1982, tentatively referring them to *Conophyton*) and unnamed columnar stromatolites (Stewart and others, 1984). The presence of cf. *Conophyton* suggested a correlation of the Greenspot with the Gamuza Formation in Caborca (Stewart and others, 1984). There are no known similarities in stromatolites between the Greenspot and Mescal Formations.



### Grand Canyon, Arizona

The Bass Limestone, Galeros, and Kwagunt Formations contain stromatolites (Table 2). The Bass Limestone has been compared to and correlated with the Mescal (Shride, 1967); however, recent syntheses indicate that they do not correlate (see Link and others, in press). Only *Collenia frequens* Walcott 1914 may be in common between the Mescal and the Bass Limestone. *Collenia frequens* has not been morphologically analyzed from either region and it is premature to make correlations based on a superficially similar stromatolite.

### West Texas

Shride (1967) suggested a possible correlation of the Castner Marble with the Mescal. Stromatolites provisionally identified as *Conophyton* have been found in the Castner Marble as well as the Allamoore Formation (Toomey and Babcock, 1983). No correlation can be made between these west Texas stromatolites and the ones in the Mescal at this time.

### Caborca, Mexico

Three stromatolites have been identified at the Group level from the Gamuza Formation in the Caborca region of Sonora: *Conophyton*, *Jacutophyton*, and *Platella* (Weber and others, 1979). The Proterozoic sequences in Caborca are correlated with the Pahrump Group and the overlying strata in southeastern California (Stewart and others, 1984). Only the *Conophyton* mentioned in Cloud and Semikhatov (1969) is in common between the Mescal and the Gamuza. Therefore, satisfactory comparisons cannot be made between these two formations based on this stromatolite.

### SUMMARY AND CONCLUSIONS

A striking feature of the Mescal Limestone is the low diversity of the columnar stromatolites in the Algal Member. Only two Groups, *Apachina* and *Tungussia*, are recognized here. *Tungussia* is represented by two Forms, *T. mescalita* and *T. chrysofila*, and *Apachina*, by only one Form. These stromatolites are restricted to only a few meters of the lower part of the member. *Tungussia* is widespread and found as far away as Roosevelt Dam and Salt River Canyon (Fig. 1). The unique and conspicuous, predominantly pseudocolumnar *Apachina henryi* is found only at one locality. This low-diversity assemblage

does not enable us to attribute a great deal of biostratigraphic significance to the Mescal stromatolites. Little variability in the environment and probably little variability in the microbiota over the presumably short period of time represented by the Algal Member resulted in little variability in the stromatolites. Nevertheless, *Tungussia* is a common middle Riphean stromatolite Group and for the Mescal such an age estimate is in agreement with the radiometric age constraints of 1450 to 1120 Ma for the entire Apache Group.

The environmental conditions prevailing during stromatolite deposition of the Algal Member are comparable to those of a cratonic sedimentary setting, such as that which occurred during the late Proterozoic in the Sahara, Africa (Bertrand-Sarfati and others, 1977). A large, flat, platform-like area is postulated to be where uniform environmental/depositional conditions prevailed during the development of the stromatolite biotomes. In the Mescal, stratiform stromatolites as well as columnar stromatolites are uniformly distributed over the area of investigation. Shride (1967) noted the lack of lateral variation within the Algal Member. The development of the columnar stromatolites appears to reflect an abrupt change from a current (possibly tidal) influenced environment to a quiet subtidal environment (lack of detrital infill, relatively un-eroded laminae and column margins). In the northern Sahara Proterozoic cratonic sedimentary setting, the relatively long-term stability of the craton is reflected in the existence of numerous geographically widespread layers of morphologically diverse columnar stromatolites. In the Mescal, conditions, although stable for the stromatolite development, were relatively short-lived; only about 20 to 25 m of section accumulated, and the accumulation may have ended suddenly with subaerial exposure and erosion before the Argillite Member was deposited. The Argillite Member unconformably overlies the Algal Member throughout much of northern Gila County (Shride, 1967). In a few areas, basalt flows separate the Algal and Argillite Members (Shride, 1967). The Algal Member therefore appears to represent a short-lived environment that was favorable for stromatolite growth; however, only a low-diversity assemblage developed.

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