THE PROBLEMATICAL PRECAMBRIAN FOSSIL *CHUARIA*

by TREVOR D. FORD *and* WILLIAM J. BREED

ABSTRACT. *Chuaria circularis* from the late Precambrian of the Grand Canyon was regarded by Walcott as a primitive brachiopod. It has subsequently been referred to as an alga, a chitinous foraminiferid, a gastropod, a hyolithid operculum, a trilobite egg, and an acritarch. It is here suggested that *Chuaria* is a compressed, unusually large planktonic organism (generally 2 to 5 mm diameter). *Chuaria wimani*, *Fermoria*, and unnamed material from Canada, Sweden, France, Siberia, India, Iran, and Australia show no systematic differences from *C. circularis* and are considered synonymous. *Chuaria* is compared with *Leiosphaeridia* and classified with this as an sphaeromorphid acritarch. All recorded occurrences of *Chuaria* are in late Precambrian strata, less than 1000 m.y. old: it may be regarded as a new stratigraphic index fossil.

Chuaria is a small carbonaceous disc-like fossil which has been found in a number of regions of late Precambrian rocks. It has been assigned to both plant and animal kingdoms and at different times to several phyla of the latter. Recent collections from the type-locality in the Grand Canyon allow a more detailed examination and have resulted in a more definite conclusion regarding its nature.

Chuaria appears to have first been noted in the Kwagunt Valley of the Grand Canyon by White (in Powell's 1876 monograph on the Uinta Mountains). Powell regarded it as a primordial fossil like *Lingulella* and *Obolella*, and assigned the sediments in the floor of the Grand Canyon and some of its tributary canyons to the Silurian, doubtless using Silurian in the old Murchison sense as pre-Devonian sediments. No name for the fossil was proposed by Powell at that time.

During the winter of 1882–1883, Walcott investigated what later became known as the Chuar and Unkar Groups of Powell's Grand Canyon Series (Walcott 1895). He spent a considerable part of his time in a search for fossils from these rocks, and 'but for the discovery of a small Discinoid shell, a couple of specimens of a Pteropod allied to *Hyolithes triangularis*, and an obscure *Stromatopora*-like group of forms, the two and one-half month's search for fossils in these groups would have been without result' (Walcott 1883, p. 441). These same fossils were later noted by Walcott (1886, p. 43) who wrote that in the '. . . Chuar strata the presence of a fauna is shown by a minute Discinoid or Patelloid shell, a small *Lingula*-like shell, a species of *Hyolithes* and a fragment of what appears to have been the pleural lobe of the segment of a trilobite belonging to a genus allied to the genera *Olenellus*, *Olenoides*, or *Paradoxides*'.

In a more definitive study of Precambrian life, Walcott described and figured the shell-like fossil as *Chuaria circularis* (Walcott 1899, pp. 234–235, pl. 27, figs. 12 and 13; cf. Pl. 61, fig. 1 herein) and referred it to the discinoid type of brachiopod. His figures were drawings, not photographs, and whilst they could be interpreted as horny brachiopods there is nothing in them diagnostic of this phylum. He also suggested that they might be opercula of hyolithids. At the same time Walcott also decided that the *Hyolithes* of 1883 and the trilobite fragment of 1886 were of inorganic origin though he figured them, again by drawings. The *Lingula*-like shell of 1886

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was not mentioned and so presumably was included within the specimens referred to *C. circularis*. Walcott (1899, p. 235, pl. 27, fig. 9) also noted an enigmatic object showing some similarity to the brachiopod *Acrothele* in a limestone 150 ft above the shale containing *Chuaria*. The specimen (USNM 33801) has been re-examined and could be a *Chuaria*, but it provides too little information to make any further inquiry profitable. No further specimens have been found. It could just as easily be a fragment of an oolith in the highly recrystallized and dolomitized oolitic limestone.

Walcott's type was listed in a catalogue of the U.S. National Museum type fossils (Schuchert 1905). However, the taxon was not noted in most standard works of fossils: it was not listed in the Zoological Record, nor mentioned in Zittel or in the summaries of American fossils by Grabau and Shimer, or Shimer and Schrock. The name does not appear in Walcott's classic work on the Cambrian brachiopods. Neave (1939) listed *Chuaria* and noted an assignment to Problematica.

In view of the above it is surprising to find that Wenz (1938, pp. 85–86) placed *Chuaria* in a new family Chuariidae which was assigned, with some doubt, to the superfamily Tryblidiacea (Gastropoda), specifically rejecting the possibility that it might be an orbiculoid brachiopod. Later, Schindewolf (1956, p. 463) dismissed *Chuaria* as inorganic, probably a concretion.

Chuaria has been mentioned in several volumes of the *Treatise on Invertebrate Paleontology* but in each case only to mention that the genus did not belong to the group concerned in that volume. In the Gastropoda volume (Knight *et al.* 1960, p. I 324) *Chuaria* was listed as a generic name improperly regarded as Gastropoda and Monoplacophora and was considered to be a 'carbon scale'. In the Miscellanea volume, Häntzschel (1962, p. W 232) followed Schindewolf's view of 1956 and classed *Chuaria* with 'Fossils probably of inorganic origin' and claimed it, without citing supporting evidence, as 'certainly inorganic'. The Brachiopoda volume (Williams *et al.* 1965) surprisingly made no mention of *Chuaria* but listed the probably identical fossil *Fermoria* as a synonym of *Protobolella*, though this in turn was regarded as a 'generic name erroneously attributed to Brachiopoda'. In the Foraminifera volume (Loeblich and Tappan 1964, p. C 786) *Chuaria* was listed as a 'generic name erroneously applied to Foraminiferida'.

In palaeobotanical literature, David White suggested (1928*a*, p. 389) that the genus represented some sort of alga 'named, though apparently not published, by Doctor Walcott, *Chuaria*'. White had evidently missed the 1899 paper and as a result Andrews (1955, p. 131) listed the genus with the wrong date. White (1928*b*) also reported finding additional specimens in the upper division of the Chuar Group, and he was the first to suggest that they were algae or at least alga-like. White's specimens have not been located. White also referred to a specimen from the Bass Limestone (at the base of the underlying Unkar Group) but this has apparently not been preserved and no further information is available. Recently both Glaessner (1966) and Cloud (1968) noted *Chuaria* as an alga. Rowell (1971) did not mention *Chuaria* in his recent review of Precambrian brachiopods, but Hofmann (1971) referred Precambrian fossils from Canada to Walcott's genus.

In a preliminary review of the situation Ford and Breed (1969, pp. 119–120) left it uncertain whether *Chuaria* was 'Chitinous Foraminifera or algal in nature' and required larger samples for further study. These samples have since been collected. Ford and Breed (1972*a*) have described the stratigraphy of the Chuar Group, and together with Mitchell (1972) have demonstrated a probable age of less than 1000 m.y.

COMPARATIVE FOSSILS

1. *Chuaria wimani* Brotzen 1941

Wiman (1894) found discs similar to *Chuaria circularis* in the Late Precambrian Visingsö Formation of Sweden. These were figured but neither described nor named by Wiman, and it was not until 1941 that Brotzen referred them to Walcott's genus, but, on account of their smaller size, erected a new species *C. wimani*. He regarded them as chitinous foraminiferids. Eisenack (1951, p. 192), however, referred them to *Leiosphaera*, a well-known early acritarch. (*Leiosphaera* was later emended to *Leiosphaeridia* by Eisenack.) Subsequently Eisenack (1966) revised this opinion on the basis of chemical tests and supported Brotzen's interpretation. On the basis of colour, composition, and wall-thickness Eisenack compared *C. wimani* with the chitinous foraminiferid *Archeochitina gotlandica* from the Silurian Visby Marl of Gotland. Meanwhile Timofeev (1960) had examined the type material by crushing and dissolving it for a study of nanno-plankton, and later (1966) compared some of the smaller 'sporomorphs' to those described from the Brioverian of France (Roblot 1964). Some of the fragments of pellicles of *Laminarites* described by Timofeev (1960) could well be pieces of *Chuaria*, as noted by Eisenack (1966). Eisenack hinted that the smaller objects might well be young *C. wimani*. Both Wiman and later Regnell (1955, p. 555) considered a possibility that the fossils might be trilobite eggs but this suggestion seems to have found little favour.

One of us (T. D. F.) has been able to study the remaining specimens of the type *C. wimani*, mounted on three glass slides (Pl. 62, figs. 2, 3, 5, 6). One of these is a serially sectioned specimen which may be that prepared for Eisenack (1966, p. 52). The findings are reported below in the description of *Chuaria*.

Timofeev (1970) has drawn attention to the existence of giant sphaeromorphid microplankton, similar to *C. wimani*, which he has found whilst dissolving rock samples from the Riphean (Upper Precambrian) of Siberia. No description has been published, but he included photographs of two specimens of *C. wimani* from Sweden renamed *Kildinella magna*.

Timofeev (1969, pl. 6, fig. 3) also figured and briefly described a further rather indeterminate specimen from the Visingsö Series as *Trachysphaeridium vetterni* sp. nov., though Eisenack (1966, p. 53, fig. 1) had previously figured it as *C. wimani*.

2. *Chuaria* sp. Hofmann 1971

Small round to oval 'brachiopod-like shells' were found by Allan (1913, pp. 174, 192) in a 50 cm shale layer 16 m below the top of the Hector Formation (Late Precambrian) of Banff National Park in Canada. These show, very poorly, irregular creases in the centre and more strongly developed concentric wrinkles around the margin.

Hofmann (1971, p. 24, pl. 11, figs. 5–7) briefly described topotype material (GSC types 24409, 24410) and referred them to *Chuaria*, though remaining uncommitted as to their nature, 'perhaps compressed planktonic spheroids, Foraminifera . . . or small medusoids similar to ones illustrated by Wade (1969)'.

Further specimens have been collected from the type locality and the present writers support Hofmann's assignment to *Chuaria*.

3. *Fermoria* Chapman 1935

The only other named fossil which seems to be comparable to *Chuaria* is *Fermoria*, first described from the late Precambrian of India and more recently from Iran (Pl. 63, figs. 1, 2).

Small carbonaceous disc-like fossils were found in the Suket Shales of the Vindhyan System of India by Jones (in Holland 1909, p. 66), who commented that they might be compared with either *Obolella* or *C. circularis*. Other suggestions (see Pascoe, 1959, p. 498) were that they belonged to *Acrothele*, known to occur in the Cambrian of the Salt Ranges. However, Chapman (1935) assigned the specimens to two new genera and four new species, *Protobolella jonesi*, *Fermoria minima*, *F. granulosa*, and *F. capsella*.

Sahni (1936) thought that there was insufficient evidence for the separation of these and placed them all in the synonymy of *F. minima*, though at the same time erecting a new generic name *Vindhyanella* for one of the specimens figured as *Protobolella jonesi* by Chapman (1935, pl. 2, fig. 1), though he admitted that the specimen was lost!

In 1954 Sahni and Shrivastava briefly described and named a single, larger, new fossil found with *Fermoria* as *Krishnania acuminata*. Their illustration (1954, fig. 4) is entirely unconvincing regarding the filaments they claim to be attached, and the writers support Glaessner (1962) in regarding it simply as a large *Fermoria*.

Misra and Dube (1952) recorded new material with *Fermoria* which they regarded as mostly inorganic pellets. Misra (1957) restated this, noting that some alleged *Fermoria* were chlorite aggregates in schist, and others were haematite spots in sandstone. Misra's plate 7, however, shows forms which could easily be badly preserved algal bodies like *Chuaria*.

Pascoe (1959, facing p. 498) figured specimens up to 4 mm diameter. He also commented that *Fermoria* left a white ash when incinerated and was therefore a plant, but at the same time he felt it possible that *Fermoria* could be an archaic form of brachiopod though with 'no reliable feature definitely attributable to this class'.

A few specimens of *Fermoria* from the Geological Survey of India collections have been examined. They are from Neemuch, Madhya Pradesh (24° 24′ north, 74° 54′ east), in the Vindhyan System. They occur either isolated or as small clusters of smooth carbonaceous discs on fissile olive-coloured shale. Taking these in conjunction with the various descriptions of other specimens, the writers have no doubt that *Fermoria* should be regarded as synonymous with *Chuaria*.

Fermoria has also been found in Iran, apparently in large numbers at several localities (Pl. 63, figs. 1, 2). Assereto (1963, pp. 507–508, fig. 2) and Stöcklin *et al.* (1964, p. 14, pl. 1, figs. 3–5) have recorded *Fermoria* in the Chapoghlu Shales (late Precambrian) of northern Iran. They figured specimens up to 3 mm diameter crowded together.

A few specimens of *Fermoria* from Iran have been examined, and a number of unpublished photographs by R. Assereto of other specimens have been available for comparison. Though mostly lacking in carbonaceous matter, the impressions on fine-grained olive-grey shale are so close to *Chuaria* as to leave no doubt that here again, organisms identical to *Chuaria* were present. Whole surfaces of chips of shale are covered with impressions, and clusters of at least fifty are indicated. They are commonly 2–3 mm in diameter. There is little indication of overlap, but concentric wrinkles are frequent particularly near the margins.

Recent interpretations of *Fermoria* have either been non-committal or that it is algal. In the *Treatise* volume on Brachiopoda (Williams *et al.* 1965, p. H 864) *Fermoria* is noted only as a synonym of *Protobolella*, which in turn is listed among the generic names erroneously ascribed to Brachiopoda. Häntzschel (1962, p. W 240) listed *Fermoria* amongst unrecognizable genera.

Glaessner (1966, p. 41) was non-committal and noted both *Fermoria* and *Chuaria* under the heading of 'other algae', thus supporting Howell (1956, p. 110), who also included *Corycium enigmaticum* in this group of uncertain algae. Ohlson (1961), though, regarded the latter as mud-pellets armoured with aegagropilous algal debris. Cloud (1968) also listed *Fermoria* as 'possibly algal but needs restudy'.

4. Unnamed fossils

In describing medusoids from the Central Mt. Stuart Beds of the Central Australian Late Precambrian, Wade (1969, p. 356, pl. 69, figs. 5–7) noted 'numerous minute unidentifiable organisms' in maroon sandstones with minor shales. Latex casts have been examined (Pl. 63, fig. 3) and the impressions clearly show the concentric wrinkles characteristic of *Chuaria*, though they are somewhat larger, ranging between 5 and 8 mm. As noted above, Hofmann (1971, p. 24) compared them with the Canadian specimens of *Chuaria*.

SYSTEMATIC DESCRIPTION

Group ACRITARCHA Evitt 1963
Subgroup SPHAEROMORPHITAE Downie, Evitt, and Sarjeant 1963
'group' MEGASPHAEROMORPHIDA Timofeev 1969
Family LEIOSPHAERIDAE Eisenack 1959
Genus CHUARIA Walcott 1899

Diagnosis. Flattened carbonaceous spheroids, now discs, from 0·5 mm to 5 mm in diameter, commonly 2–2·5 mm, showing wrinkles and cracks irregularly or concentrically arranged owing to crushing; no surface ornament; no pores; openings restricted to gaps where spheroid burst open in a few specimens; translucent resinous yellow in prepared specimens.

Chuaria circularis Walcott 1899

Plates 61–63

1899 *Chuaria circularia* Walcott, pp. 234–235, pl. 27, figs. 12, 13.
1932 *Neobolus minima* Chapman, p. 29 (nom. nud.).
1933 *Obolella jonesi* Chapman, p. 20 (nom. nud.).
1933 *Fermoria minima* (Chapman), p. 20 (nom. nud.).

1933 *Fermoria granulosa* Chapman, p. 20 (nom. nud.).
1933 *Fermoria tripartita* Chapman, p. 20 (nom. nud.).
1935 *Fermoria minima* Chapman, pp. 114–116, pl. 1, figs. 1, 3.
1935 *Fermoria granulosa* Chapman, p. 116, pl. 1, figs. 2, 4; pl. 2, fig. 5.
1935 *Fermoria capsella* Chapman, p. 117, pl. 2, figs. 3, 4.
1935 *Protobolella jonesi* Chapman, pp. 117–118, pl. 1, figs. 5, 6; pl. 2, fig. 1.
1936 *Vindhyanella jonesi* (Sahni), p. 467.
1941 *Chuaria wimani* Brotzen, p. 260.
1954 *Krishnania acuminata* Sahni and Shrivastava, p. 40, fig. 4.
1963 Problematica Assereto, pp. 502–503, fig. 2.
1969 minute unidentifiable organisms, Wade, p. 356, pl. 69, fig. 7.
1969 *Kildinella magna* Timofeev, p. 14, pl. 6, figs. 4, 5.
1970 *Kildinella magna* Timofeev, pl. 1, figs. A, B, D.
1971 *Chuaria* sp. Hofmann, p. 24, pl. 11, figs. 5–7.

Nomenclatorial notes. The name *C. circularis* was published by Walcott in 1899 and thus has Linnean priority. All remaining names have been placed in synonymy as the present writers do not feel that the known fossils show sufficient features for consistent diagnosis of separate species, let alone genera. Furthermore, there has been an element of doubt in that most writers have compared their material with *C. circularis* and have distinguished it only on the basis of either size or on features which are mostly diagenetic. Rowell (1971, pp. 72–73) has discussed the confused nomenclatorial history of *Fermoria*, and it need not be repeated except to note that he overlooked the fact that Chapman had introduced the names without diagnoses in 1933, two years before the formal descriptions (Chapman 1935).

Species diagnosis. As for genus.

Type specimens. Walcott's (1899) type material was catalogued under U.S. National Museum no. 33800 and consists of six flakes of shale, each with one or more specimens. One flake is unfossiliferous, and there is also one small bottle that contains indeterminate fragments, again without any observable fossil. The original of Walcott's figure 13 cannot be identified in the collection. The original of his figure 12 is probably the specimen illustrated here as Pl. 61, fig. 1; this specimen is now designated lectotype and is still catalogued under USNM 33800. A number of specimens have been selected from the collections made by Ford and Breed (1969, 1972) and these have been added to the U.S. National Museum reference collection and are catalogued under USNM catalogue 36, no. 181859.

Type locality. See under Stratigraphic Occurrence below.

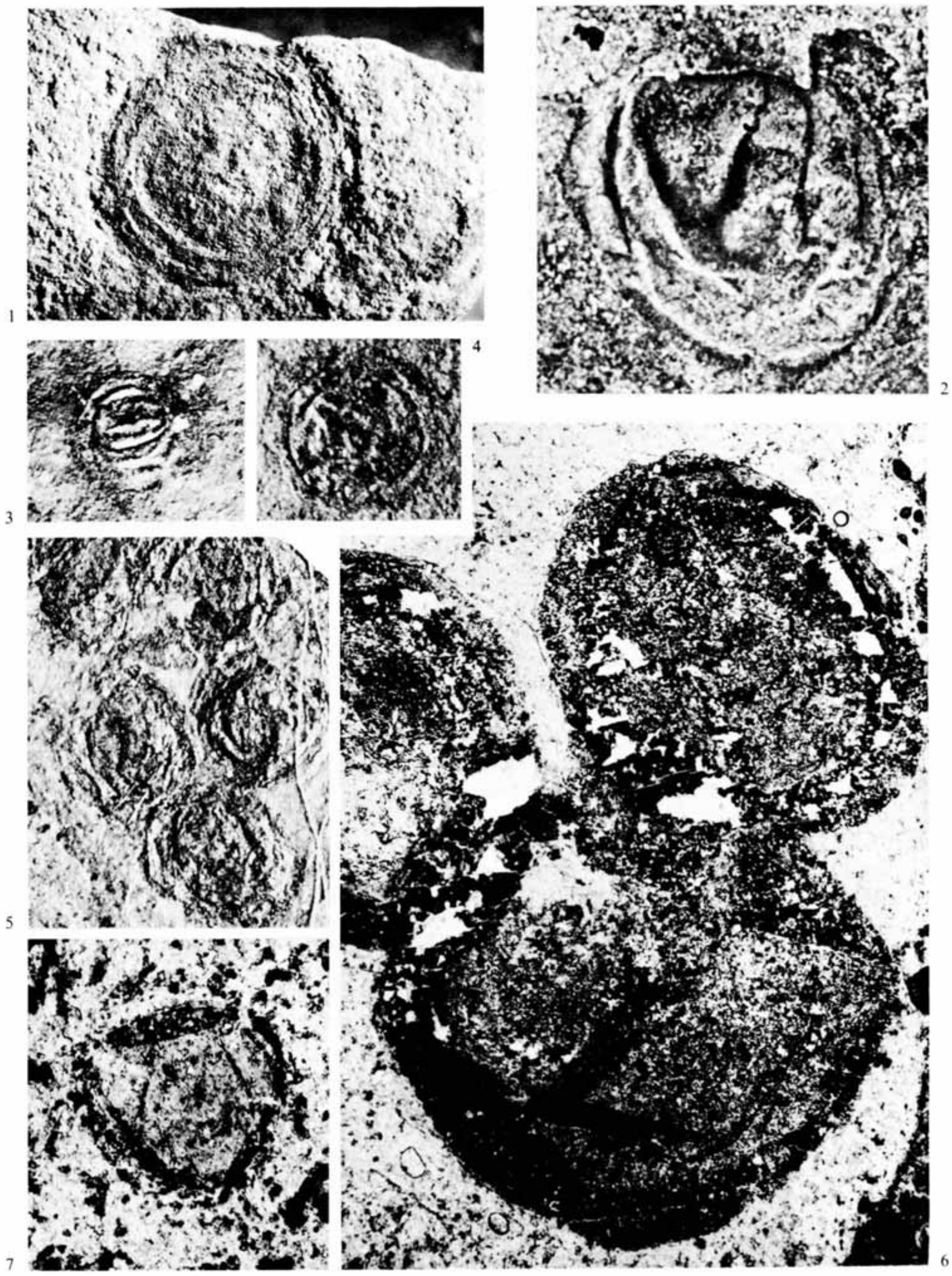
Dimensions. Individuals are commonly 2 to 2·5 mm in diameter. Walcott (1899, p. 234) recorded specimens ranging from 2 to 5 mm diameter though the largest illustrated (pl. 27, fig. 12) is barely 3 mm.

The Indian specimens of '*Fermoria*' seen by the authors range between 2 and 3 mm though Chapman (1935, p. 115) noted the largest as 4·5 mm diameter.

The Iranian specimens of '?*Fermoria*' according to Stöcklin *et al.* (1964) ranged from 1 mm to 'several mm', but the specimens seen by the authors range only between 2 and 3 mm. Assereto's unpublished photographs indicate specimens up to 6 mm being common though the scale on the photos raises some doubts. Wade's specimens from Central Australia range up to 8 mm whilst those from the Hector Formation only reach 4 mm. Brotzen (1941), Eisenack (1966), and Timofeev (1969) noted a size range from 0·5 mm upwards to about 2·5 mm and the last two have indicated that there is a continuous range downwards to much smaller sizes. Eisenack noted his smallest specimens as being only 62 μm but expressed the feeling that there should be still smaller juveniles. This extreme range down into the sizes normally

EXPLANATION OF PLATE 61

Figs. 1–7. *Chuaria circularis* from Awatubi Member, Kwagunt Formation, Chuar Group, late Precambrian, of Nankoweap Butte, Grand Canyon, Arizona. 1, Lectotype, ×10, U.S. Nat. Museum, 33800. 2, ×25, Univ. Leic. 49398b. 3, ×25, Univ. Leic. 49375. 4, ×25, Univ. Leic. 49495. 5, Small cluster, ×25, Univ. Leic. 49392. 6, Peel of small cluster, ×40, Univ. Leic. 56744. 7, Peel showing infolded margins, ×25, Univ. Leic. 56743a.



FORD and BREED, *Chuaria*

expected for nanno-plankton raises considerable difficulties both of nomenclature and definition, since nanno-plankton of this general nature have been placed in a number of genera and species by palynologists, chiefly in Russia (see Downie 1967; Timofeev 1965, 1969, 1970). Surface ornament and textures present in juveniles are not necessarily present in the mature forms, so that *Chuaria* may include adults of several smaller species. The definition of *Chuaria* is thus arbitrarily restricted to forms larger than 0·5 mm. Roblot (1964) figured a 'sporomorph' 256 μm in diameter from the Brioverian of Normandy which could well be a small *Chuaria*.

Remarks. Topotype specimens of *C. circularis* occur as black carbonaceous discs on the bedding laminae of dark blue-black shale. The discs may be solitary or in clusters, of which the largest so far seen numbered twenty-three. Individuals in the clusters never show overlap, though some lateral crushing may be seen. This is taken to indicate that the individuals were spheroidal, or at least inflated discoidal, when deposited, since spheroids do not normally pile up on top of one another. The clusters do not suggest that there was any direct connection between individuals but rather that they came to rest washed together in random fashion. The same observation can be made regarding the specimens from Iran, where clusters of fifty or more have been seen.

Chuaria shows no surface ornament, except wrinkles and cracks due to crushing. Examination with the scanning electron microscope simply shows the grain size of the enclosing sediments impressed on the fossil. Frequent mud-cracked and ripple-marked surfaces indicate intermittent desiccation, and the wrinkles are thus probably due to shrinkage on drying. They show no regular behaviour except for the concentric wrinkle or wrinkles near the margin of many specimens. This is particularly well seen in the Iranian specimens. Serial sections of *C. 'wimani'* show, as Eisenack (1966) noted, two simple walls with a thickness of 50 to 70 μm. The preservation of *C. circularis* from the Grand Canyon has not permitted successful serial sections as yet. The walls of *C. 'wimani'* meet about 0·25 mm from the margin, giving the false impression of a narrow marginal flange.

A number of diagenetic effects have been observed on both *C. circularis* and *C. 'wimani'*, and they appear to have counterparts in some descriptions and photographs of '*Fermoria*'. Most obvious is the effect of minute cubes of pyrite in the shale, which give a granulose effect, presumably the cause of Chapman distinguishing *F. granulosa* as a separate species. A solitary cube can be seen in some photographs of *C. 'wimani'*. Otherwise cracking and distortion seem to be the main effects. Many *C. circularis* show radial cracks in the margin, commonly three or four but sometimes many more. This may be the reason why Chapman distinguished *F. tripartita*. Some specimens show openings in the young stages according to Eisenack,

EXPLANATION OF PLATE 62

Figs. 1–6. *Chuaria circularis* from the late Precambrian of the Grand Canyon and Sweden. 1, Peel with marginal crushing simulating a flange, ×25, from Grand Canyon, Univ. Leic. 56745. 2, *C. 'wimani'*, separated and mounted, showing wrinkling of flanks, ×30, Visingsö Series, Sweden. Univ. Uppsala Visingsö Colln. 3, *C. 'wimani'*, separated and mounted, showing burst open appearance, ×30, Visingsö Series, Sweden (= Wiman 1894, pl. 5, fig. 2). Univ. Uppsala Visingsö Colln. 1–9. 4, Peel, ×25, from the Grand Canyon. Univ. Leic. 56743b. 5, 6, *C. 'wimani'*, two serial sections, showing thickened or duplicated flange on one side, ×35, Visingsö Series, Sweden. Univ. Uppsala Visingsö Colln. 1–9.

FORD and BREED, *Chuaria*

but the only one observed in the 'mature' specimens is quite clearly where the spheroid burst open, either on initial crushing or perhaps during life (Pl. 62, fig. 3).

The specimens from the Hector Formation show more relief than any of the others, but this is also thought to be a diagenetic effect in the rather more indurated argillite matrix. Small round slickensided marks are probably crushed gas bubbles and indicate considerable compaction. Some *Chuaria* from the Hector are convex and others concave on the same lamina and both show wrinkles due to shrinkage or compaction. The impressions in the Australian material are sufficiently strongly developed in fine-grained sandstone to indicate that the globular bodies were not fully compressed when the sandstone was indurated.

Chemical composition. As Eisenack (1966) observed, the fossils are easily incinerated and leave a white ash. Eisenack found this was silica in his specimens, but some clay minerals and pyrite appear to be present in others. He regarded the silica, clay, and pyrite as of diagenetic origin. The substance is insoluble in KOH, concentrated HCl, HF, and H_2SO_4 even after heating. Cold concentrated HNO_3 has no effect, but boiling HNO_3 bleaches the substance. Schülze solution bleaches the substance more quickly, but can be completely destructive. Eisenack examined some specimens of *C.* '*wimani*' for phosphate by chemical means, with negative results. Examination of *C. circularis* from the Grand Canyon by electron microprobe by Mr. Jarosewich in the Smithsonian Institution also failed to reveal phosphorus. The last test indicates that *Chuaria* is not of brachiopod nature, whilst the remainder suggest only that it is organic, largely carbon. Eisenack also noted pronounced shrinkage on treatment with KOCl which, he claimed, distinguished *Chuaria* from pollen, spores, and hystrichospheres (and acritarchs presumably), as it was a characteristic reaction of fossil chitinous foraminiferids. However, this test is not considered valid by all palynologists. Further tests by electron microprobe are thought to be pointless as they would only determine elements that were likely to be present in the enclosing shale.

Biological affinities. As Eisenack (1966) and Timofeev (1970) have noted, there is a size range from nanno-plankton up to 2 mm. Timofeev has applied the name *Kildinella* (a sphaeromorphid acritarch) with a new trivial name *magna* (1969, 1970) to a specimen previously named *C.* '*wimani*' by Brotzen, without discussion of reasons for so doing. He has further placed this genus in two separate 'groups' of acritarchs, Sphaeromorphida and Megasphaeromorphida, without making it clear what status his 'groups' have in relation to the Group Acritarcha of Evitt (1963) and the Subgroup Sphaeromorphitae of Downie, Evitt, and Sarjeant (1963).

Assignment to higher taxa also presents problems. The 'group' Megasphaeromorphida erected by Timofeev (1969) is little more than a convenient grouping for large planktonic organisms, and seems to be broadly equivalent to superfamily status. Alternatively the present authors feel that there is some merit in placing

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EXPLANATION OF PLATE 63

Figs. 1–4. *Chuaria circularis* from the late Precambrian of Iran, Australia, and Grand Canyon. 1, 2, From the Chapoghlu Shale, W. Elburz, Iran, ×10, Univ. Leic. 58123. 3, From Central Australia, ×10, latex cast of University of Adelaide, Geology Department spec. F16472. 4, Cluster from the Grand Canyon, ×10, Univ. Leic. 49398a.

1

2

3

4

FORD and BREED, *Chuaria*

Chuaria with *Leiosphaeridia* in the family Leiosphaeridae. Comparison with the descriptions of *Leiosphaeridia* and *Tasmanites* provided by Wall (1962) and by Schopf (in Tschudy and Scott 1969) shows that *Chuaria* is similar to both but much larger. *Tasmanites*, however, has a punctate wall and has been compared with the modern *Pachysphaera pelagica* and *Halosphaera minor* of the Class Prasinophyceae, Phylum Chlorophyta. *Chuaria* has no visible punctation, so that it is more appropriately referred to the family Leiosphaeridae of the Acritarcha.

All current writers (e.g. Glaessner 1966; Cloud 1969; Timofeev 1970) have noted *Chuaria* as a fossil alga. The writers support this assignment and, following Glaessner (1966) and Timofeev (1970), regard *Chuaria* as an unusually large acritarch-like organism, or organisms, comparable with *Leiosphaeridia*.

It may be noted that many late Precambrian and Cambrian micro-plankton with diameters from 0·1 to 0·25 mm have been recorded (e.g. Roblot 1964; Timofeev 1965, 1969, 1970). Perhaps only a few of these forms grew to the size of *Chuaria*. Obviously more palaeopalynological research needs to be done on these rocks to extract the full range of nanno-plankton as well as the larger forms. Downie (in Ford and Breed 1969) provided preliminary notes on the nanno-plankton. In spite of *Chuaria* being placed in a group separate from *Pachysphaera*, the observation by Parke (in Wall 1962, p. 359) that the latter releases a flagellated stage raises the possibility that *Chuaria* may have done so. Few specimens show any sign of an opening but they may either have split equatorially and so show no opening whilst lying in this plane, or they may have been immature when fossilized. One specimen of *C.* '*wimani*' (Pl. 62, fig. 3) has obviously split open but this may have been during burial or extraction.

STRATIGRAPHIC OCCURRENCE

Walcott (1899, p. 234) noted that his specimens were collected 730 ft (219 m) beneath the summit of the Chuar terrane in the Kwagunt Valley of Grand Canyon. On referring to his measured section of the Chuar (1894, pp. 508–512) this appears to be close to the Cherty Pisolite in the Walcott Member of the Kwagunt Formation as defined by Ford and Breed (1972*a*, 1973), but Walcott was ambiguous in that the measurement of 730 ft (219 m) could have been either by altitude or by stratigraphic thickness. However, Ford and Breed (1969, 1972*a*, 1973) found *Chuaria* in shales over a thickness of about 100 ft (30 m) on Nankoweap Butte, overlooking Kwagunt Canyon, with the greatest abundance in two beds about 30 and 80 ft (9 and 24 m) below the Flaky Dolomite, a horizon at the base of the Walcott Member and the top of the Awatubi Member. Rare specimens were also found some 5000 ft (1500 m) lower in the Chuar Group, in shales about 100 ft (30 m) below the top of the Tanner Member. The cherty pisolite near the base of the Walcott Member has recently yielded a flora of microscopic filamentous and spheroidal algae (Schopf, Ford, and Breed 1973).

The age of the Chuar Group has been discussed by Ford *et al.* (1972) and by Ford and Breed (1972*a*, 1973) and appears to be less than 1000 m.y., but definitely Precambrian, i.e. Upper Riphean.

The Swedish Visingsö Formation containing *C.* '*wimani*' is now regarded as belonging to the Varegian Formation, which is the younger part of the Eocambrian, deposited less than 950 m.y. ago (Magnusson 1965).

The Iranian specimens come from the Chapoghlu Shale regarded by Stöcklin *et al.* (1964) as in the lower part of a series of Upper Precambrian to ? Lower Cambrian age.

The Hector Formation of Canada is unconformably covered by Cambrian and rests unconformably on Beltian, and is thus part of the Windermere Series, recently dated by Harrison and Peterman (1971) as between 570 and 850 m.y. Licari and Cloud (1968) reported the discovery of nanno-plankton resembling the modern green algal family Oocystaceae in these beds.

Timofeev (1970) noted that Megasphaeromorphida occurred in the Upper Riphean of Eastern Siberia, and Shatsky (1952) also recorded *Chuaria* in the Upper Riphean, though he gave no details.

The occurrences of *Fermoria* are more difficult to place owing to the confusion of records of truly organic remains with those of inorganic substances. It must suffice to say that the Vindhyan rocks are regarded by most writers on India as being of late Precambrian age (Howell 1956; Pascoe 1959).

The Central Australian occurrence is in beds assigned to the topmost division of the Upper Precambrian. The presence of numerous medusoids suggests a correlation with the Ediacaran of South Australia, but none of the medusoids is common to both localities and the Ediacaran fauna has not been found in association with *Chuaria* elsewhere.

Sporomorphs up to 256 μm diameter have been recorded from the Brioverian of Normandy by Roblot (1964, pl. 11, fig. 12) which could well be a small *Chuaria*. The Brioverian is generally regarded as late Precambrian.

Thus all known occurrences of *Chuaria* and fossils here regarded as synonymous, are in late Precambrian rocks, broadly falling within the Upper Riphean division of Precambrian time, though the lack of radiometric age data on most of the sediments concerned allows no placing more accurate than between 1000 and 570 m.y. ago.

CONCLUSIONS

It is concluded that *Chuaria* is of plant origin, most probably being a large leiosphaerid acritarch. An arbitrary lower size limit is adopted of forms larger than 0·5 mm. They are generally preserved as flattened hollow spheroids, with cracks and wrinkles owing to crushing and diagenesis. Forms previously named *C. wimani*, *Kildinella magna*, and *Fermoria minima* are thought to be at present indistinguishable from *C. circularis*. The stratigraphic range seems to be limited to the Upper Riphean, roughly from 1000 m.y. ago to the beginning of the Cambrian. Occurrences are now known in Arizona, Canada, Sweden, France, Siberia, Iran, India, and Australia, and it seems clear that these carbonaceous spheroids provide a stratigraphic index fossil for late Precambrian rocks.

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T. D. FORD
Department of Geology
University of Leicester
Leicester LE1 7RH

W. J. BREED
Museum of Northern Arizona
Flagstaff, Arizona, U.S.A.

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Addendum. Since writing the above, the authors have heard that Dr. W. C. Gussow has prepared a note on *Chuaria* from the Hector Formation, of Banff National Park, Canada. This will be published in *Journal of Palaeontology*, 1973, **47,** no. 6.