Palaeont. afr., **20**, 1–26 (1977)

COLUMNAR STROMATOLITES FROM THE EARLY PROTEROZOIC SCHMIDTSDRIFT FORMATION, NORTHERN CAPE PROVINCE, SOUTH AFRICA — PART I: SYSTEMATIC AND DIAGNOSTIC FEATURES

by

J. Bertrand-Sarfati*

Centre Géologique et Géophysique, Université des Sciences et Techniques du Languedoc
Place E. Bataillon, 34060 Montpellier Cedex — France

and

K. A. Eriksson

Department of Geology, University of the Witwatersrand, Jan Smuts Ave., Johannesburg 2001 — South Africa

ABSTRACT

The Schmidtsdrift Formation (Transvaal Dolomite) is a Lower Proterozoic stromatolite-bearing carbonate unit. A good succession of columnar stromatolites occurs along the Boetsap River (Northern Cape Province). Using the method of serial sections to draw the gross morphology of columns and following the actual classification based on a succession of different characters, many new groups and forms have been found: *Topinamboura insulata* is a bulbous column with wart-like projections spreading out everywhere on the smooth surface. *Radiatina isotropa* presents closely packed radiating columns forming compact bioherms. The small rhythmically superposed columns of *Tibia cristata, Tibia plumata* and *Sapinia fucoides* offer tiny bushy columns with a constant crestal zone, a very unusual feature, giving an angular shape to the laminae. Some of the stromatolites belong to previously described groups, from the same area as *Katernia africana* or *Katernia perlina* new form, which present true bushy columns forming thin biostromes; or, from other parts of the world, as *Pilbaria boetsapia* and *Pilbaria inzeriaformis,* two new forms, attributed to a Lower Proterozoic group described in Australia. Besides description of morphologies and mode of occurrences, detailed studies of lamina microstructures have been carried out. Very interesting fabrics have been described but, until now, no true organic remains (cells) have been found. The conclusions emphasize the importance of detailed systematic description of stromatolites in order to make a biostratigraphical model of the Lower Proterozoic and to clear up confusions with Upper Proterozoic stromatolites which also present varied assemblages of ramified stromatolites.

CONTENTS

*Contribution CGG n° 204

INTRODUCTION

The Schmidtsdrift Formation is a facies equivalent of the Malmani Dolomite in the Transvaal (Eriksson *et al.*, 1976) which is dated relative to younger lavas at greater than 2 224 ± 21 m.y. (D. Crampton, personal communication, 1972).

Early work on the Schmidtsdrift Formation was undertaken by Young between 1928 and 1943. In three of his contributions (1933, 1934, 1940), Young made reference to columnar stromatolites from the Schmidtsdrift Formation and Groot Boetsap River. These two localities have subsequently been studied in more detail in a palaeoenvironmental context by Visser and Grobler (1972) and Truswell and Eriksson (1973) respectively. Columnar stromatolites are especially well developed in the Groot Boetsap River section where Truswell and Eriksson (1973) noted a great diversity of morphologies. Samples have been taken in this area in order to describe columnar stromatolites in terms of the presently known Russian classification. Linnean binary names are used. In this classification different characters enter dealing with shape of columns, ramification, nature of marginal surface, mode of occurrence, and micro-

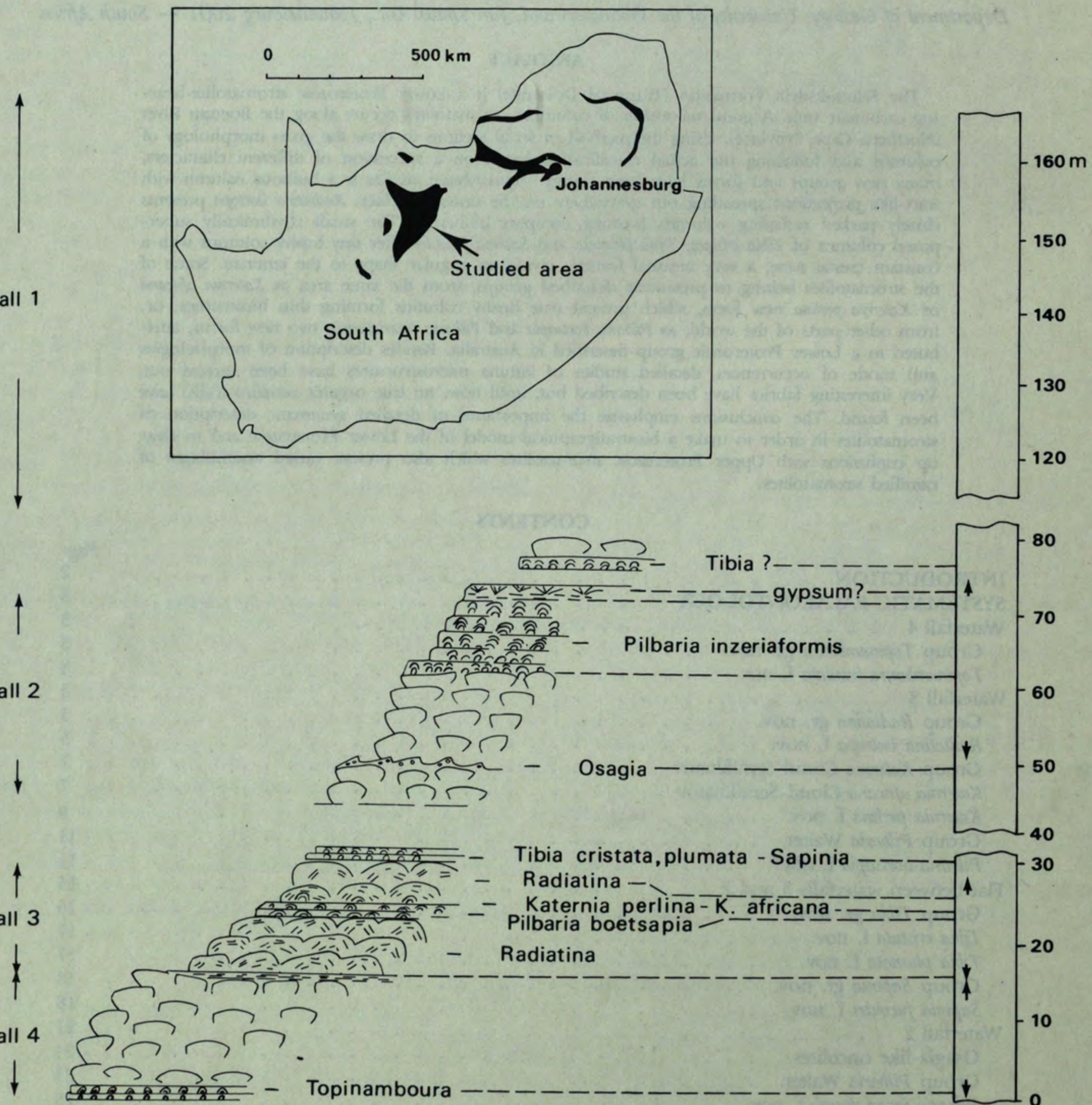


Figure 1. Section of the Groot Boetsap River on the right (according to Truswell and Eriksson, 1973, p. 20); on the left schema of the outcrop showing location of the different stromatolite groups. The individual thickness of domes is greatly exagerated; inset, locality map of the Transvaal Dolomite.

structure of laminae. For this purpose, in addition to thin section studies, reconstructions of the columns were made by drawing of serial sections through the samples (Krylov, 1963). These were compared with other stromatolites described in the available literature. In the present case, few of them are known from lower Proterozoic carbonates, and comparisons have mainly been made with Riphean stromatolites and a few Australian forms circa 2 000 m.y.

We will now describe the stromatolites following their chronological succession along the Groot Boetsap River. Four waterfalls along the river provided well exposed outcrops (fig. 1).

SYSTEMATIC PALAEONTOLOGY

Waterfall 4

(fig. 1)

At the very base of the waterfall is a 1,2 m thick bed of contorted and bulbous *Topinamboura* (gr. nov.). The ramified columns form small bushes 20 to 30 cm high. Overlying this bed in a sharp contact with the columns is a thick sequence of domical stromatolites, with few discrete columns. Domes are linked, oblate to convex-shaped. Dolomitization retains sometimes few structures (Truswell and Eriksson, 1973, p. 9). The sequence ends with a thin bed of shales and spheroids.

Group *Topinamboura* gr. nov.

Type form
Topinamboura insulata

Group Name
From Topinambour, French name of an American plant with potato-like tubers.

Diagnosis
Bulbous sparsely distributed columns with small wart-like projections and slightly divergent branching, with the daughter columns spreading out laterally at various angles. Marginal surface is very smooth with a well defined wall. The microstructure shows trapped particles without defined lamina boundaries.

Topinamboura insulata f. nov.
(figs. 2a–d, 4a–c)

Holotype
SA 2, from three samples in the same horizon and one from an outcrop near the previous one.

Form Name
From the Latin *insula* (island) for the isolated, widely spaced column.

Description
The discrete columns are generally vertical or slightly oblique, never horizontal. They are bulbous with short straight portions which rapidly ramify. Diameter varies greatly (2–10 cm) and some parts increase laterally to three or four times their initial size, overlapping smaller columns. Horizontal section is lobate with complex contour form. Axes of columns changed during growth. Ramification shows separate daughter-columns in divergent position continuing to grow for a few centimetres and also lots of small bumps (one or two centimetres as a maximum) spreading out at right angles, in every direction. Along the surface are long deep depressions differing from niches; they may be horizontal, oblique or vertical. The column margins show no peaks, bridges or coalescence. The surface is smooth, outlined by a continuous wall (less than 2 mm thick). Laminae are moderately convex, generally asymmetric with a slightly visible stratification. In horizontal portions they are quite flat but in the oblique one they are vertical to recumbent. The total relief of the walled column is variable, sometimes as high as 10 to 15 cm. A crust envelops the columns prior to sedimentary filling.

Microstructure
The succession of laminae is regular but without clear physical discontinuity between mats. Different laminae are defined by the rough alternation of microsparitic and corpuscular layers. The microsparitic one is made of xenotopic dolo-microsparite with dark limits of crystals, probably due to recrystallization of a muddy carbonate. The corpuscular layer contains dark grains (micritic pelloids) in a matrix of larger crystals. The black grains appear as rounded or elongate pelloids of micrite obviously different from the stromatolite laminae but probably also algal (organic matter content). They are relatively well sorted (between 0,05 to 0,12 mm with a length up to 0,9 mm). The layers are not very thick and never show graded-bedding. Elongate grains lie parallel to the surface of curved laminae.

The wall changes from thin mats (no more than 0,02 mm for a doublet and up to 15 doublets) to an homogeneous texture in the curved upward portions where it reaches a thickness of 4–5 mm. In some cases the continuity with stromatolite mats is clearly visible, especially on the small bumps.

Interspace filling
(a) Prior to the sediment deposition, the column is enveloped by a non-algal crust. In the overlapping portions it is a thick dolomitic radiaxial crust made by the superposition of very thin laminae (up to ten). When the column flattens some grains are trapped between these layers and in the flat portions big grains falling by gravity are coated by the clear bladed crystal layers. The continuity of the crust prevents interpretation as a vadose cement. The crust also can extend upon sediment interspace filling.

(b) The sedimentation of the interspaces takes place following, not during, the column and crust growth. It presents layers of microsparitic carbonate (muddy) containing thin beds of small particles with

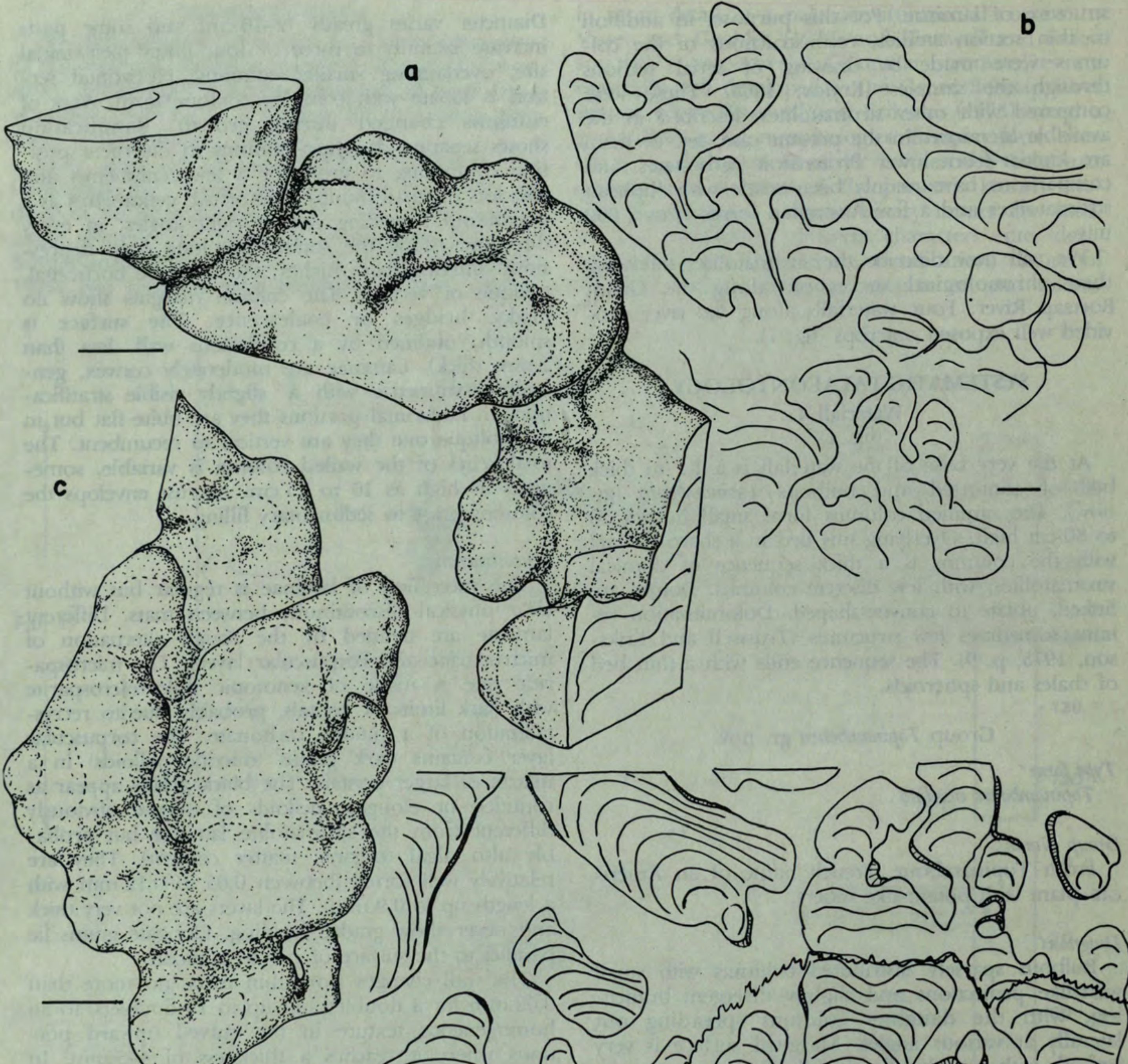


Figure 2. *Topinamboura insulata*
(a) contorted column (SA 2, JBS coll.);
(b) ramified columns (drawing from JBS field photograph);
(c) bulbous columns with small bumps on the surface (SA 1, JBS coll.);
(d) clear dolomitic envelope (e) along the overlapping portions of columns (SA 31, drawing from a peel, Young coll.).
Scale bars, all 2 cm.

small sized slumps and micritized surfaces. Abundant lenses of coarse material alternate with them forming small pockets in depressions of the column surface. The grains are not genetically different from those found within the laminae but are much bigger. They are dark micritic pelloids or aggregates, very poorly sorted (minimum at 0,12–0,2 mm, maximum at 1 to 1,5 mm, and thin films 0,03 mm thick). They show rounded and elongated bodies and strange vermiform, thin, and very dark micritic elements of probably algal origin. Nevertheless they are not comparable to the stromatolitic laminae of the neighbouring columns. They seem to come from elsewhere, perhaps from leathery algal mats disrupted prior to lithification. Peeling of mats can be due to biological activity (Monty, 1972, p. 777). This could explain their contorted appearance and, as they were richer in organic matter, their black colour. They are cemented by clear carbonate.

(c) There are many signs of pauses in the sediment filling indicated by micritized surfaces. They can be seen on eroded portions of the columns, on sharply cut laminae without crust or wall, on part of the crust and on muddy sediment upper surfaces. This sediment is an homogeneous micritic mud with silt-size particles and graded-bedded coarser grains in a sparry matrix; the upper flat surface with smaller grains testifies a discontinuous sedimentation in an agitated environment. No cracks have been found in the sediment and the particles are not *in situ* intraclasts.

(d) Along the overlapping portions of the columns outlined by the crust are protected voids, generally between crust and coarse sediment. These cavities were later filled by clear anhedral dolomite crystals.

They are fringed along the surface of the crust by small dolomite rhombs.

Comparisons

This form is a very unusual one. Irregular shape of column restricts the comparison to only few of the presently described stromatolites: *Baicalia* Krylov and *Poludia* Rabben. *Baicalia* and *B. burra* Preiss and especially *B.* cf. *burra* from Nabberu Basin present bulbous columns, some of them (Preiss, 1976, p. 27, fig. 16g) very similar to our form, but they are differentiated by the absence of wall and the close spacing of *Baicalia*. *Poludia* is defined by angular axes of growth as in *Topinamboura* but it has also a variable surface and coalescing closely spaced columns with oblique ramification. The association of the different characters of *Topinamboura* is completely new, also the type of microstructure.

Waterfall 3

The outcrop is composed of superposed large elongate flat domes interbedded with flat biostromes:

(a) At the base low relief domes (1,5–2,5 m long and 0,5–0,8 m thick) overlap each other. These bioherms are built by fan radially arranged columns of *Radiatina* (g. nov.) and upwards mixed bioherms are built by successive layers of *Radiatina* and *Katernia africana* Cloud Semikh. The tops of the bioherms are capped by slightly undulated laminae. On the edges rough columns are in continuity with the laminae making up the bioherms. Small pockets of carbonate breccia are found between some of the domes. Sometimes beds of shales are interbedded between the domes.

(b) A biostrome (0,8 m high) built by the straight discrete large columns of *Pilbaria boetsapia* (f. nov.) is sharply cut at the top by an erosional surface and overlain by flat laminae filling the irregularities and giving rise to the small vertical columns of *Katernia perlina* (f. nov.) and *K. africana*. The small bushy columns are often interbedded with flat lying or slightly undulate laminae of the same microstructure.

(c) At the top of the waterfall, new bioherms of *Radiatina* appear obviously the same as the previous, surrounding without any discordance a central zone built by short *Pilbaria*-like columns.

Group *Radiatina* gr. nov.

Type form
Radiatina isotropa

Group Name

From the latin *radiatus* in relation to the fan-like radial arrangement of the convex part of laminae.

Diagnosis

Very closely spaced columns with connecting laminae, fan-like radially arranged in a bioherm. The laminae are nearly flat with an asymmetric bumpy convex zone just before the interruption of laminae. Ramifications begin in the crestal zone at a constant angle.

Radiatina isotropa f. nov.
(figs. 3a, c; 7a)

Holotype

SA 6; base of fall 3; from five samples from different bioherms, beneath and above *Pilbaria* and *Katernia* biostromes.

Form Name

From the Greek *iso* + *tropos* (equal + turn) because of the regular repartition of crestal zone lines all over the bioherm.

Description

The close spacing of the columns prevents one from drawing them. Column shape is moderately turbinate with an horizontal section elongate at the base and lobate at the top of the bioherm. In vertical section the interspace filling appears in relief due to weathering. The laminae run almost flat and parallel with a very low total relief. On one side of the column, generally external, the lamina bumps, thick-

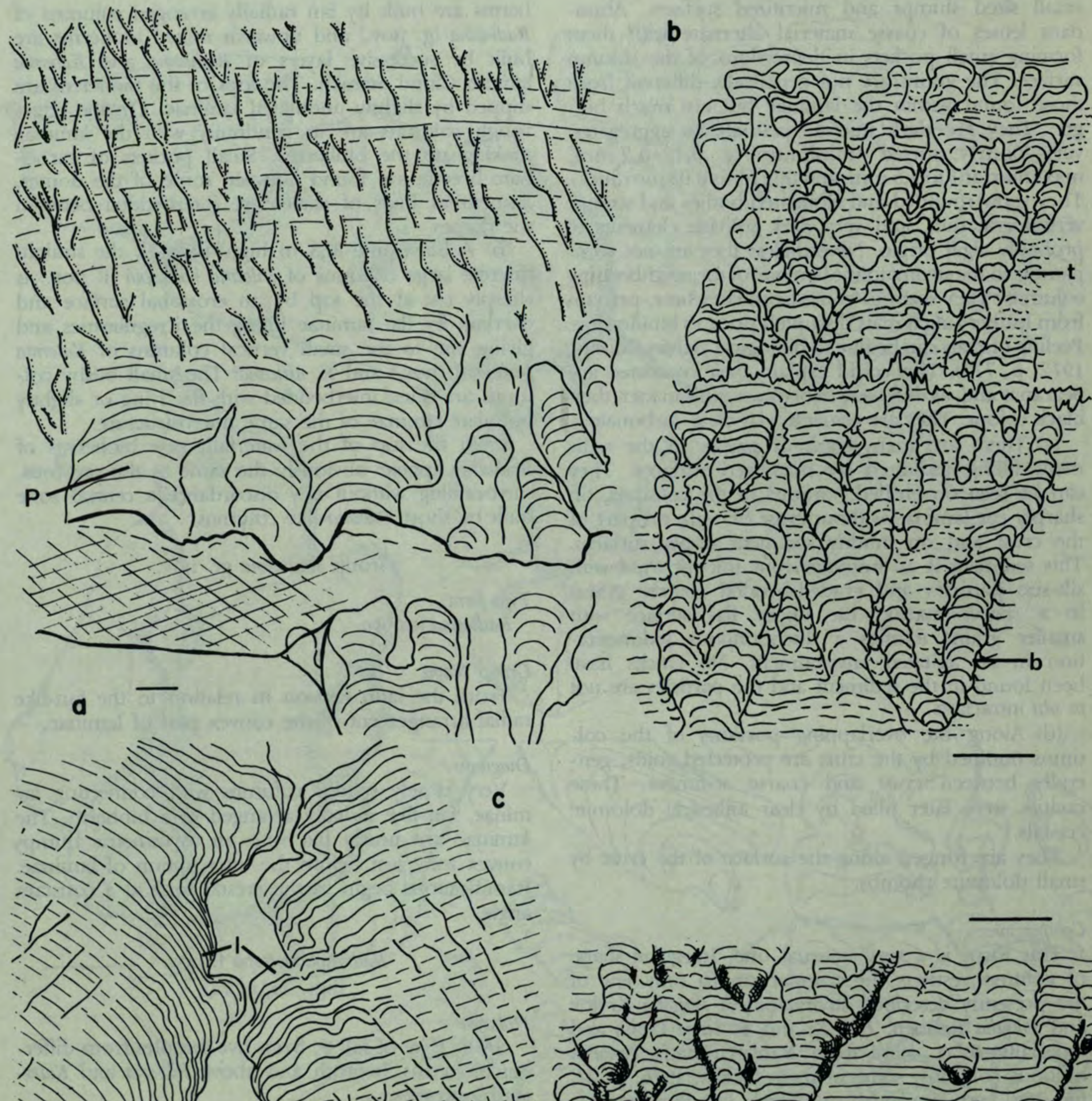


Figure 3. (a) *Radiatina isotropa* ramified columns directly growing on *Pilbaria*-like columns (P) forming the central part of the bioherms (top of waterfall 3), (drawing from JBS field photograph);
(c) roughly columnar laminae (l) on the edges of two adjacent bioherms (drawing from JBS field photograph).
Katernia africana
(b) columnar form with slightly different shape from base (b) to top (t) (SA 35, Eriks. coll.).
(d) columnar to pseudo-columnar forms intermediate with *Radiatina* (Young coll.).
(b) and (d) drawing from peels.
Scale bars, all 2 cm.

ens, curls back and stops. This feature is called here a "crestal zone". It is generally thin, with a high degree of inheritance. A sparitic zone outlines it along the sharp edge followed by a cup-like laminated thin (2–3 mm) interspace. Then the new flat lamina begins, forming the other side of the column. The ramification, more abundant near the top and the edges of the bioherm, begins in the crestal zone with an upward deplacement of the second crestal zone, following an angle of approximately 60 °.

Microstructure

The laminae are poorly defined with no boundaries between them, except a discontinuous more or less clear carbonate layer at the base. Very small grains are found, especially in the more micritic layers, with few silt-size quartz and thin straight flat lying "filaments". The dark micritic pelloids are mostly rounded, with sometimes a clear central zone and darker envelope, and could be unicell colonies developed *in situ*, especially in *Radiatina* from the top of fall 3. They are generally small and well sorted. The flat-lying thin "filaments" are found especially in the stromatolite laminae. They are short, generally with thin dark limits defining a tube of clear carbonate (less than 0,012 mm). Some of them are monocrystals. On its sharp edge, the crestal zone is outlined by a sparitic pseudo-wall made of big crystals of sparite with dark boundaries. It differs from a wall made of coalescing laminae because of its sparitic nature. It cannot be confused with infilling carbonate, because of its relationship with the plunging laminae. This sparitic coating gives a strange relief to the crestal zone.

Interspace filling

It represents a very thin zone along the crestal zone frequently laminated with an upward convexity. The matrix is sparitic, different from the pseudo-wall and containing rounded, dark micritic grains of bigger size than in the stromatolite layers. They never present flat "filaments".

Comparisons

This form stands completely apart: fan-ramified columnar forms are known from the Riphean, especially *Anabaria* Komar, and in the Saharian area, *Serizia radians* Bertrand-Sarfati and *Tifounkeia* Bertrand-Sarfati but the three of them have normally spaced columns with convex-shaped laminae and true ramification (*Anabaria* in one plan and others in all directions) and none of them have a crestal zone. On the other hand, the crestal zone is completely different from that of *Conophyton* Maslov, which is more convex, made of vertical films or mats generally folded, and larger in size (up to 2 or 3 cm in diameter).

Group *Katernia* Cloud and Semikhatov

Type form

Katernia africana Cloud-Semikhatov, 1969, pp. 1046–47, Plate 3, Figures 4–5; the sample comes from Schmidtsdrift and is compared to a Boetsap columnar form.

Revised Diagnosis

Luxuriantly branching columns with many connecting layers and lateral surfaces ragged, in domal bioherms.

Katernia africana Cloud and Semikhatov

(figs. 3b and d; 7b and c)

Description

In Boetsap, they are mainly columnar with a laminated infilling that resembles interconnecting laminae. Columns are turbinate and straight. Horizontal section is generally sub-circular. The ramification begins upon an enlarged portion of column by two convex zones on the laminae, in external positions, so the ramification leads to daughter columns placed laterally on the ramification which is sometimes parallel and sometimes markedly divergent. The ramification rate increases upward with a size diminution, and columns become more bulbous and short. The laminae are slightly convex to flat in the larger portions of the columns and show a sudden plunging of the lamina on the edges in a kind of crestal zone. Tangential cutting presents very deeply convex laminae. Surfaces of columns are smooth with a pseudo-wall along the margins of the deeply convex laminae. In the flat laminated portions the laminae end sharply and sometimes extend through the infilling.

Microstructure

The laminae differ according to their shape. The convex laminae are mats of micrite-microsparite with sharp upper limits and a more sparitic layer at the base; radial alignments of small crystals that could be ghosts of filaments are visible within the micritic laminae. The crestal zone (inherited convex portion of laminae) is, most of the time, visible on each side of columns and along the edges there is a pseudo-wall of clear calcite crystals. In the flat laminae, small rounded pelloids (0,01 to 0,05 mm) are found most of the time in the sparitic zone at the base of the lamina. The rate of detrital material increases as the size of columns decreases.

Recrystallization is important, especially in the sparitic pseudo-wall (dolomite rhombs), but this wall cannot be only a recrystallization feature.

Interspace filling

Small rounded micritic pelloids (not larger than 0,15 mm) are found in a microsparitic to sparitic matrix. In the upper parts, where columns are smaller, the infilling is more thin-grained and alternating with sparitic layers in a convex downward laminated pattern.

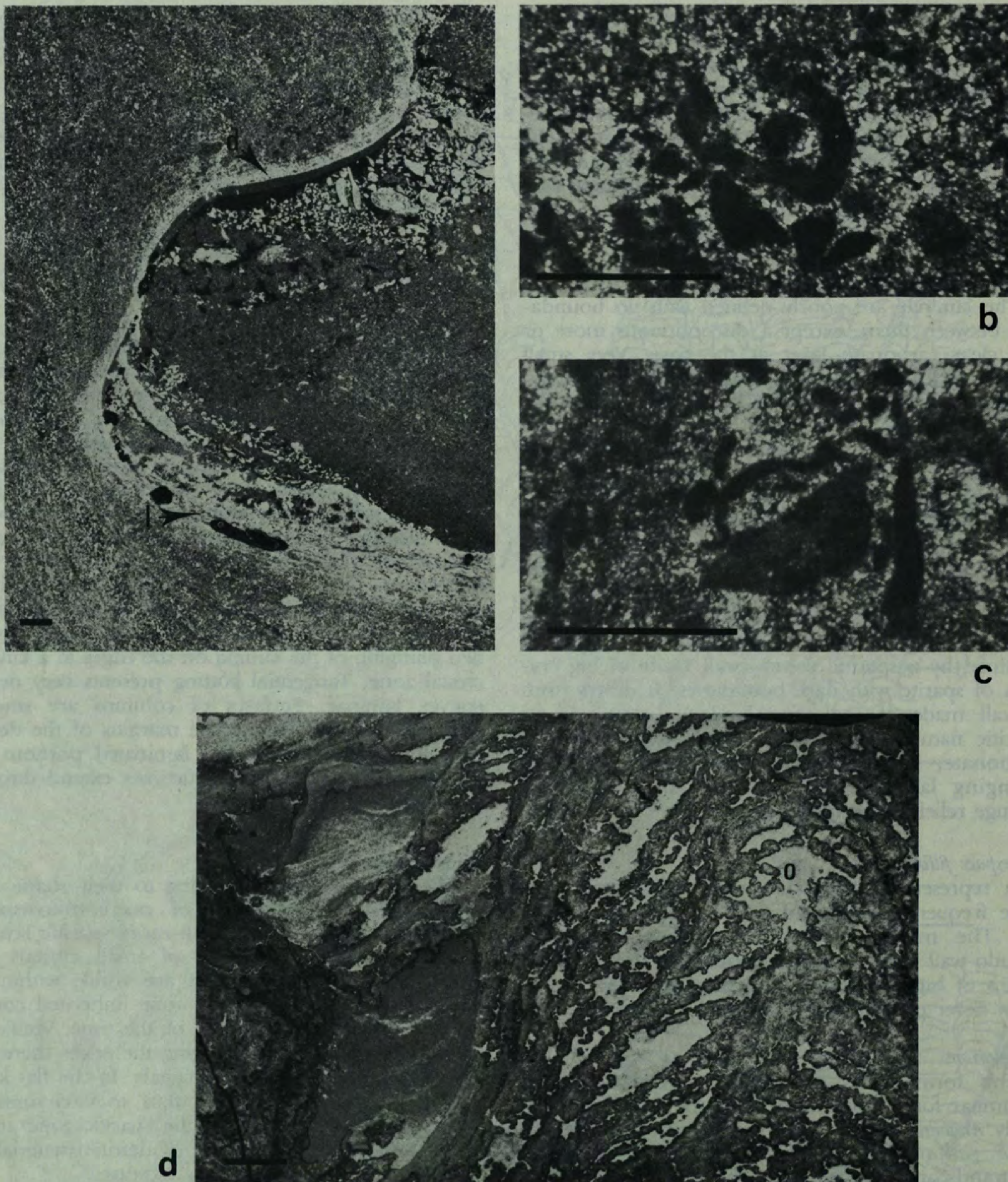


Figure 4. *Topinamboura insulata*
(a) column showing the drusy crust (d) along the columns at the top, passing to separate layers (l) on the flat portion (SA 2, JBS coll.). Scale bar, 1 cm;
(b) and (c) vermiform structures in the sedimentary infilling (SA 2, JBS coll.);
Scale bars, all 1 mm.
Pilbaria boetsapia
(d) recrystallization of the central zone in rounded pseudo-ooid (o) (SA 10, JBS coll.);
Scale bar, 1 cm.
Negative prints from thin sections.

Comparisons

This form presents relationships in the field with both *Radiatina* and *Katernia perlina.* Their relationships are also found in the structure of the columns where the main features are present in the three forms: crestal zone in *Radiatina* and *K. africana;* pseudo-wall in the three of them; angle of ramification also the same for the three forms. We do not agree with the definition of *K. africana* given by Cloud and Semikhatov which insists on the interconnecting laminae. (See Revised Diagnosis). Here we have a true columnar form and the interconnecting algal laminae are often distinct from the stromatolite-laminae. In the Sibley group of Aphebian age, Hofmann (1969, Pl. 4) described very tiny columns, more often coalescing: they expand in every direction and have different microstructures. *Gruneria* Cloud-Semikhatov has been compared to *K. africana* but has too many connecting laminae and larger columns. *Alcheringa narrina* Walter is of approximately the same age but has a very compact growth forming coalescing bushes with thicker laminae. *Alcheringa* has also well-defined laminae very different from this one.

Katernia perlina f. nov.
(figs. 5a–e, 6a–d, 7d)

Holotype

SA 11, from eight samples, three from the Young collection.

Form Name

From the vulgar Latin *perla* (pearl) because the columns have branches reminiscent of a string of pearls.

Figure 5. *Katernia perlina*
(a), (b), d) holotype (SA 11, JBS coll.);
(c), (e) similar form from Schmidtsdrift synclinorium (SA 38, Young coll.).
Scale bars, all 1 cm.

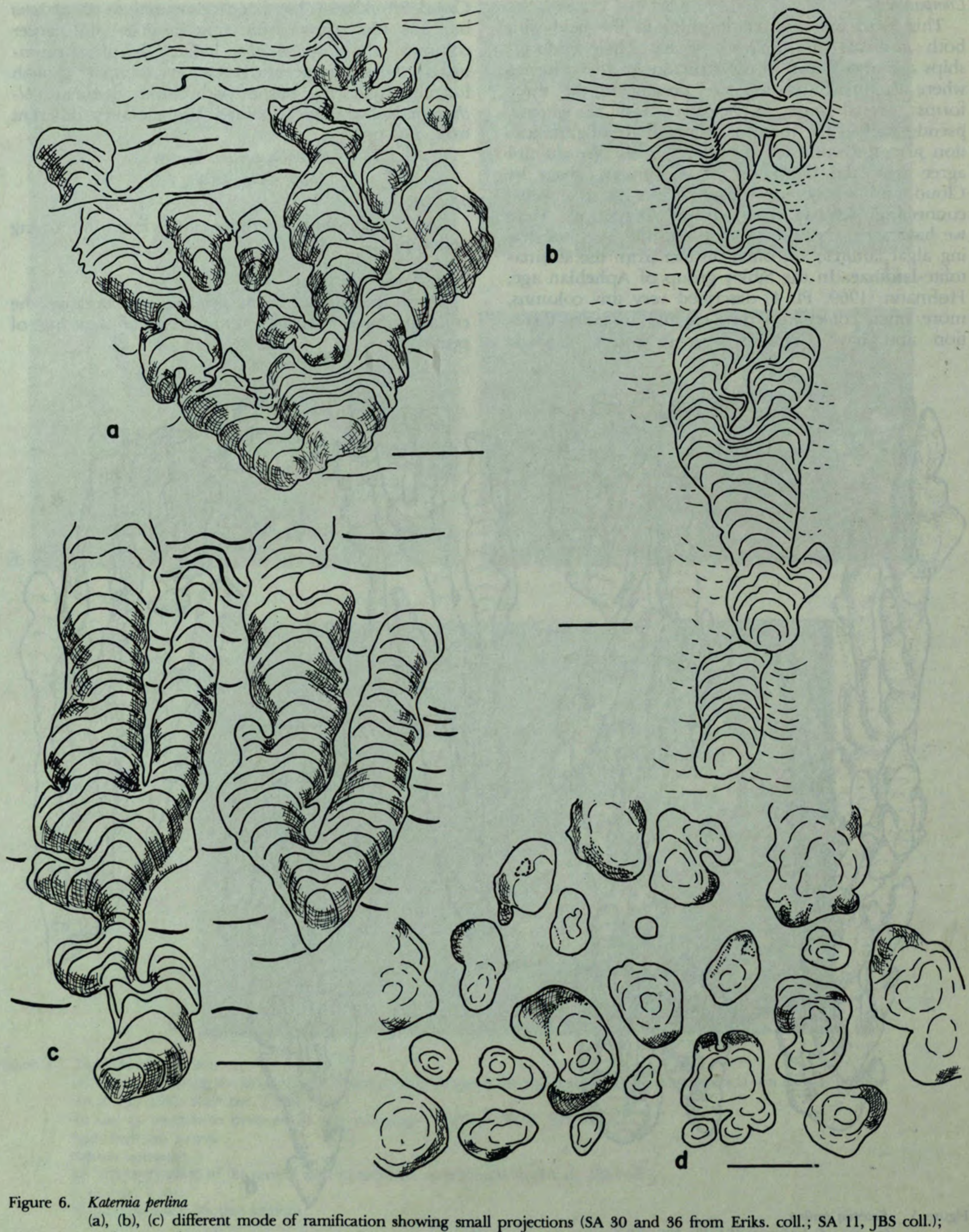


Figure 6. *Katernia perlina*
(a), (b), (c) different mode of ramification showing small projections (SA 30 and 36 from Eriks. coll.; SA 11, JBS coll.);
(d) horizontal section:
(drawing from enlarged peels)
Scale bars, all 1 cm.

Description

Small pearl-like, slightly turbinate, vertical columns with a diameter less than one centimetre and subcircular or slightly lobate horizontal section. Interspace between columns reaches ten centimetres, but every small straight and unramified portion is never more than 1,5 to 2 cm high. The ramification resembles parts of *K. africana,* especially the smaller columns of this type. As columns enlarge, laminae flatten and are disrupted in the middle and two smaller columns develop with steeply convex laminae on the outer edges. One of the new columns stops and the other ramifies after 1 or 2 cm. The digitations are sometimes very short and the whole column presents a characteristically bumped shape. Very often the continuity of the different portions of one bush is not visible on the surface of the sample and appears only on the drawing. The laminae are convex with a relief of 0.5 to 1 cm for a diameter of less than 1 cm. The margin surface is smooth with enveloping laminae and a sparitic pseudo-wall as in *K. africana* and *Radiatina.*

Microstructure

Laminae are not well defined but, when they are not too recrystallized, it is possible to see at the bottom of the lamina discontinuous lenses of sparite, with small micritic pelloids and very few quartz grains (from 0,01 to 0,03 mm) passing to a micritic layer without any boundary. Few thin dark pelloids are found in this layer which is sometimes also discontinuous. Near the edges, the micritic laminae only plunge deeply and fade away in the sparitic pseudo-wall. In some cases, the sparitic base is reduced and the micritic upper mat appears as cushions irregularly superposed. They are clearly limited at the top. The wall always has a sharp boundary with the infilling. When the column is tangentially cut at the base of a ramified branch the wall is well developed showing that it is a part of the algal growth.

Secondary alteration

First, the sparitic pseudo-wall is recrystallized in bladed crystals of sparite arranged perpendicularly to the edges. Sometimes it is almost impossible to see the continuity with the micritic plunging layer. Sometimes late joints cut the crystals with an infilling of clear calcite. Within the columns, the same type of recrystallization occurs and the lenses are surrounded by bladed crystals leading to pseudo ooids with a dark core and a dark dissolution boundary. In heavily weathered samples, ferrous oxide appears in undulated rings, concentrical to the margins. No trace of the primary microstructure of laminae then remains.

Interspace filling

It is often more detrital than in *K. africana:* intraclasts of dark micrite (up to 1,5 to 2 mm) are embedded in a sparite. Surfaces of the layers are of dark micrite with a precise upper limit. They probably are algal but they have no continuity with the stromatolite layers.

Comparisons

It differs from *Radiatina* by the convex shape of laminae giving rise to small straight ramified columns. It differs from *K. africana* by the true columnar growth, spacing of columns, smooth margin, less turbinate shape and more important rate of ramification. In the Transvaal dolomite they are comparable to a small ramified column from Schmidtsdrift, also mixed with *K. africana,* differing only by the absence of the sparitic pseudo-wall. There are similarities also with columns of *Sapinia* (see p. 18 et sqq.) with lots of ramification and sparitic wall but different other features. Besides these local comparisons, they are so small that it is difficult to compare them to normal size columns: only *Patomia* Krylov, especially *P. ossica,* have similar size but less regular ramification pattern and no recrystallized wall. Also *Patomia* ind. (Walter, 1972b, p. 165) which has comparable age presents straighter vertical portions of columns. It differs from *Gymnosolen ramsayi* Steinmann by the frequence of ramification and also the texture of laminae. The wall in *Gymnosolen* is multilamellate and made of coalescing micritic mats.

Group *Pilbaria* Walter

Type form

Pilbaria perplexa Walter 1972, p. 167, Figures 7, 51–52, Plate 4, fig 4; Plate 29, figs 2–7.

Diagnosis

Subcylindrical long, straight, parallel, very smooth columns with small elongate niches with projections.

Pilbaria boetsapia f. nov.
(figs. 4d, 8a–d, 9)

Holotype

SA 10, from two big samples.

Form Name

From Boetsap; name of the locality of sampling.

Description

Very large (more than 10–12 cm in diameter), straight, subcylindrical, rather bulbous, vertical columns. The multilobate horizontal section shows lateral projections generally asymmetric and without preferential orientation. Ramifications are moderately frequent and occur as small projections, always protected in deep niches (pocket-like depressions, Walter, 1972, p. 167), and the ramified branch stays completely inside of the main column. On the edges appear small digitations which are just depressions in the laminae and do not lead to true branching. In the upper third of the columns appears parallel true ramification, leading to a size di-

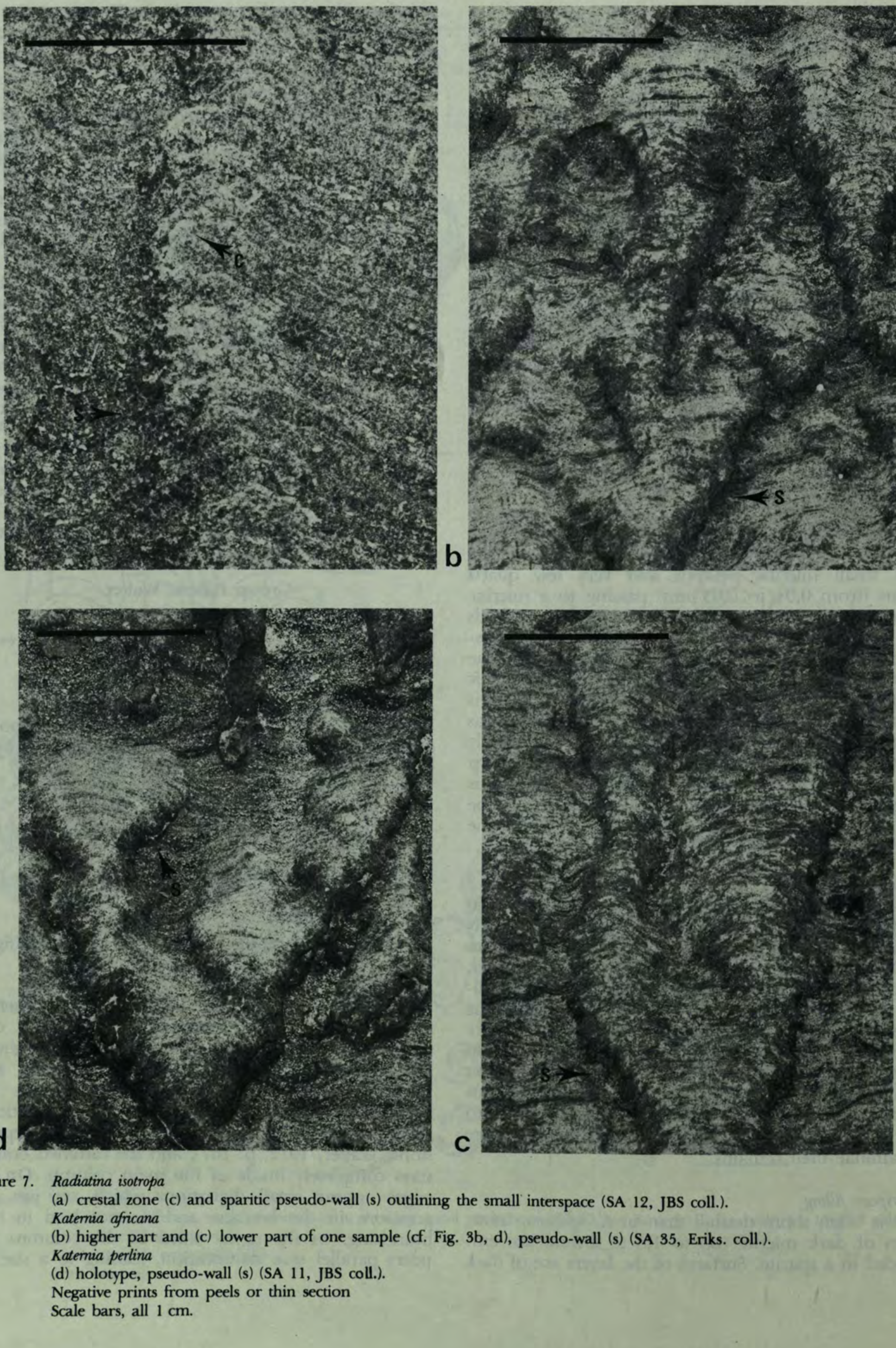


Figure 7. *Radiatina isotropa*
(a) crestal zone (c) and sparitic pseudo-wall (s) outlining the small interspace (SA 12, JBS coll.).
Katernia africana
(b) higher part and (c) lower part of one sample (cf. Fig. 3b, d), pseudo-wall (s) (SA 35, Eriks. coll.).
Katernia perlina
(d) holotype, pseudo-wall (s) (SA 11, JBS coll.).
Negative prints from peels or thin section
Scale bars, all 1 cm.

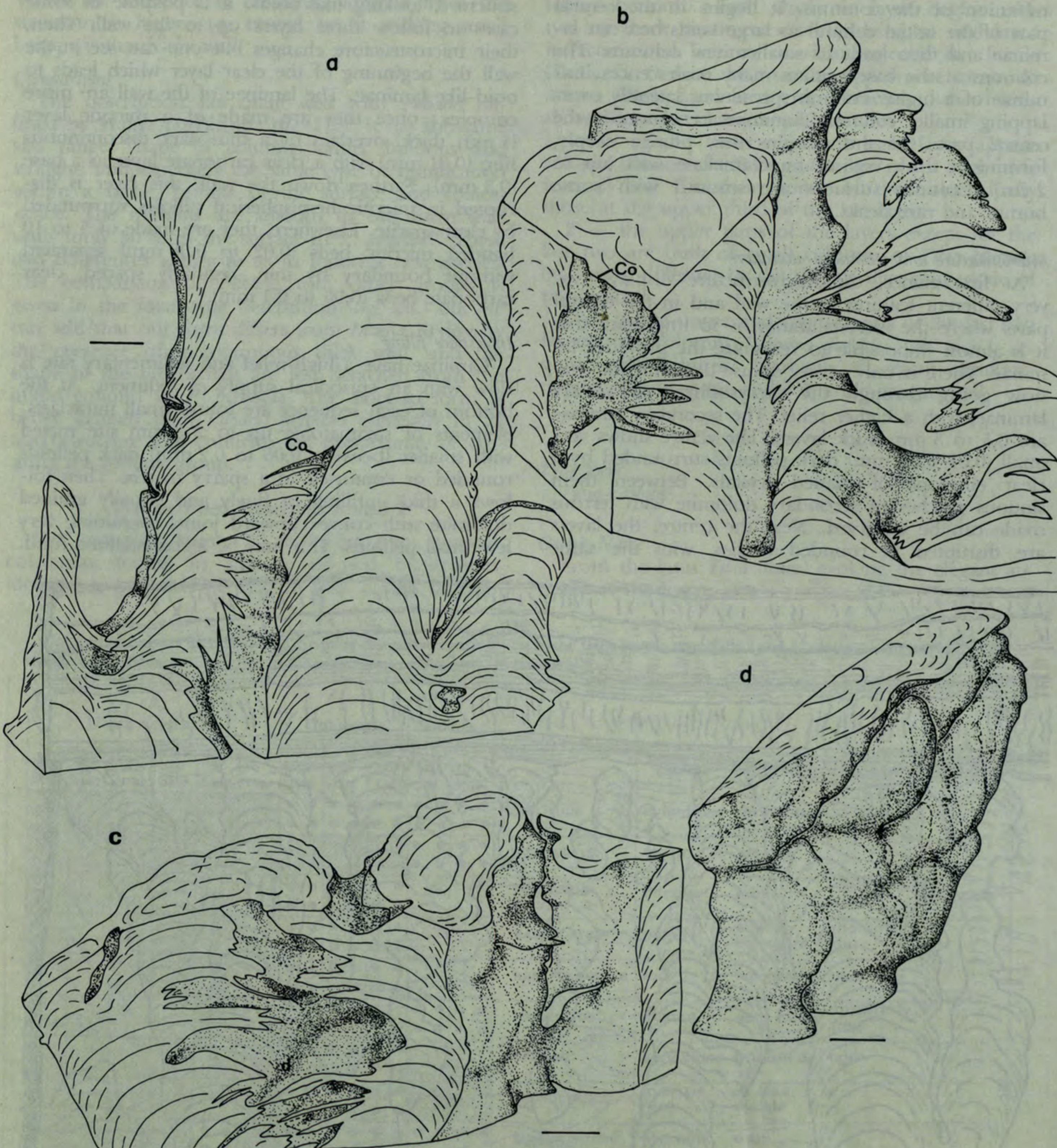


Figure 8. *Pilbaria boetsapia*

(a) coalescence (Co) and small bumps on the surface;
(b) coalescence (Co) and ramification in a niche; on the right small individual short columns isolated within the matrix;
(c) ramification in the upper third of columns beginning with a series of depressions (d) in the central part of columns;
(d) ramification in deep niche.
(SA 10, JBS coll.).
Scale bars, all 2 cm

minution of the columns. It begins in the central part of the initial column as large voids between laminae and then leads to smaller new columns. The columns at the base present many coalescences. Laminae of a higher column spread out laterally overlapping smaller columns. Laminae are convex in the central part. On the margins they plunge deeply, forming a thick vertical multilamellate wall (up to 2 cm). Column surfaces are smooth with some bumps and rare peaks.

Microstructure and secondary alteration

At first glance, the microstructure displays two very different features in the wall and in the central parts where the recrystallization is so important that it is almost impossible to recognize the primitive laminae. There is only a very diffuse dark micritic shadow going through the recrystallized secondary laminae, with a higher relief. The secondary laminae are 0,5 to 3 mm thick layers. The centre shows very small (0,01–0,06 mm) dark pelloids surrounded by a clear envelope of bladed crystals. Between them sinuous patches of secondary dolomite with ferrous oxide can be observed. Near the centre, the layers are disrupted in rounded bodies, with the same structure, looking like ooids. It is possible in some cases to follow these layers up to the wall. Then, their microstructure changes but one can see in the wall the beginning of the clear layer which leads to ooid-like laminae. The laminae of the wall are more complex: once they are made of a micritic layer (1 mm thick) overlain by a thin dark discontinuous film (0,01 mm) with a clear carbonate layer as a base (0,3 mm). Farther down the wall, this layer is disrupted in micritic hemispherical pillows surrounded by clear sparite. Elsewhere, they are made of 5 to 10 banded micritic beds (0,02 to 0,06 mm) separated without boundary by thin, regularly spaced, clear carbonate beds (0,06 to 0,1 mm).

Interspace filling

Laminae have a high relief and sedimentary rate is slow with an episodical supply of sediment. At the bottom of each sequence are found small intraclasts: elements of stromatolite up to 2–3 mm size mixed with smaller (between 0,06 to 0,2 mm) dark pelloids rounded or contorted in a sparry matrix. Then follows a thick infilling of finely and equally grained dolomite with convex upward joints containing very few small pelloids. This may be a recrystallized mud.

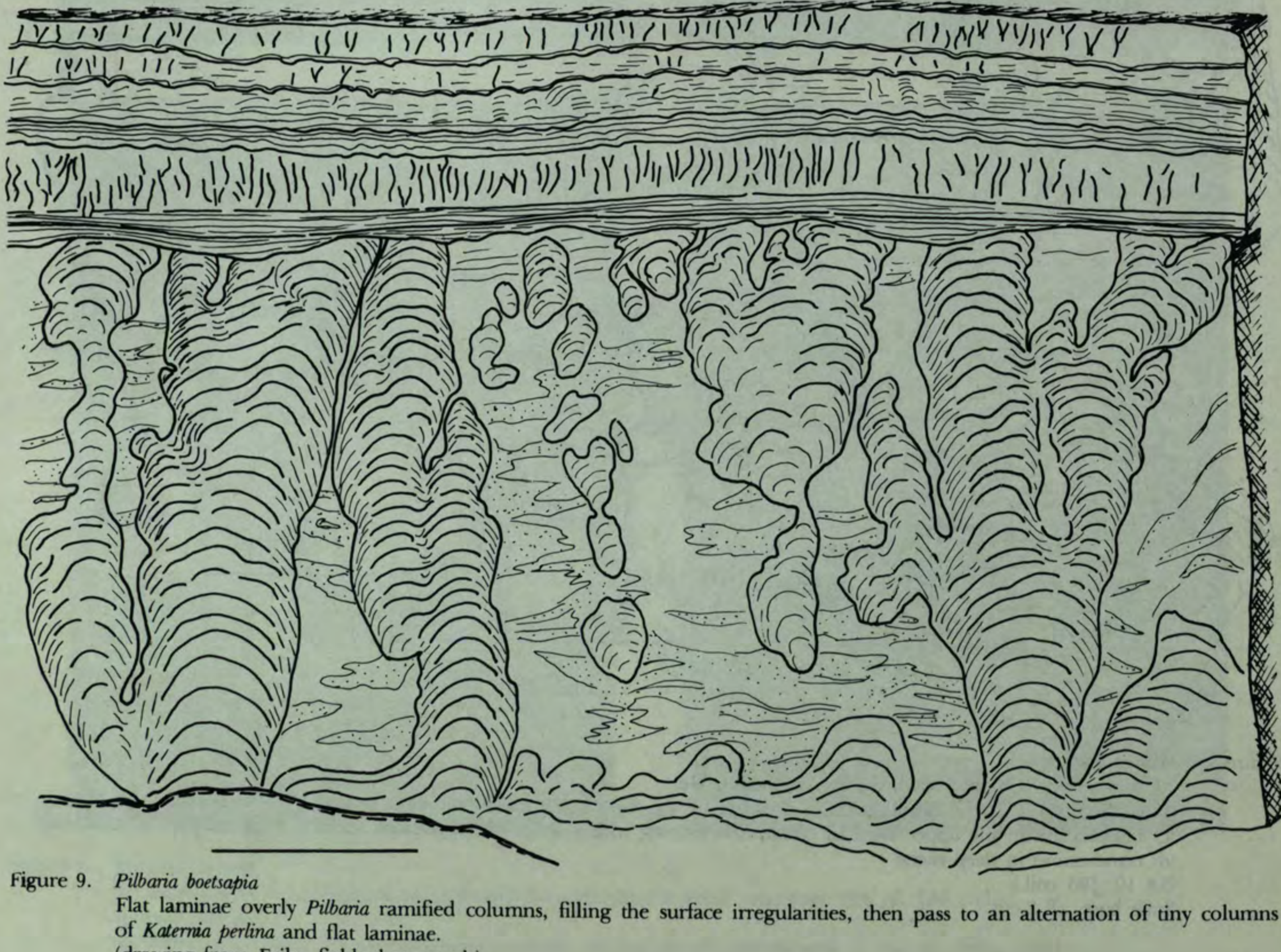


Figure 9. *Pilbaria boetsapia*
Flat laminae overly *Pilbaria* ramified columns, filling the surface irregularities, then pass to an alternation of tiny columns of *Katernia perlina* and flat laminae.
(drawing from Eriks. field photograph)
Scale bar, 15 cm.

When the sequence is finishing, laminae from the stromatolite higher up extend on it making small bumps without any wall.

Comparisons

The description fits quite well with *Pilbaria* defined by Walter (1972, pp. 167–170). It has the same size range, shape of columns rather bulbous and straight, and especially the same type of ramification within a niche, bumps of the surface and coalescence. The margins are smooth in our form with walls (only 30 % of the surface in *P. perplexa*). These two differences authorize us to found a new species. The comparison of *Pilbaria* with other groups is given in the form-type description (op. cit.) but we can add that our form differs from *Inzeria* Krylov by the presence of a continuous thick wall, and the shape of the niches that are less detached from the initial column in *P. boetsapia*. The Boetsap form is better defined than *Pilbaria perplexa* especially in its microstructure and confirms the opportunity of creating the *Pilbaria* group.

Flat between Waterfalls 3 and 2

Five successive layers, 30 to 35 cm high, present columnar forms in slightly domed biostromes (doming is probably in relation with domal stromatolites beneath). Each rhythmic layer begins with two or three centimetres of flat-lying to undulated interconnected laminae overlain by columnar forms (Table 2). Despite their similar appearance (tiny columns, finely laminated microstructure), the forms show distinctive characters (Table 1):

1 — in the lower third of each layer appear straight columns of *Tibia cristata* (gr. nov.). Slight differences are found in some of them, principally those at the upper third of the last layer.

2 — the upper parts of the layers except for the last two are built of small columns of *Tibia plumata* (gr. nov.), differing by the slightly divergent mode of ramification.

3 — in the upper and central parts of the last two layers, the columns (*Sapinia fucoides* (gr. nov.) acquire new features: markedly divergent ramification, turbinate shape and a sparitic pseudo-wall.

Group *Tibia* gr. nov.

Type form
Tibia cristata

Group Name

From the latin *Tibia* (flute) evoking the elegant attitude of the form.

Table 1

Column characters used to define the three distinctive forms found in the flat between waterfalls 2 and 3 (see fig. 1). An increase in the variability of characters is shown in the upper part of the layer (15 base and top).

	A Tibia cristata						B T.plumata			C Sapinia					
	13a base	13b base	14a base	14b base	15 base	15 top	13a top	13b top	14a top	14b top	15 mid.	▨ (hatched)	●● (dots)	░ (stippled)	▥ (bars)
ATTITUDE 1	▨	▨	▨	▨	▨	▨	●●	●●	●●	●●	●●	cylindrical	turbinate		
ATTITUDE 2	▨	▨	▨	▨	▨	▨	▨	▨	▨	●●	●●	vertical	oblique		
HORIZONTAL SECTION	▨	▨	▨	▨	▨	▥	●●	▨	●●	░	░	circular	lobate	multiloba-te	elongate
RAMIFICATION	▨	▨	▨	▨	▨	▨	●●	●●	●●	░	░	parallel	slightly divergent	markedly div.	
RAM. FREQUENCE	▨	▨	▨	▨	▨	●●	●●	●●	●●	░	░	rare	frequent	very freq.	
PROJECTION	▨	▨	▨	░	▨	●●	░	░	░	●●	●●	absent	very freq.	moderatly freq.	
SPACING	▨	▨	▨	▨	▨	▨	●●	●●	●●	░	░	very close	intermed.	open	
MICROSTRUCT.	▨	▨	▨	▨	▨	▨	●●	●●	●●	▨	▨	micritic mat	id. less visible		
SUPERPOSITION	▨	▨	▨	▨	●●	▨	●●	●●	●●	●●	●●	seasonal	even		
CRESTAL ZONE	▨	▨	▨	▨	▨	▨	●●	●●	▨	▨	▨	frequent	disconti-nuous		
CREST. POSITION	▨	▨	▨	●●	●●	▨	▨	▨	▨	●●	●●	central	lateral		
SURFACE	▨	▨	▨	▨	▨	▨	●●	●●	●●	░	░	smooth	ragged	sparitic	
LAMINAE STOPPING	▨	▨	▨	▨	▨	▨	●●	●●	●●	░	░	mixed	sharp	enveloping	

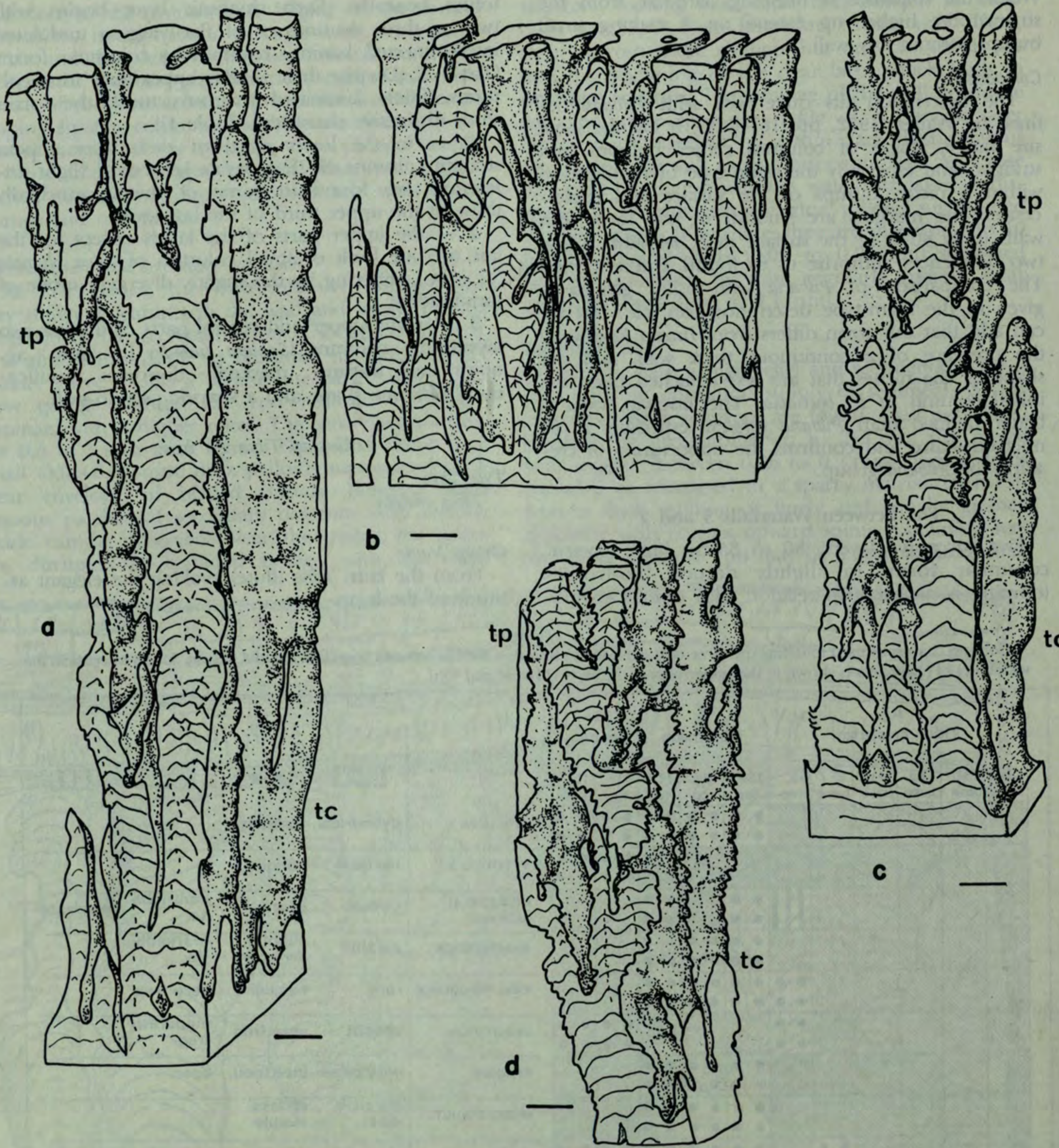


Figure 10. *Tibia cristata* (tc) at the base and *Tibia plumata* (tp) at the upper part
(a), (c), (d) (respectively SA 13b, 13a, 14a, JBS coll.);
(b) *Tibia cristata* isolate base of (a).
Scale bars, all 1 cm.

Diagnosis
Tiny, discrete, straight columns, ramification running from parallel to slightly divergent. The microstructure is composed of micritic mats very regularly superposed, presenting in the centre of columns a small (less than 1 mm) wart-like protuberance. The high inheritance of this crestal zone leads to deeply convex laminae shape.

Tibia cristata f. nov.
(figs. 10a–d; 11a, b, d and f; 12a)

Holotype
Base of SA 13-a, from seven samples of the same area.

Form Name
From the Latin *crista* (crest) in respect to the crestal zone shown by these forms.

Description
Small (between 1 and 2 cm of diameter) closely spaced vertical columns with a more or less circular horizontal section. Ramification is rare and generally passive (parallel), ramified branch stops quickly after branching. Coalescences are quite frequent, also interconnecting laminae. At the passage to *Tibia plumata* many small columns disappear and the others enlarge and begin to ramify.

The surface of the columns is very smooth, even if laminae are sharply interrupted along the edges. Laminae are very regularly stratified with a very equal thickness. They are moderately convex, except when they present a crestal zone which leads to a deeply convex pattern, in vertical section. This crestal zone appears mainly in the central parts of columns. It has a good inheritance and could be followed for tens of centimetres. Seasonal laminae appear in some of the layers.

Microstructure
As the microstructures of *Tibia cristata* and *Tibia plumata* are very similar, we will describe them together. They appear as a "doublet" dark and clear layer with an upper limit well defined. The dark micritic layer is continuous with less than 0,2 mm thickness. The clear microsparitic layer is generally discontinuous and its thickness is around 0,4 mm. In fact there are few differences between them. On the margin, laminae are sharply interrupted and present in *T. plumata* small peaks and irregularities capping small voids filled by sparry calcite. The upper dark mat extends often through the interspace, joining adjacent columns by a convex upward lamina. The main feature is the crestal zone. It is very difficult to define because it has no special structure. The crestal zone appears as a conical micritic bump on the top of a normally convex lamina and cross-cutting the clear layer. It extends in every direction as a very small bump (up to 1,2 to 1,3 mm). The next lamina then has a more deeply convex shape and it reproduces also the crestal zone, so the feature goes on for one to five centimetres. It seems, but we cannot prove it, that there are very small (5 to 10 microns thick) tabular filaments through the dark laminae and radiating in the crestal zone. It differs from the *Radiatina* crestal zone by its central position and its smaller size. Sometimes the crestal zone ramification leads to short branches. In a S.E.M. study Macgregor *et al.* have described "tapering filaments" in these columns (1974, fig. 5).

Secondary alteration
All over the rock, and forming a roughly banded pattern, is a dolomitic angular network of crystals easier to see in the infilling where they could be confused with detrital grains. It is not present in the small voids on the edges of *T. plumata.*

Interspace filling
Microsparitic thick layers with very few grains are overlapped by thin discontinuous micritic dark laminae convex downwards and sometimes in continuity with the upper part of the darker layer of the columns. The probably muddy sediment is contemporaneous with the column growth.

Comparisons
Early Proterozoic forms comparable to *Tibia* are *Gruneria* and *Eucapsiphora* Cloud-Semikhatov. *Gruneria,* however, has rarely discrete columns. Comparison with *Eucapsiphora* is more interesting but the gross form of *Tibia* is more evenly cylindrical without enlargement before branching and no connecting layers throughout the whole colony. The mode of occurrence is very different: *Eucapsiphora* grows encrusting high places and sometimes overhangs. This form can be compared to many of the small branching columns of upper Riphean stromatolites: *Gymnosolen* Steinmann, *Jurusania* Krylov, *Boxonia* Koroliuk or *Kulparia* Preiss and Walter. It differs from both *Gymnosolen* and *Boxonia* by the absence of wall and the type of branching. From *Jurusania,* the distinction is based on the smoothness of surface and absence of peak and cornices. Also it is easily distinguished from *Kulparia* by the presence of a wall and the biostrome setting. But even if there are some affinities between *Tibia* and Riphean stromatolites, they mainly differ by the existence in *Tibia* of the unusual crestal zone structure giving an angular shape to the laminae and the smooth surface without enveloping laminae or wall.

Tibia plumata f. nov.
(figs. 10a, c and d; 11c; 12b)

Holotype
Upper part of SA 13-b, from four samples in the same area.

Form Name
From the Latin *pluma* (feather), because the form has a light ramified framework.

Description

Small tiny columns straight and more or less turbinate with a lobate horizontal section. The ramification is more frequent than in *Tibia cristata* and is either parallel or slightly divergent. The digitations are in small straight columns (2 cm high) or less frequently in permanent columns of equal diameter. The surface of columns is ragged and the laminae projected as angular peaks. The crestal zone is also present but less continuous. Laminae super-position is very even and no seasonal differentiations are visible. The lamina shape is gently convex to angular and near the edges there is an interruption of laminae which continues afterward for a few millimetres, making a kind of projection that is more striking in *Sapinia.*

Microstructure and interspace filling

They do not differ from *Tibia cristata.* Most of the time, the microstructure is less defined and interspaces are larger with small pockets of very small pelloids.

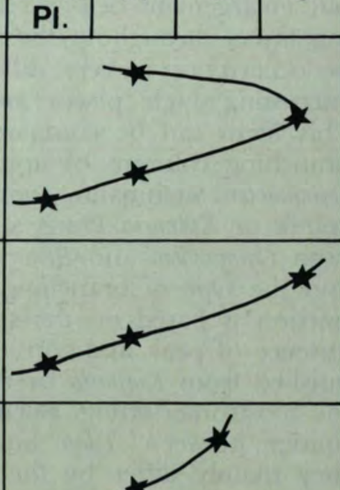
Comparisons

Comparable Riphean forms are *Kulparia* Preiss and Walter and *Eucapsiphora* Cloud-Semikhatov, except for the crestal zone and bioherm setting. They differ from *T. cristata* only by the turbinate attitude and divergently mode of ramification. One form mentioned by Hoffman (1974, p. 863, fig. 10) as a basin floor stromatolite can be compared to *T. plumata* of Aphebian age by the conical shape and low relief of laminae, absence of wall. Unfortunately there are no indications about microstructure, ramification, etc.

Table 2

Rhythmicity in the chronological succession.
A: *Tibia cristata;* C: *Sapinia fucoides*
B: *Tibia plumata;* L.pl.: Planar laminations.

nº Sample	Form	Lam. Pl.	A	B	C
15	A C A L. Pl.				
14 b	C A L. Pl.				
14 a	B A L. Pl.				
13 b	B A L. Pl.				
13 a	B A L. Pl.				



Group *Sapinia* gr. nov.

Type form

Sapinia fucoides

Group Name

Sapinia, from the French "sapin", a conifer tree.

Diagnosis

Tiny regular columns with very frequent ramification always at the same angle, and small bumpy digitations on the surface. The surface is outlined by a sparitic pseudo-wall.

Sapinia fucoides f. nov.
(figs. 12c–d; 13a–e)

Holotype

SA 14-b, from four samples coming from the same area.

Form Name

From the Latin *fucus,* name given to a forking brown algae.

Description

The columns are tiny, oblique and turbinate with a diameter between 0,5 and 2,5 cm. The horizontal section is multilobate. Interspaces between columns are larger than in *Tibia* (between a third and half of the total volume). The ramification has two different settings: one in two small markedly divergent columns. In some of the samples, daughter-columns are asymmetrical and the shorter ones are always in the same position in respect to the main column. The other type is a very short digitation, as the small pseudo-columns are not longer than 4–5 mm. They are made by a short, straight interruption of the laminae parallel to the direction of normal ramification and they are really distinct from the main column. The discontinuity is filled by sparry calcite. They appear only in the outer portion of columns. In the inner portion, columns show more inter-connecting laminae. The surface of columns is smooth with short enveloping laminae and a sparitic pseudo-wall along the crestal zone, larger than in *Tibia* (2–3 mm).

Microstructure

The lamina microstructure is the same as that of *Tibia* with perhaps a little more silt-size pelloids and quartz in the flat laminae. Crestal zone resembles more *Radiatina,* with a larger bumping of the lamina outlined by a sparitic pseudo-wall. It is possible to see the plunging micritic laminae overlapping crystals of the pseudo-wall arranged perpendicularly to

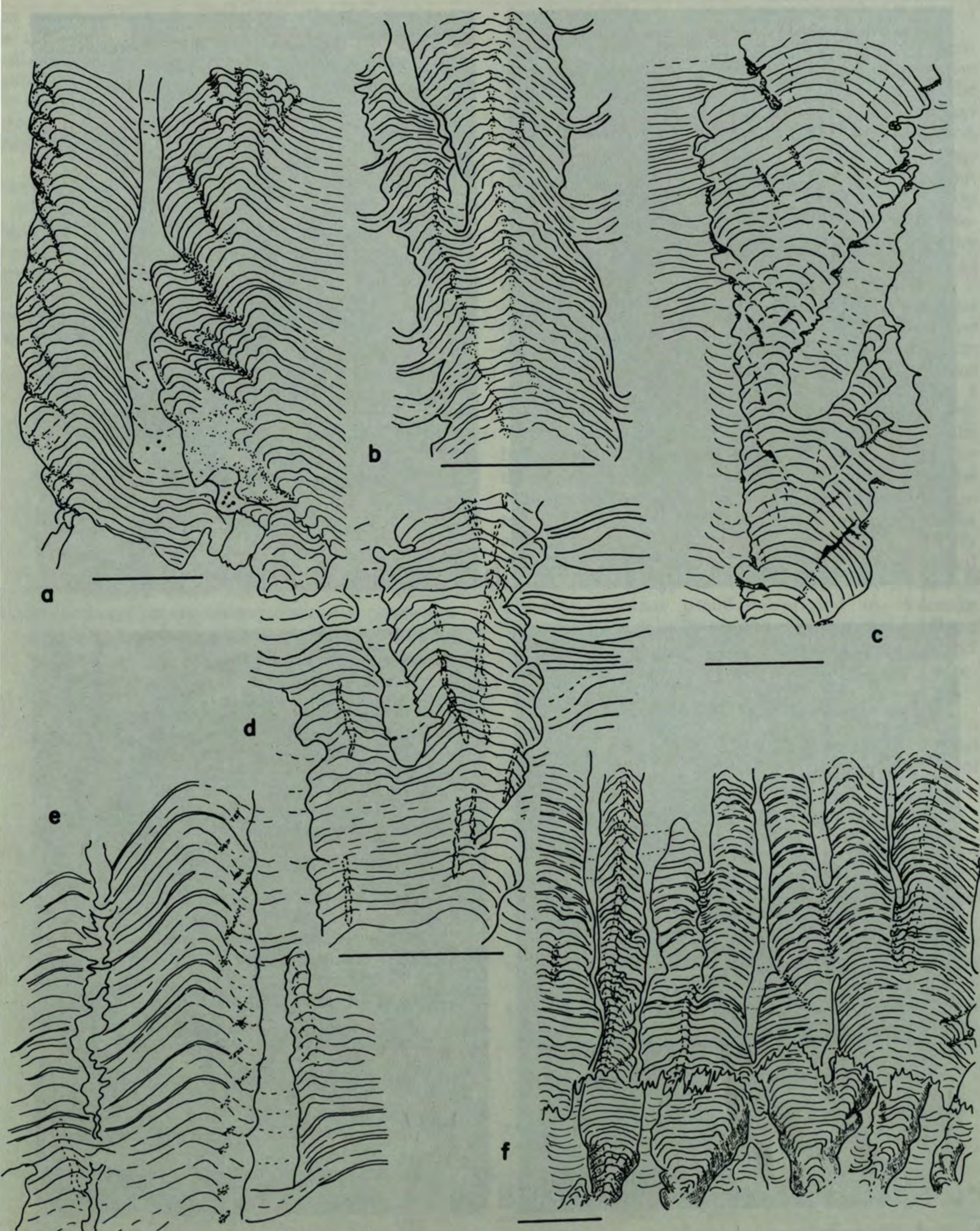


Figure 11. *Tibia cristata*

(a) and (f) columns overlying *Sapinia* (SA 15, JBS coll.);
(b) holotype: base of the first layer of *T. plumata* (SA 13a, JBS coll.);
(d) base of *Sapinia* (SA 14b, JBS coll.)
(e) base of SA 13b (JBS coll.)
Tibia plumata
(c) SA 13a (JBS coll.).
Drawings from enlarged peels.
Scale bars, all 1 cm.

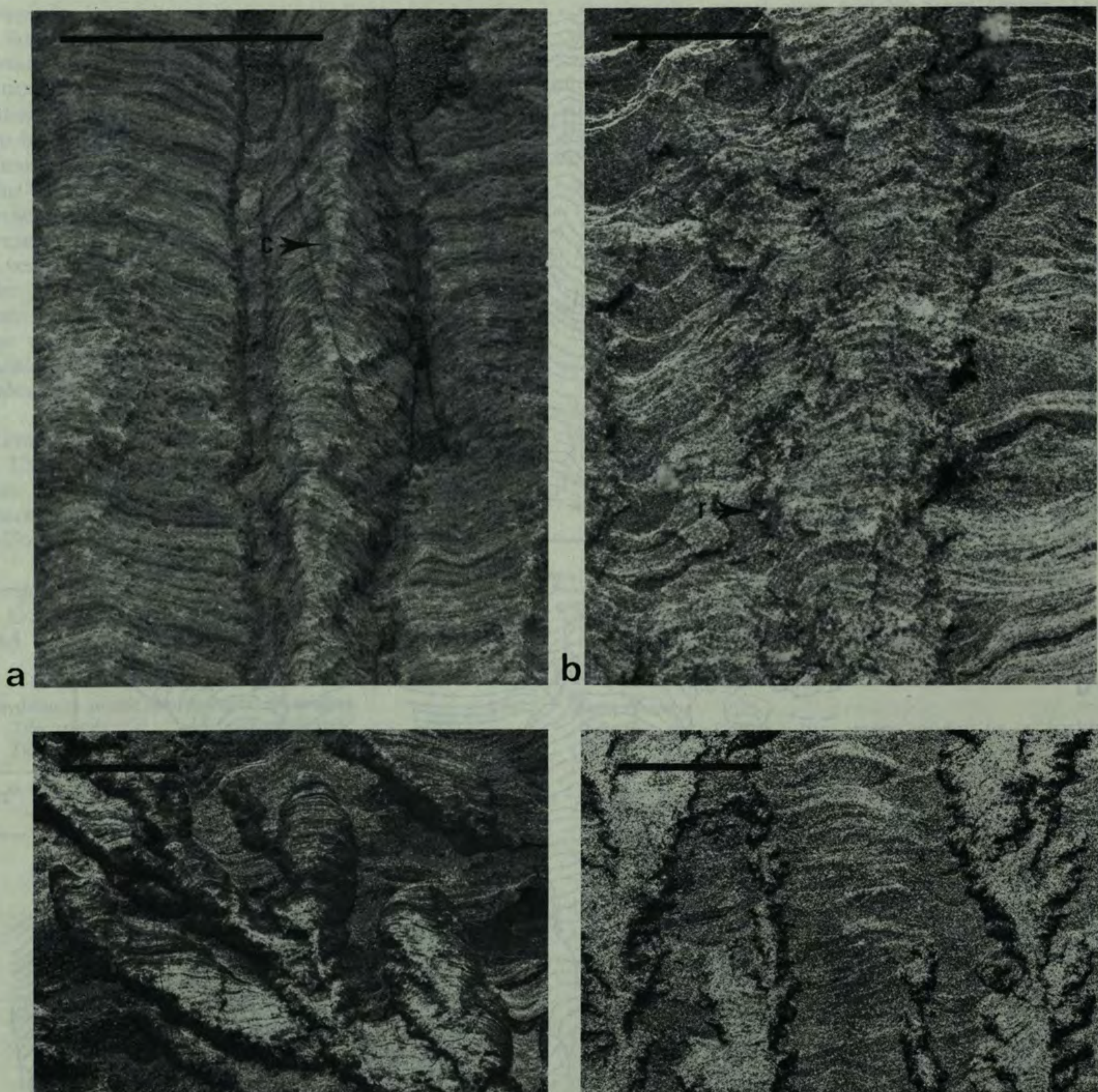


Figure 12. *Tibia cristata*
(a) crestal zone (c) (SA 15, JBS coll.).
Tibia plumata
(b) rugged surface (r) (SA 13b, JBS coll.).
Sapinia fucoides
(c) inclined columns, sparitic pseudo-wall (s) (SA 48, Eriks. coll.)
(d) straight columns cut perpendicularly to the direction of the general inclination; sparitic pseudo-wall (s) (Young coll.).
Negative prints from peels.
Scale bars, all 1 cm.

the margins of previous laminae. This fabric cannot be related to a neomorphic origin of the pseudo-wall. The sparry filling of small discontinuity separating digitations is different from the sparite filling the voids on the margins of *Tibia plumata* and it presents an undubitable boundary with the sediment filling of the columns.

Interspace filling
It is a very finely laminated sediment, perhaps algal but not connected directly to stromatolite laminae. Micritic thin laminae are frequently convex upward and along the column margins are crescents of microsparite with small pelloids at the base and a fringe of sparite crystals at the top. They are generally discontinuous.

Comparisons
First of all we will discuss the reasons why we make three distinct forms. The microstructures are fairly similar and can support the idea that there are no changes in the algal coenose throughout the whole biostrome. The sediment infilling, carbonate mud and algal laminae, is also quite the same. Nevertheless gross morphologies present several characters that differ (Table 1) and in absence of clear use and definition of what Krylov (1975, p. 73) named "bioherm series" we have to give different names to forms having several distinctive characters.

We will now compare *Sapinia* to tiny columns of the same age.

One of them is the *Patomia* ind. described by Walter (1972b, pp. 165–166) which shows, as the Riphean one, small tiny ramified columns with bumpy surfaces. However, they differ by the wall which is multilamellate in *Patomia* Krylov and the ramificated pattern which is more complex (two sets of ramification) and more regular in *Sapinia*. At least *Patomia* Walter has no defined microstructure and the Riphean one shows undulate highly convex laminae with a multilamellate wall. The other possible comparison is with *Katernia perlina* with which it has some common features, especially the sparitic pseudo-wall and the mode of ramification. But in *K. perlina* are never found the small marginal digitations nor the asymmetric wall, and the microstructure is completely distinct. Other possible comparisons could be made with Riphean stromatolites such as *Tungussida* which presents active and frequent ramification. *Tifounkeia* Bertrand-Sarfati is comparable by the size and the slightly divergent ramification, but does not present any of the other features of *Sapinia*. *Parmites* Raaben has turbinate columns, often ramified but with a radiating pattern and also it has ragged surface and flat laminae. *Katavia* Krylov presents bumpy but less ramified and bigger columns. Differences with *Vetella uschbasica* Krylov are present as this form is more compact with interconnected laminae, no crestal zone. We conclude that *Sapinia* and *Tibia* are completely original forms.

Waterfall 2

Low elongate domes with few ramified stromatolites and generally flat-lying to undulated laminae are found at the base of the fall. In the middle of the fall, a massive bed of oncolitic grainstone displays big ripples interpreted by Truswell and Eriksson (1973, fig. 15, p. 14) as deposited in a high energy environment. Above them new domes occur not very different from the previous ones. Near the top of the outcrop appear biostromes of straight columnar forms. They present several layers separated by erosional surfaces and overlain by new columns of the same structure and shape: *Pilbaria inzeriaformis*, f. nov. Upon the undulate surface the new columns begin in continuity or not with the previous one (fig. 15f). One of the layers presents straight discrete columns (eroded?) enveloped by the uppermost concordant laminae to the very base. Aquiring a mushroom-like shape, they touch each other at the top. Around the heart-like cavity between columns at the base concentrical layers of sparry calcite are separated by thin dark boundaries (fig 14f). Coarse dolomite fills the central core. The general column size decreases from base to top and they present less seasonal laminae. On the flat above the fall, small domical stromatolites, generally non-columnar, contain one layer of flat-lying cryptalgal laminae with juxtaposed big "rosettes" of crystals of probably gypsum pseudomorphosed in dolomite (Bertrand-Sarfati, 1976). At the very top of the fall are elongate columns and shales marking (Truswell and Eriksson, 1973, p. 20) the end of a regressive sequence.

Osagia-like oncolites

The mega ripples described by Truswell and Eriksson (op. cit.) are made by an accumulation of small spherical bodies.

Description
The sediment is a dolomitic grainstone with lenses of "grumelous" matrix (Cayeux, 1935) formed by small grains (between 20 to 200 microns) cemented by large crystals. The big grains forming the framework (0,5 to 3 mm) are poorly sorted. They are more or less spherical built by a thick well-defined cortex of concentrical sparitic layers (up to 40 for biggest grains). Many grains present a discontinuous growth of this envelope with inverted pattern (Logan *et al.*, 1964) preventing us from attributing them to oolites. Very few envelopes present disrupted external laminae.

Interpretation
It is not easy to recognize the original framework: is it a grainstone or a recrystallized packstone? Two features favour this latter interpretation: (a) existence of syntaxial crystals through the cement and the oncoid testify that cement is of second order; (b) presence of large quantities of very small elements contained within larger crystals could signify an initial muddy or silty matrix. The origin of the grains is also uncertain: con-

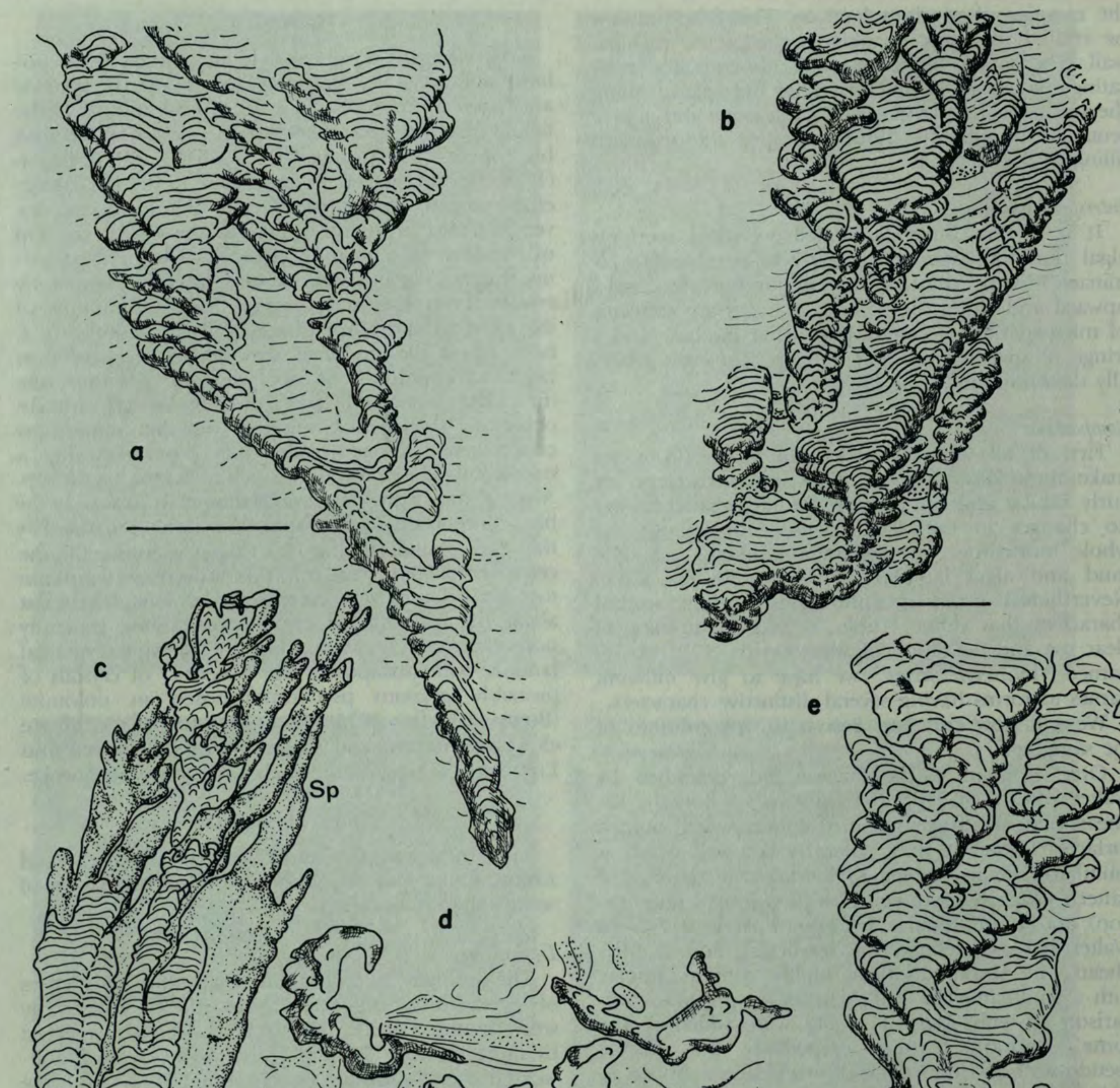


Figure 13. *Sapinia fucoides*
(a), (b) and (e) drawing from enlarged peels; (e) cut perpendicularly to the direction of the inclination i.e. in a plan perpendicular to b (SA 14b, 15, 48 from JBS and Eriks. coll.);
(c) succession of *T. cristata* (tc) and *Sapinia* (Sp) (SA 14b, JBS coll.);
(d) horizontal section of the top of (c).
Scale bars, all 1 cm.

cretionary grains (caliche pisolites) or oncolites: (a) as many vadose pisolites, the grains are highly asymmetric with sometimes strange re-entrant angles of new laminae upon the previous laminated spheroid (Dunham, 1969). But here asymmetry is not evenly oriented on each grain and we find none of the other features of vadose pisolites (Scholle and Kinsman, review 1974, pp. 912–913); (b) the possibility of an algal origin in the absence of true organic remains is supported by the existence of normal spherical *Osagia*-like grains but there is no true analogue in modern environments (Loreau, personal communication). Modern forming oncolites have a smaller size with a large nucleus and only few concentric laminae (Loreau and Purser, 1973). Asymmetric oncolites are known from quiet water environments (Freeman, 1962) and they often present an incomplete envelope with internal unconformity.

Conclusion

We cannot be sure of the original structure of the rock but there are good possibilities that it has been first a packstone. Oncolites are asymmetric and therefore could have been generated either in a shallow and protected quiet water environment or in deeper water beneath the wave action zone. The surface of oncolites presents very few abrasion features and transportation in highly agitated environment cannot be proven: fore-reef ripples in the Australian Great Barrier Reef are present in quiet water (Monty, 1974, film).

Group *Pilbaria* Walter

Type form

Pilbaria perplexa Walter 1972, p. 167.
Plate 4, fig. 4; Plate 29, figs 2–7; text figs. 7, 51–52.

Pilbaria inzeriaformis f. nov.
(figs. 14 a–f, 15)

Holotype

SA 23, from four samples from the same area.

Form Name

From *Inzeria* Krylov, Riphean stromatolite group to which this form is very similar.

Description

Straight, subcylindrical columns with a diameter varying between 2 and 10 centimetres. Horizontal section shows closely spaced subcircular shape of columns with deep invagination when a ramification is cut. Frequence of ramification is variable from one layer to another. Most of the time it shows a parallel type which leads to smaller columns or to one short column quickly stopped. In this case it is included in a niche within the initial column. Columns show periodic enlargements and constrictions outlined by a depression of the surface. They correspond to the same kind of digitation found in *Sapinia* or in *P. boetsapia*. The relief of deeply convex laminae reaches 3 to 5 cm and the column surface is smooth with enveloping laminae forming a multilamellate wall less continuous than in *P. boetsapia*. There are few interconnecting laminae. Some layers present seasonal differentiation of laminae zone with distinct microstructure. Laminae unconformities appear in the central portion with bumps or folds. They are soon rubbed out by the following lamina rapidly filling the depressions. This produces a discontinuous conical shape to the laminae.

Microstructure and secondary alteration

There are few differences between central portions of columns and walls, just a decrease of the laminae thickness (from 1,5–3 mm to 0,2–0,8 mm in the wall). Microstructure is complex and presents four different elements: (a) a micritic mat with small dark pelloids sometimes vermiform (0,06 mm); (b) bigger grains of brown micrite and a clearer centre (0,1 to 0,3 mm) in a sparry matrix appearing within the mat; (c) a dark filmy upper limit; (d) clear sparitic layers striated by dark thin films (less than 0,006 mm) most of the time discontinuous. The succession of these elements is relatively variable. The big grains occur in continuous mats or within hemispherical bumpy fenestrae, with a somewhat inverted graded bedding. The filmy and sparitic doublets could develop separately giving rise to distinct zones of laminae. Then the regular thin films pinch and swell separating microsparitic layers (up to 1,5 to 2 mm high) containing few pelloids. Along the slopes the thickness of the whole zone decreases, films are grouped interbedded with sparite and some of them overlap the interspaces. A clear sparitic zone then appears under the films as a cement. The recrystallized central part of columns (as for *P. boetsapia*) contains rounded bodies with bladed crystals arranged around a core where few pelloids remain. On their surface and between them are dark insoluble residue in a dolomite network. Sheathed filaments have been described by Macgregor *et al.*, (1974, fig. 3).

Interspace filling

It is more detrital than the *P. boetsapia* infilling, with few layers of muddy neomorphic dolomite. The detrital elements are of the usual kind in this area: rounded pelloids and vermiform black algal debris. As in *P. boetsapia* there are stromatolitic mats expanding over the infilling, making small bumps. They are most of the time distinct from the columns mats.

Comparisons

We have attributed the different columns from distinct layers to the same form because they show very slight changes: a decrease in size and a variability of the seasonal differentiation of the laminae zones. *Pilbaria inzeriaformis* has features reminiscent of *P. boetsapia*: niches, short small digitations on the margins of columns, wall, laminae expanding upon

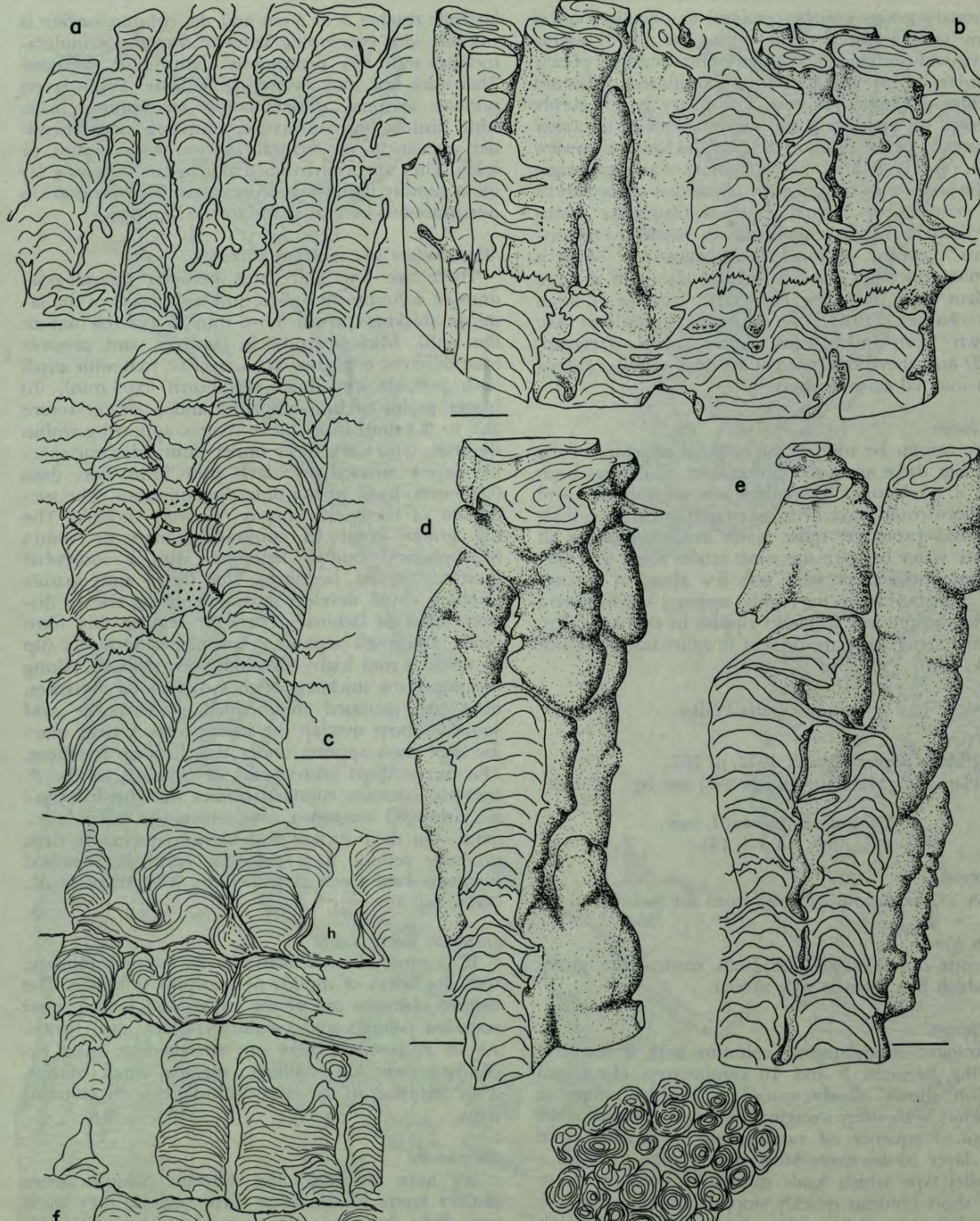


Figure 14. *Pilbaria inzeriaformis*
(a) holotype
(f) successive layers of columns; the upper one showing heart-like (h) cavities.
Drawing from field photographs, (a) from JBS, (f) from Eriks.;
(b) small forms at the top of the waterfall 2 (SA 16, JBS coll.);
(c), (d) and (e) holotype (SA 23, JBS coll.; (c) drawing from peel);
(g) horizontal section (drawing from JBS field photograph).
Scale bars all 2 cm, except (f) = 17 cm.

the interspaces, superposition of loosely packed laminae in the central portions with fenestrae. Differences are few: columns straighten without coalescences, they display true ramifications and a

Figure 15. *Philbaria inzeriaformis* Microstructure (SA 23, JBS coll.). Scale bar, 1 cm.

more complex microstructure especially by the existence of films and seasonal zones of laminae. *Pilbaria* group has been compared to *Inzeria* Krylov and this form is perhaps more comparable to *Inzeria* than *P. boetsapia*. It differs principally by the shape of laminae, the microstructure with films and a more continuous wall. Its resemblance to *P. boetsapia* has determined the attribution to *Pilbaria* group.

CONCLUSION

Palaeoenvironment of stromatolites

This was not the aim of our study, but an actualistic tidal model has been proposed for this Schmidtsdrift Formation in Boetsap (Truswell and Eriksson, 1973, pp. 7–18). Two sequences are distinguished: a transgressive one, from the *Topinamboura* beds to the shales beneath *Radiatina* bioherms; the second, regressive, begins with pulses during the growth of *Radiatina* domes, then through an agitated zone with oncolitic megaripples, finishes in the intertidal zone with the upper columns of *Pilbaria inzeriaformis*. We must remember that interpreting stromatolites sequences in terms of tidal environment according to columnar forms, in the lack of associated evidences of subaerial exposure (desiccation cracks, etc.) is a dangerous simplification. Many authors emphasize the number of factors involved in stromatolite morphology: biological (Awramik, 1973, 1976) and environmental (Serebriakov, 1975) as well as the environmental diversity of stromatolites (Monty, 1973; Hoffman, 1974, 1976; Donaldson, 1976b).

Mechanisms of the laminae microstructure

The microstructures are particularly well preserved in the Schmidtsdrift sequence and show great similarities in their mechanisms of growth with present-day algal laminae. But everywhere in Precambrian stromatolites, the microstructures, even for complex laminae, are characterized by a very evenly repeated superposition of laminae for long periods. This gigantism is also presented by the *Osagia*-like oncolites with up to forty concentric laminae for two to five in modern analogue. This is one of the more unusual features of Precambrian stromatolites.

Complexity of the ramification

Until recently, stromatolite studies have been concentrated on Soviet Union Riphean Formations and they outlined an increase in the ramification complexity throughout Lower and Middle Riphean, leading to an explosion of columnar forms during Upper Riphean. With the increasing number of studies on Lower Proterozoic assemblages it becomes evident that stromatolites of this age contain lots of ramified forms presenting every kind of ramifications previously known from Upper Riphean. Our study illustrates also this fact and we can compare *Pilbaria* ramification type to the Gymnosolenid, *Tibia cristata* to the Kussiellid type and *Sapinia* and *Katernia* to the Tungussid type. Other works emphasize also this fact: in Australia Walter (1972b) and Preiss (1976), in Canada Campbell (1975), Donaldson (1976a) and Hoffman (1974, 1976). It is now evident that one can find in Lower Proterozoic as many types of ramification as in the Upper Riphean.

Biostratigraphic importance

As a consequence of this point, criticisms have been made regarding the biostratigraphic importance of stromatolites. They are founded on the fact that typical Riphean groups are represented in Aphebian formations (Donaldson, 1976a, p. 377). These comparisons are based on two sets of characters only: ramification and/or nature of the lateral surface. These characters lead in the best case to a rough definition of the group only. If one wants a better definition, it appears necessary to take account of a bulk of characters (see Table 1) that is to work at the form level instead of the group level (Preiss and Walter, 1975; Preiss, 1976).

In this study we have described columnar stromatolites presenting original features: the crestal zone which is quite different from that of *Conophyton* and the sparitic pseudo-wall distinct from a multilammellate wall. Beside these peculiar features, the association of characters leading to the definition of groups and forms are very distinctive and we have been able to define new groups and forms completely different from Riphean ones. These stromatolites built successive layers, the lateral evolution of which are not known, except for *Sapinia* and *Tibia* found in the vicinity of the Boetsap River outcrop and for *Katernia* found in the Potchefstroom synclinorium.

REFERENCES

AWRAMIK, S. M. (1973). Environmental and biological controls on stromatolite morphology: stromatolites of the Gunflint Iron Formation. *In: Symposium on Environmental Biogeochemistry, 1973, Logan, Utah,* 3–4 (abstracts).

——— (1976). Gunflint stromatolites: microfossil distribution in relation to stromatolite morphology. *In:* Walter, M. R., Ed., *Stromatolites,* Elsevier, Amsterdam, 311–320.

BERTRAND-SARFATI, J. (1972). Les stromatolites du Précambrien supérieur du Sahara nord-occidental; inventaire, morphologie et microstructure des laminations; corrélations stratigraphiques. *C.N.R.S., Paris, Sér. Géol,* **14,** 245 pp.

——— (1976). Pseudomorphoses de gypse en rosettes dans un calcaire cryptalgo-laminaire du Précambrien inférieur (système du Transvaal. Afrique du Sud). *C. R. Soc. Géol. Fr.,* **18,** 99–102.

CAYEUX, L. (1935). Roches sédimentaires de France — Roches carbonatées. Masson et Cie, Paris.

CAMPBELL, F. H. A. (1975). Stromatolite development in the Aphebian Goulburn Group, Bathurst Inlet area, Northwest Territories, Canada. *In: First Intern. Symp. on Fossil Algae, Erlangen* (in press).

CLOUD, P. E. and SEMIKHATOV, M. A. (1969). Proterozoic stromatolite zonation. *Am. J. Sci.,* **267,** 1017–1061.

DONALDSON, J. A. (1976a). Aphebian stromatolites in Canada: implications for stromatolite zonation. *In:* Walter, M. R., Ed., *Stromatolites,* Elsevier, Amsterdam, 371–380.

——— (1976b). Paleoecology of Conophyton and associated stromatolites in the Precambrian Dismal lakes and Rae groups, Canada. *In:* Walter, M. R., Ed., *Stromatolites,* Elsevier, Amsterdam, 523–534.

DUNHAM, R. J. (1969). Vadose pisolite in the Capitan Reef (Permian), New Mexico and Texas. *In: Depositional Environments in Carbonate Rocks. Soc. Econ. Paleontol. Mineral., Spec. Publ.* G. M. Friedman (Editor), **14,** 182–191.

ERIKSSON, K. A., TRUSWELL, J. F. and BUTTON, A. (1976). Palaeoenvironmental and geochemical models from an early Proterozoic carbonate succession in South Africa. *In:* Walter, M. R., Ed., *Stromatolites,* Elsevier, Amsterdam, 635–643.

FREEMAN, T. (1962). Quiet water oolites from Laguna Madre, Texas. *J. Sediment. Petrol.* **32,** 475–483.

HOFMANN, H. J. (1969). Stromatolites from the Proterozoic Animikie and Sibley groups, Ontario. *Geol. Surv. Can., Pap.* **68–69,** 77 pp.

HOFFMAN, P. (1974). Shallow and deep water stromatolites in lower Proterozoic platform-to-basin facies change, Great Slave lake, Ontario. *Amer. Assoc. Petrol. Geol. Bull.,* **58,** 856–867.

——— (1976). Environmental diversity of Middle Precambrian stromatolites. *In:* Walter, M. R., Ed., *Stromatolites,* Elsevier, Amsterdam, 599–611.

KOMAR, V. A. (1964). Columnar stromatolites from the Riphean of the North of the Siberian platform. *Uch. Zap. Nauchno-Issled. Inst. Geol. Arkt., Paleontol. Biostratigr.,* **6,** 84–105 (in Russian).

KOROLIUK, I. K. (1956). Stromatolites from the lower Cambrian and Proterozoic of the Irkut Amphitheatre. *Tr. Geol. Inst. Razeab-Goryuch. Iskop. Akad. Nauk S.S.S.R.,* **1,** 161 pp. (in Russian).

KRYLOV, I. N. (1963). Columnar branching stromatolites of the Riphean deposits of the Southern Ural and their importance for the stratigraphy of the Upper Precambrian. *Tr. Geol. Inst. Akad. Nauk S.S.S.R.,* **69,** 133 pp. (in Russian).

——— (1967). Riphean and Lower Cambrian stromatolites of Tien-Shan and Karatau. *Tr. Geol. Inst. Akad. Nauk S.S.S.R.,* **171,** 88 pp. (in Russian).

——— (1975). Riphean and Phanerozoic stromatolites in the U.S.S.R. *Tr. Geol. Inst. Akad. Nauk S.S.S.R.,* **274,** 209 pp. (in Russian).

LOGAN, B. W., REZAK, R. and GINSBURG, R. N. (1964). Classification and environmental significance of algal stromatolites. *J. Geol.* **72,** 68–83.

LOREAU, J. P. and PURSER, B. H. (1973). Distribution and ultrastructure of Holocene ooids in the Persian Gulf. *In: The Persian Gulf,* Springer Verlag, Berlin, 279–328.

MACGREGOR, I. M., TRUSWELL, J. F. and ERIKSSON, K. A. (1974). Filamentous algae from the 2 300 m.y. old Transvaal Dolomite. *Nature,* **247,** 538–540.

MONTY, C. (1972). Recent algal stromatolitic deposits, Andros Island, Bahamas. Preliminary report. *Geol. Rundsch.* **61,** 742–783.

PREISS, W. V. (1976). Proterozoic stromatolites from the Nabberu and Officer basins, Western Australia, and their biostratigraphic significance. *Geol. Surv. South Australia,* Report of Investig., **47,** 51 pp.

——— and WALTER, M. R. (1975). Stromatolites of the Australian Precambrian: use in intra and intercontinental correlations. *In: Correlation of the Precambrian. Intern. Geol. Correl. Progr., Moscou,* 74–75 (abstracts).

RAABEN, M. E. (1964). Stromatolites of the Upper Riphean of the Poludov Mountains and their vertical distribution. *Byull. Mosk. O.-Va. Ispyt. Prir., Otd. Geol.,* **39,** 86–109 (in Russian).

SCHOLLE, P. A. and KINSMAN, D. J. (1974). Aragonitic and high Mg calcite caliche from the Persian Gulf. A modern analog for the Permian of Texas and New Mexico. *J. Sediment. Petrol.,* **44(3),** 904–916.

SEREBRIAKOV, S. N. (1975). Peculiarities of formation and location of Riphean Siberian stromatolites. *Akad. Nauk S.S.S.R., Tr. Geol. Inst.,* **200,** 175 pp. (in Russian).

STEINMANN, G. (1911). Uber *Gymnosolen ramsayi:* eine Coelenterate van der Halbinsel Kanin. *Bull. Soc. Geogr. Finl.* **31,** 18–23.

TRUSWELL, J. F. and ERIKSSON, K. A. (1973). Stromatolitic associations and their palaeo-environmental significance: a re-appraisal of a Lower Proterozoic locality from the Northern Cape Province, South Africa. *Sediment. Geol.* **10,** 1–23.

VISSER, J. N. J. and GROBLER, N. J. (1972). The transition beds at the base of the Dolomite series in the northern Cape Province. *Trans. geol. Soc. S. Afr.,* **75,** 265–274.

WALTER, M. R. (1972). Stromatolites and the biostratigraphy of the Australian Precambrian and Cambrian. *Palaeontol. Assoc. London, Spec. Pap.* **11,** 190 pp.

YOUNG, R. B. (1933). Conditions of deposition of the Dolomite Series. *Trans. geol. Soc. S. Afr.,* **36,** 121–135.

——— (1934). A comparison of certain stromatolitic rocks in the Dolomite Series of South Africa with modern algal sediments in the Bahamas. *Trans. geol. Soc. S. Afr.,* **37,** 153–162.

YOUNG, R. B. (1933). Conditions of deposition of the Dolomite Series. *Trans. geol. Soc. S. Afr.,* **43,** 17–22.