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EARLIEST PHANEROZOIC OR LATEST PROTEROZOIC* FOSSILS FROM THE ARABIAN SHIELD

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ABSTRACT

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We report here the first biologically definable fossils from pre-Saq (pre-Middle Cambrian) rocks of the Arabian Shield. They include the distinctive helically coiled tubular filaments of the oscillatorialean blue-green alga *Obruchevella parva* as well as two size classes of spheroidal unicells of uncertain affinity. Also present is the conical stromatolite *Conophyton* and unidentified stromatolites. All occur in cherty limestones of the Jubaylah Group, northern Saudi Arabia, a nonmarine to locally marine taphrogeosynclinal sequence that fills depressions along the northwest-trending Najd faults.

Conophyton has heretofore been found only in strata older than about 680 Ma (except for puzzling records in modern hot springs) while *Obruchevella* is so far known only from rocks between about 680 and 470 Ma old. Thus it appears that the Jubaylah Group is close to the Proterozoic-Phanerozoic transition. The simple spheroidal nannofossils are not diagnostic as to age. Their relationships within what appears to be early diagenetic chert suggest a classical algal-mat association. The brecciated and microchanneled appearance of much of the fossiliferous rock, its locally dolomitic nature, and the prevalence of cryptalgalaminate favors a very shallow, locally turbulent, and perhaps episodically exposed marine or marginal marine setting.

The Jubaylah Group lies unconformably beneath the Siq Sandstone (basal member of the Saq Sandstone) of medial Cambrian age, rests nonconformably on crystalline basement,

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*The "Subcommission on Precambrian Stratigraphy" of the International Union of Geological Sciences in July 1977 recommended the use of the time-honored term Proterozoic for time and events between Archean and Phanerozoic (James, 1978) and this usage has been adopted by the U.S. Geological Survey (Sohl and Wright, 1978). To date the Subcommission has not reached a decision on placement of the Proterozoic—Phanerozoic boundary. In this paper, however, we follow the practice of including in the Phanerozoic, and thus regarding as post-Proterozoic, those sub-Cambrian rocks and events that are referable to the paleontologically defined Ediacarian System of Termier and Termier (1960) as discussed by Cloud (1976). For clarity in discussion, the term Precambrian with a capital P is here avoided and rocks older than Ediacarian (or Vendian are designated as pre-Phanerozoic.

and has yielded a K-Ar whole-rock age (on andesitic basalt) of ~540 Ma. To judge from the fossils, however, that age may be as much as 100 Ma or more too young.

INTRODUCTION

Samples of stromatolitic limestone collected by Hadley from the 3000-m-thick Jubaylah Group at Jabal Umm al 'Aisah, northeastern Hijaz quadrangle, Saudi Arabia, in 1974 (his Station BFT-10, samples 93786 and 93788, see Fig. 1) were found to contain a form of *Conophyton*, suggesting a pre-Phanerozoic (pre-Ediacarian) age.

The age being equivocal and important, and the prospect for microfossils untested, samples of dark chalcedonic chert were collected from supposedly correlative limestones in the Mashhad Area, some 400 km to the west of Jabal Umm al 'Aisah, at the northern edge of the Arabian Shield. The cherty limestone of the Mashhad area comprises the lower third of the Muraykhah Formation, a 350-m-thick unit of carbonate rocks in the upper part of the mainly clastic and volcanic Jubaylah Group, having a total thickness of 875 m. The Jubaylah in this area is separated by unconformities from crystalline rocks of known Proterozoic age below and the Siq Sandstone Member of the Saq Sandstone of Cambrian and Ordovician age above (Powers et al., 1963). Only one of the Mashhad samples (116083) yielded microfossils, or, more precisely, nannofossils. This sample, from float at Hadley's station JCT-2, produced simple spheroids of size groups averaging ∿8 μm and ∿40 μm in diameter. Sample 93790 (Station BFT-10), however, a siliceous gray bimodal limestone from the Jubaylah Group at Jabal Umm al 'Aisah, revealed specimens of the helical, probably blue-green algal nannofossil known as *Obruchevella*, and poorly preserved nannofossils similar to the larger spheroids from Mashhad were found in HCl maceration residues from Jabal Umm al 'Aisah (sample 93787).

These several fossils, assuming essential stratigraphic equivalence between the rocks called Jubaylah at Mashhad and Jabal Umm al 'Aisah, pose some interesting questions about age and correlation to sequences elsewhere. Following a long pre-Phanerozoic history, *Conophyton* seems to have disappeared from the stratigraphic record about 680 Ma ago, at or just preceding the beginning of basal Phanerozoic (but sub-Cambrian) sedimentation — the Ediacarian System of Termier and Termier (1960; Cloud, 1972, 1973, 1976, pp. 24—26). *Obruchevella parva* Reitlinger, found at the same Arabian locality as the *Conophyton*, is known from deposits of Ediacarian age in Siberia (Vendian or Yudomian above the level of the Varangian tillites), just above the youngest fossil *Conophyton*. The genus *Obruchevella*, however, ranges up to strata as young as Ordovician, has a modern analog in the living blue-green alga *Spirulina*, and is most frequently reported from rocks of Early Cambrian age.

The abundant simple microspheroids are not distinctive as to age, but the

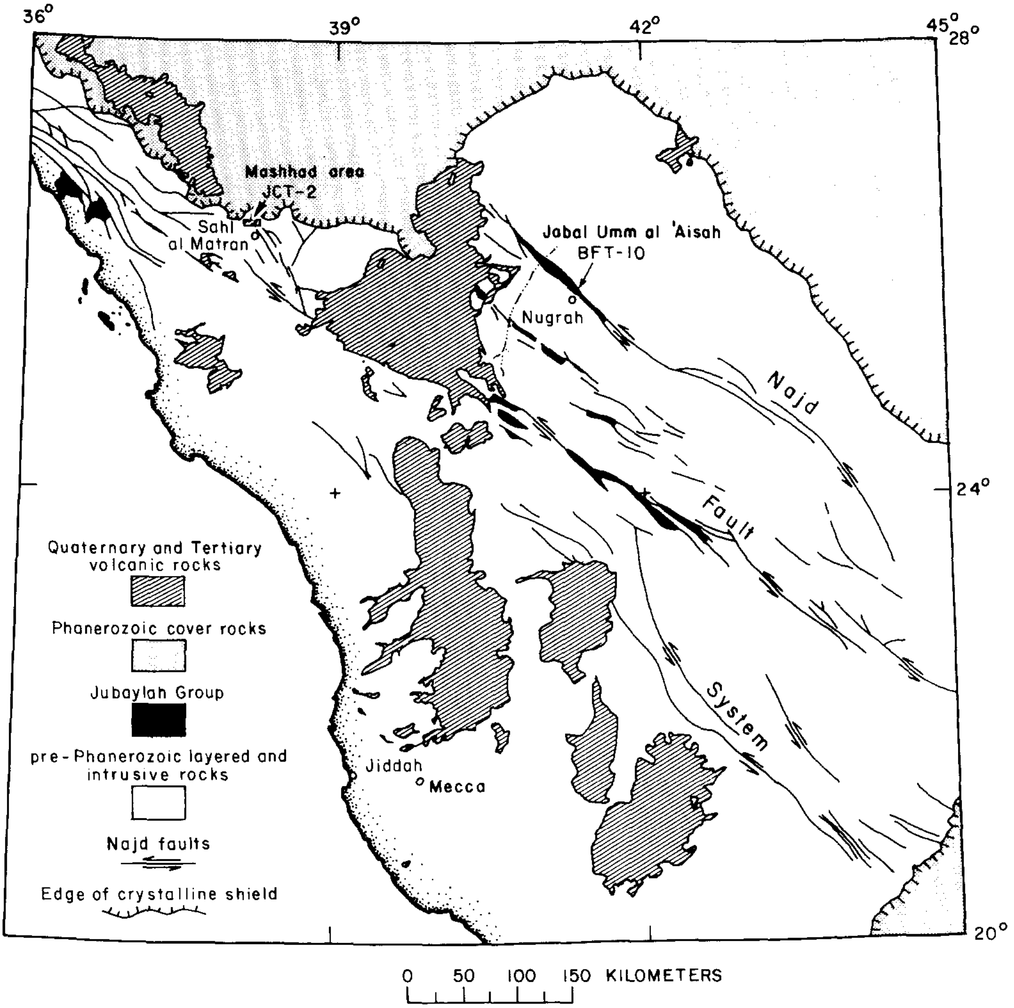

Fig.1. Index showing the location of the Mashhad and Jabal Umm al 'Aisah areas in the northwestern part of the Arabian Shield (after Hadley, 1974, fig.1).

absence of more complicated forms and the relatively large size of some (average diameter $\sim 40\ \mu m$) would be most consistent with a later pre-Phanerozoic age.

Taken together this evidence suggests a stratigraphic position for the Jubaylah Group that is very close to the transition from Proterozoic into Phanerozoic — a time of signal importance in crustal evolution and the history of life and one about which little is as yet known with much certainty. The microbial fossils are the first to be reported from the Arabian Shield.

STRATIGRAPHY

The Jubaylah Group, in which the fossils occur, was named by Delfour (1967) after exposures at Jabal Jubaylah, not far southwest of Jabal Umm al 'Aisah (Delfour, 1977). The Jubaylah rocks rest unconformably on clastic and felsic volcanic rocks of the Shammar Group in the Mashhad area (Hadley, 1973). Elsewhere on the Arabian Shield they overlie older Proterozoic metasedimentary and metaigneous rocks.

Jubaylah stratigraphy at Jabal Umm al 'Aisah was described by Delfour (1967, 1970) and in the Mashhad area by Hadley (1974). The ∿875 m of Jubaylah strata in the Mashhad area (Fig.2) consist of three formations. (1) From the base upwards these are the Rubtayn Formation, mainly sandstone, siltstone, and conglomerate of prevailingly nonmarine origin; (2) the Badayi Formation, andesitic basalt flows (probably also nonmarine); and (3) the Muraykhah Formation, marine siliceous limestone and dolomite with interbedded fine clastic sediments. The carbonate rocks of the Muraykhah

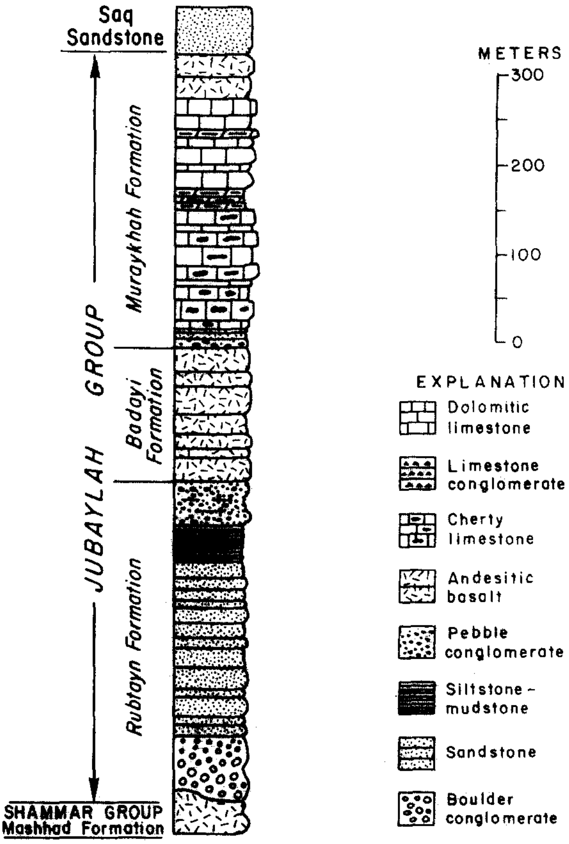

Fig.2. Stratigraphy of Jubaylah Group in Mashhad area.

formation are cherty and siliceous in the lower part, become dolomitic upward, implying a marine origin, and are locally capped by andesitic basalt.

Outside the Mashhad area the succession is more variable. In the Jabal Umm al 'Aisah area the Jubaylah Group is reported to attain a thickness of as much as 3000 m (Delfour, 1970, p.17). Here medial volcanic rocks are missing and the lower conglomeratic part is followed directly by a limestone unit, in turn succeeded by more conglomerate and a thick terminal sandstone sequence. The fossil-bearing strata in both localities are from a lower cherty and siliceous portion of the only limestone unit in the sequence and are, therefore, considered to be approximate stratigraphic equivalents.

The siliceous limestones and succeeding dolomitic limestones of the Jubaylah Group seem to represent a marine or mainly marine incursion or incursions (with minor volcanic episodes) in a sequence of mainly nonmarine clastic and volcanic rocks that filled growing, fault-bounded basins. These faults belong to the extensive Najd system of left-lateral faults that trends northwest-southeast across the Arabian Shield (Hadley, 1974; see also Fig.1), subparallel to the Red Sea, Persian Gulf, and Zagros Mountains — a very ancient zone of crustal movement, it would seem.

AGE

The age of the Jubaylah Group is not established with certainty, but several lines of evidence bear on it. The Jubaylah Group has been dated directly by K-Ar whole rock methods that yield a minimal age on interbedded andesitic basalt of 540 ± 20 Ma (Aldrich et al., 1978). Its age is also bracketed by its position between the overlying Siq Sandstone Member of Middle Cambrian age and underlying upper Proterozoic rocks. In addition, the age of the Najd fault system is relevant to the age of the Jubaylah Group because the Jubaylah sequence was deposited within Najd fault basins. And, as implied above, we here present paleontological evidence for age.

In the northern part of the shield, the Jubaylah Group is overlain unconformably in several areas by the Siq Sandstone Member (Hadley, 1973; Delfour, 1970). The Siq Sandstone Member is the lowermost unit of the Saq Sandstone (Powers et al., 1966). It is extensively exposed in northwestern Saudi Arabia (U.S. Geological Survey and Arabian-American Oil Co., 1963). The Saq, originally assigned a Cambrian(?) age, is now considered to include both Cambrian and Ordovician (Powers et al., 1963, p.D21). The Ordovician assignment, however, applies only the Ram and Umm Sahm sandstone members which form the upper part of the Saq. Arthropod tracks in shale lenses in the Ram and Umm Sahm beds were identified in 1960 by Cloud (informal report to Glen Brown) as belonging to a species of the genus *Cruziana* that is distinctively Ordovician and apparently Early Ordovician (Powers et al., 1963, p.D22). The Siq and Quweira beds on the other hand, the lower sandstones of the Saq, are confidently assigned to the Cambrian because of the presence in them of middle Cambrian trilobites, in interbedded limestones in Jordan (Powers et al., 1963, p.D22).

The Jubaylah Group unconformably overlies the Shammar and Murdama Groups as well as upper Proterozoic granite. Whole-rock Rb-Sr ages for the Murdama and Shammar range from 650 to 570 Ma and 600 to 570 Ma, respectively (Fleck et al., in press). Granite and granodiorite in the Jabal Umm al 'Aisah area, similar to rocks on which the Jubaylah rests directly, yield a Rb-Sr whole-rock age of 557 ± 15 Ma (Baubron et al., 1976; Delfour, 1977) implying that the Jubaylah is younger than 557 Myr. Whole-rock Rb-Sr methods applied to red granites of the Shield, however, have given erratic results in the past (Fleck et al., in press). A more likely maximal age for the Jubaylah in the Jabal Umm al 'Aisah area is a whole-rock Rb-Sr date of 600 ± 25 Ma on the Shammar Group (Baubron et al., 1976).

The Jubaylah Group was deposited in part contemporaneously with formation of the Najd fault system and also is offset by late movement of the Najd faults (Hadley, 1974). Fleck and others (1976), suggest that the Najd fault system formed between 580 and 530 Ma ago.

Taken together the above evidence implies that the Jubaylah Group is older than Middle Cambrian but probably younger than $\sim$600 Ma. This might suggest an Early Cambrian age but no Early Cambrian fossils have been found in the apparently marine Jubaylah carbonate rocks — no trilobites, no archaeocyathids, no cribricyathids, none of the problematical but distinctive subconical shelly species that distinguish rocks of this age. Instead we see, at Jabal Umm al 'Aisah, the stromatolite *Conophyton*, heretofore confidently reported as a fossil only from pre-Phanerozoic rocks--that is from rocks known to occur beneath strata that contain the soft-bodied Ediacarian fauna or its equivalents. At the same locality are representatives of the helically coiled blue-green algal genus *Obruchevella*, whose still relatively rare occurrences are mainly Cambrian or younger. In the southern Aldan Shield of southeastern Siberia, however, the species *Obruchevella parva* Reitlinger, seemingly conspecific with our Arabian form, occurs in the Tinovsk Suite of late Yudomian and hence ostensibly of Ediacarian age (Reitlinger, 1959, p.21). Its presence in the Jubaylah Group, therefore, suggests an Ediacarian age for these rocks, as discussed more fully under the section on microbial fossils below. In addition, in the Mashhad area, are the two mentioned size-classes of otherwise featureless spheres which, in consideration of their size and the absence of spiny, hirsute, or otherwise ornamented forms, would seem more consistent with a pre-Phanerozoic than a Phanerozoic age.

We are not persuaded, therefore, that the Jubaylah Group is as young as the radiometric numbers would suggest, especially in view of the known unreliability of whole-rock ages and the tendency of K-Ar and Rb-Sr numbers to give ages that are too young. On the other hand it is clear that either *Conophyton* or *Obruchevella* is here occurring beyond its previously known range as a fossil. All of which leads us to conclude that the Jubaylah is most likely older than Cambrian, but probably little or no older than Ediacarian. Until more conclusive data may become available, therefore, we can say with confidence only that the fossils indicate a position very close to the base of the Paleozoic (which, following Cloud, 1976, we here place at $\sim$680 Ma). Specifically we would suggest a sub-Cambrian but not a Proterozoic age, because we are inclined to place more credence in the *Obruchevella parva* than in the unusual *Conophyton*. Thus the fossils suggest to us a possible equivalence with the Vendian of Eurasia and the Edicarian of Australia.

FOSSILS

Localities

Localities from which fossils have been obtained are indicated in Fig.1 and described below.

Station BFT-10. Jabal Umm al 'Aisah, northeastern Hijaz Quadrangle (Brown et al., 1963; Delfour, 1977), 15.9 km northeast of Nugrah, at 25°40'N and 41°40'E. Includes samples 93786 and 93788 with *Conophyton* and sample 93790 with *Obruchevella* from a mottled gray, siliceous and stromatolitic, polymodal, micrite-matrix microbreccia in the lower third of a limestone unit of the Jubaylah Group, perhaps equivalent to the Muraykhah Formation of the Mashhad area. In addition sample 93787, also from Station BFT-10, revealed much cryptalgal lamination and some fragments of columnar stromatolites, while residues from HCl maceration of this sample contained poorly preserved $\sim$40 μm spheroids similar to those from Station JCT-2 (sample 1160803) described below. Collector D.G. Hadley.

Station JCT-2. Mashhad area (Hadley, 1974), Sahl al Matran quadrangle (Hadley, 1973), south side of hill directly east of Mashhad. Sample 116083, a float block, with $\sim$8 and $\sim$40 μm spheroids in mottled gray chert from cherty gray limestone of the lower part of the Muraykhah Formation. Collectors D.G. Hadley, D.L. Schmidt, and D. Stoeser.

Methods of study

Search for fossils involved low magnification examination of fresh, weathered, polished, and HCl-etched surfaces, and high magnification optical study of numerous thin sections, both parallel to and at right angles to bedding surfaces, as well as of maceration residues (both HCl and HCl followed by HF).

Rock pieces for maceration were chosen from sawn slabs, eliminating exposed and weathered surfaces, and cleaned in a solution of H_2SO_4 and $K_2Cr_2O_7$ for several hours (Jackson et al., 1974). After immersion in dilute HCl until effervescence ceased, residues were examined optically at a range of magnifications. HCl-treated residue from sample 93787, Station BFT-10, revealed large brown spheres similar to those seen in thin sections of sample 116083, Station JCT-2. Maceration was then continued in HF. None of the HF residues, however, yielded fossil remains even though thin sections showed the simple spheres to be embedded in a clear, chalcedonic matrix. Thus either the spheroids are not organic despite their amber color, or they are too delicate to withstand the treatment to which they were exposed. Scanning electron microscope (SEM) studies of freshly fractured surfaces and of maceration residues provided no additional information.

Orientation of biological structures and lithic textures within the rock and their paleoecological implications

All samples studied reveal evidence of breakage, microchannel scouring, and growth and diagenetic alteration of algal mats, implying a very shallow, episodically agitated setting. Although the rocks are well bedded, bedding is discontinuous and angular clasts of a range of sizes are abundant between zones of cryptalgalaminate. Much of the cryptalgalaminate is diagenetically silicified and irregular patches and stringers of chalcedonic chert are common. The chert shows microstromatolitic growth and rupture patterns and random growth orientation (Figs.4A—D) implying that it grew in place post-depositionally as a silica-gel, either shouldering adjacent sediments aside or filling open space, or both. The fossils occur as described below.

Conophyton was found both as fragments and as small clusters of cones seemingly in position of growth.

Obruchevella shows a preference for a silicified clastic limestone consisting of delicate, dark, platy, cryptalgal fragments and granule-sized clasts of other debris set in a light-gray, very fine-grained matrix (Fig.3E). It occurs within the matrix and not the cryptalgal fragments. This rock also includes rare, small, thin-skinned oncolites in which the relatively large core is a fragment of cryptalgalaminate.

The spheroidal nannofossils reveal a curious relationship to the cryptalgalaminate of sample 116083 (Station JCT-2). They occur not within the silicified cryptalgalaminate itself (Fig.3F) but in horizontally elongated pods or lenses of brown, tan, and white mottled chert that disrupt the cryptalgalaminate (Fig.4A). Within these chert pods are small, microlaminated

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Fig.3. Stromatolites and lithic samples, Jubaylah Group, Jabal Umm al 'Aisah and Mashhad areas.

A—C. *Conophyton* sp., Jabal Umm al 'Aisah. (A) Polished surface showing horizontal profiles of three truncated cones. (B) HCl-etched surface showing partial horizontal profiles of two truncated cones (outlined by dashes) and irregular distribution of calcitic clots within and beyond stromatolites. (C) Polished vertical surface of cone showing axial structure; margins outlined by dashes.

D. HCl-etched surface of partially silicified stromatolitic limestone from Jabal Umm al 'Aisah.

E. Polished surface of *Obruchevella*-containing microbreccia from Jabal Umm al 'Aisah. Light-colored clasts are exotic volcanic granules, dark fragments are intraclasts.

F. Cryptalgalaminate from Muraykhah Formation, Mashhad area, similar to that at base and top of Fig.4A. Probably ancient algal mat material but devoid of microbial remains.

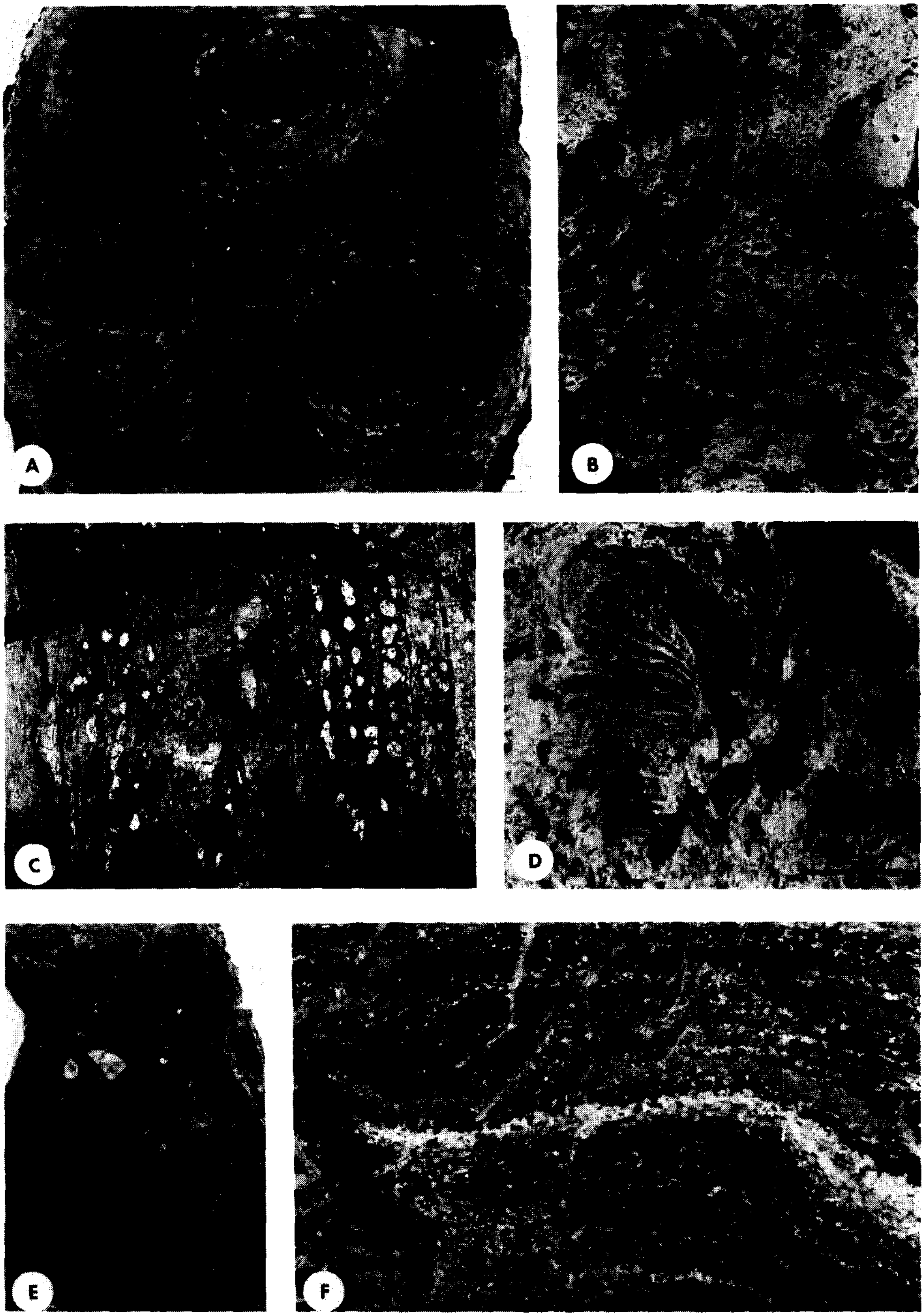

Fig. 3.

domelets, columns, and semibotryoidal bodies (Fig.4D) that face in different directions and show local angular breakage (Fig.4D lower right and upper left; Fig.4B, left, below center) as if they had grown in place within the sediments as noted above.

The positions of the spheroidal nannofossils within these chert masses are shown in Figs.4B—D. In these photographs one can, with some effort, see both that, although there is some mixing, the two size classes of spheroids occur as generally separated populations that are preferentially located in different laminae, in different parts of laminae, and in different parts of the clear unlaminated material that occupies the space between laminated forms — including some space that directly abuts the broken edges of laminated material (Fig.4B, left, below center). As a result of these unusual relations and the frequent presence of microcrystalline overgrowths, we early on held doubts about the biogenicity of the spheroids. But the composite nature of some of the large endosporangium-like spheroids (Fig.5G), the ruptured appearance of empty spheroids of the same dimensions (Fig.5F, right; 5D, center), the presence of two distinct populations of spheroids of narrow size range within populations, the relations of the spheroids to the microlaminae (Figs.4B—D), and their similarity to modern forms have persuaded us that they are very probably fossil microorganisms.

Fig.4. Distribution of spheroidal nannofossils in chert of Muraykhah Formation, Jubaylah Group, Mashhad area; *Obruchevella* from Tindir Group of Alaska.
A. Cryptalgalaminate of Muraykhah Formation, at base and top separated by mottled fossiliferous chert. The letter Z is in approximately the same position as the Z in view D.
B—D. Enlarged views of different parts of same vertical thin section showing random growth of laminar chert, contemporaneous breakage, and distribution of spheroidal unicells. The X in view B and Y in view C are at the same locations as X and Y in view D. (B) Cherty microcolumnar growth-structure descending from above (see also upper left of D) is separated by a narrow band of concentrated ∿40 μm spheroids from the sharp edge of a vertically laminated chert fragment below. A crack at right edge of this fragment is also filled with the larger spheroids. (C) Larger spheroids (∿40 μm) follow a band between the pair of facing arrows on the left at the right edge of the chalcedonic, upward-growing microdome that is shown above Z in view D. They are bordered by concentrations of ∿8 μm spheroids on either side. The two facing arrows at the upper right also mark a concentration of the larger spheroids at the left side and bottom end of a downward-growing, faintly laminated, chalcedonic column (Y in views C and D). (D) In addition to details enlarged in B and C, this view shows variously oriented growth-structures above the basal cryptalgalaminate and within the chalcedony lens of A. This random orientation indicates that the chalcedony either grew within an opening in the algal mat or wedged the mat apart by diagenetic growth into it from different directions. As the spheroidal unicells appear to have lived within, or at the rims of these siliceous growth structures at the time, the processes involved presumably took place close enough to the surface for light penetration and shortly after deposition of the cryptalgalaminate.
E,F. *Obruchevella* of probably two different species from limestone ∿150 m below top of Tindir Group, east-central Alaska (collected by Gary Kline, 1976). (E) Showing axial profile of coil with open loops, outer and inner diameters, and cross sections of coiling filament; (F) an exterior view of a smaller bent coil with appressed loops.

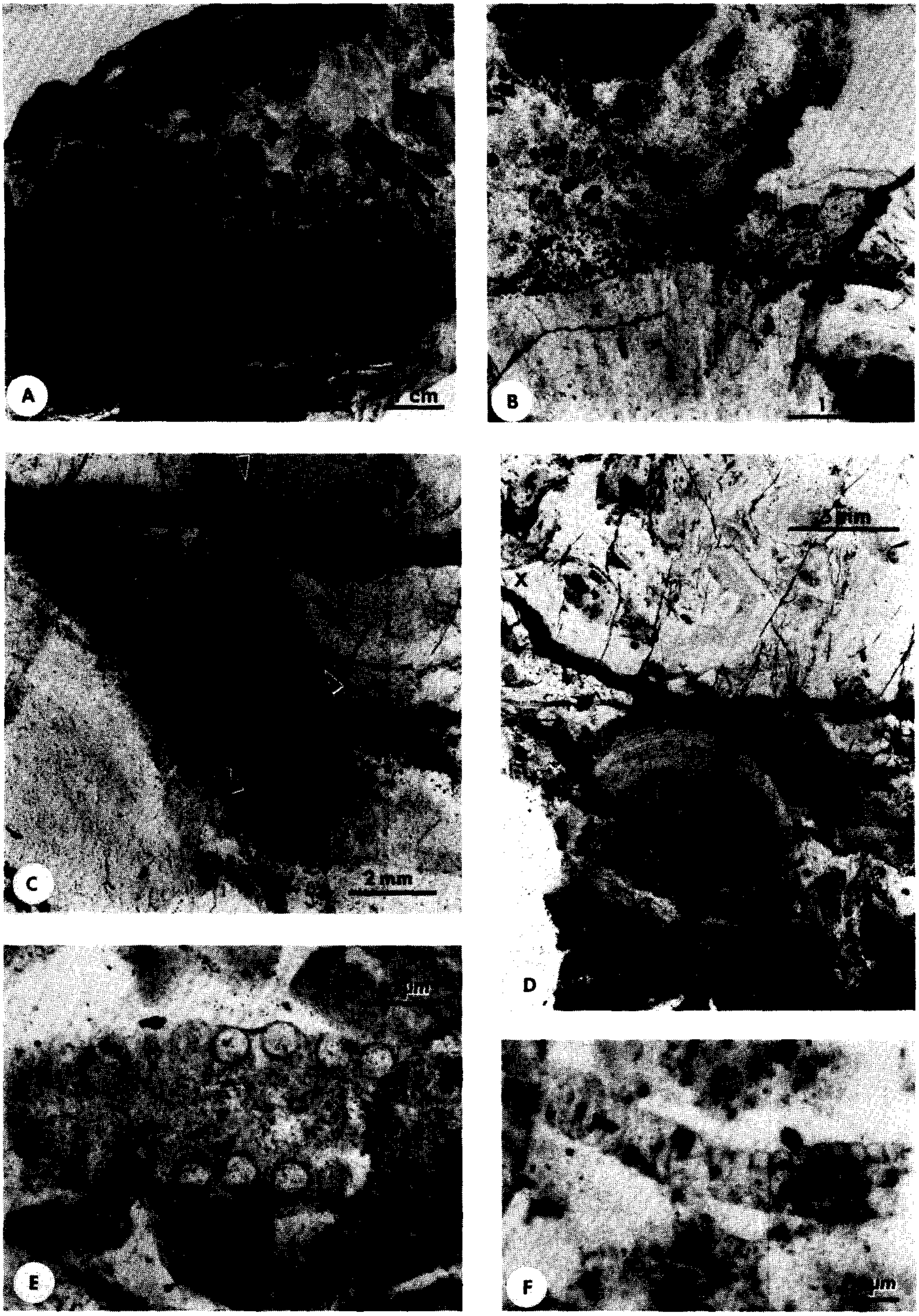

Fig. 4.

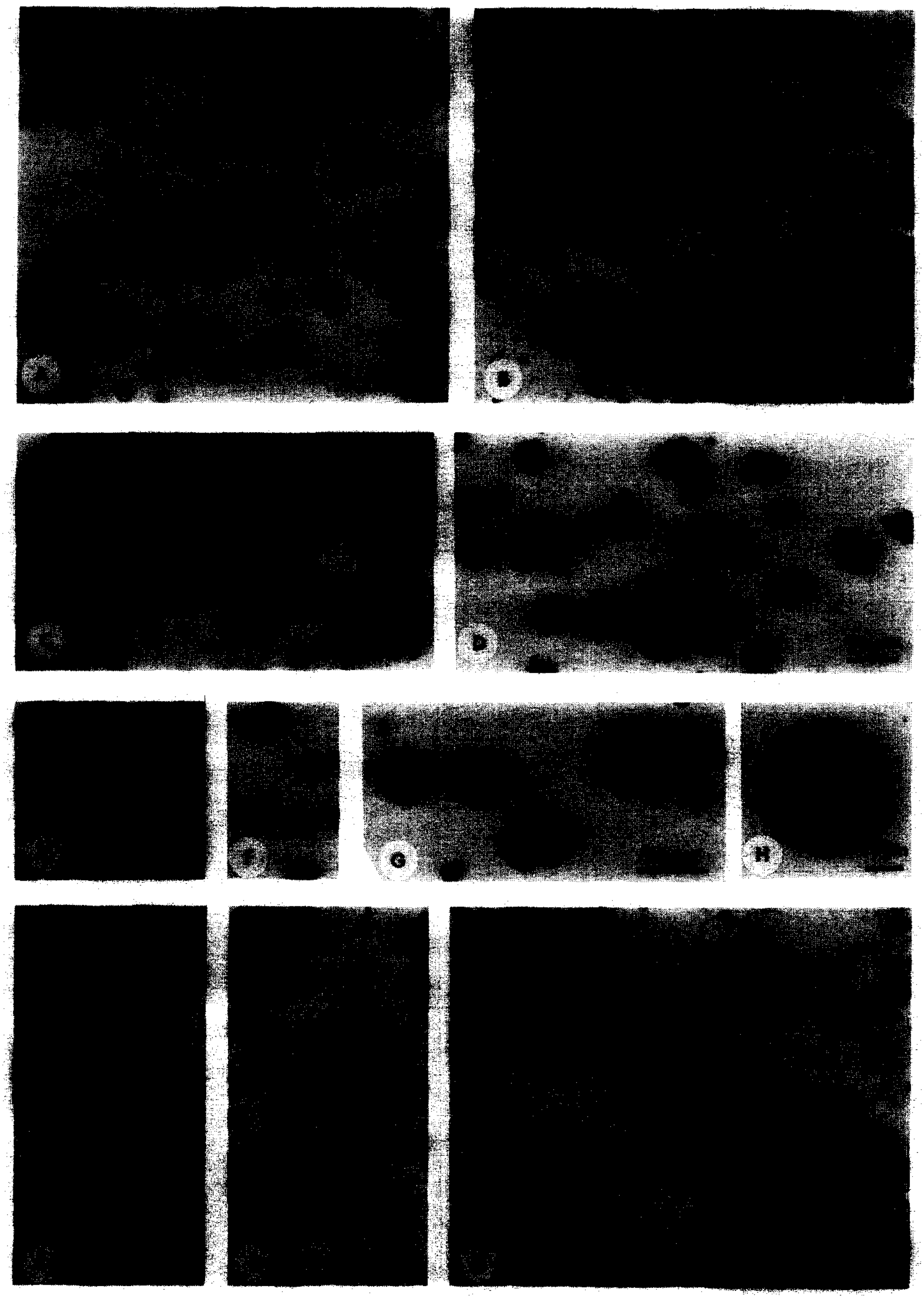

Fig. 5.

Ranging in diameter from 3.7 to 69.5 μm, these fossils are much too large to be bacteria and therefore are most probably blue-green algae and their endosporangia, plus perhaps more advanced eucaryotic algae as well, all requiring light in order to photosynthesize. It seems likely, therefore, that they lived near enough to the surface for light to penetrate and long enough for the translucent silica gel in which they were embedded to attain a local thickness of 5 to 6 cm or more. This would suggest an exposed or very shallowly inundated position immediately beneath the surface of a temporarily stable but actively growing algal mat — one in which pockets of gas and water were common as a result of algal photosynthesis and decay and provided space for diagenetic sedimentary growth. Given the presence of dissolved silica in the interstitial or supernatant waters, such a setting would be highly conducive to its precipitation as a silica gel, antecedent to the chalcedony in which the algal spheroids are now imbedded. The occurrence of living green and blue-green algae under similar conditions at depths of up to half a meter in modern translucent and diaphanous substrates is well documented (Cameron and Blank, 1966) and the growth of gelatinous silica domes within the sediment could be oriented in any direction, as we see in Figs.4A—D.

An important question concerns the relative age of these fossils. Could the chalcedonic chert and its contained nannofossils be much younger than the cryptalgalaminates that bound it above and below? Evidence of opposing growth directions such as shown in Figs.4B—D clearly establishes the post-sedimentational origin of the chert. It apparently formed in place within the former algal-mat material of the cryptalgalaminate (e.g., top and bottom of Fig.4A), either prying it apart or filling prior open spaces. We judge it, including its contained fossils, to have been a very early diagenetic feature.

Stromatolites

Conophyton sp. (Figs.3A—C)

Description. Erect, steeply conical, laminated, subcylindrical columns, 4—6 cm in diameter, with well-developed axial zones. In cross section, columns are circular to oval. Columns slightly bent from vertical but in no preferred

Fig.5. Nannofossils from Muraykhah Formation, Mashhad and Jabal Umm al 'Aisah areas.
A—C. Smaller spheroids from Mashhad area showing pairing (A), abundance and concentration along microlaminae that trend from upper left to lower right (B), and collapsed cellular contents making dark spots (C).
E. Ruptured sporangia of a modern pleurocapsalean cyanophyte (after Waterbury and Stanier, 1978) for comparison with D, F, and G.
D, F, G, H. Larger spheroids from Mashhad area, showing size variation and ruptured walls (D, F, G) and composite spheroid suggestive of ripe sporangium (H).
I—K. *Obruchevella* parva Reitlinger showing variation in size of filament and coil and openness of loops. A horizontal cross section of a coil is shown at the upper right of K, and a probably fortuitous axial rod in J may be a straight filament of another species.

orientation. Contiguous columns discrete, not connected by laminae continuous from one column to another.

The laminated structure consists of alternating thicker, light-colored laminae 1.1—2.0 mm thick and thinner dark laminae 0.9—1.5 mm thick (Fig.3A) that are interrupted by white calcitic clots. In thin section the dark laminae are seen to consist of alternating darker and lighter microlaminae. The darker members of these sets are lensoidal, have an average maximum thickness of 23 μm, and can rarely be traced for more than 80 μm. Lighter microlaminae are continuous and range from 16 to 40 μm thick.

Axial zone distinct, resembling the Type III crestal zone of Komar et al (1965, p.23); crestal laminae rounded, not sharply conical, and the thickest portions tend to be staggered along opposing sides of the central axis.

The sublenticular calcitic clots occur irregularly and mostly within the dark stromatolitic laminae. They also occur locally in interspaces between the stromatolites but not in the axial zone. Laterally within the columns, the long axes of these clots are oriented parallel to the stromatolitic laminae. Clots appear as partial secondary replacements of laminae and are composed of radially arranged calcite crystals with a commonly dolomitic interior.

Discussion. Only two partially silicified blocks containing *Conophyton* were available for study. The conical shape and well-developed axial zone are diagnostic of *Conophyton*, but additional material is needed for further taxonomic refinement and detailed comparisons with known forms. To judge from available material, and photographs of Soviet material sent to us by V.A. Komar and M.A. Semikhatov, the microstructure resembles the microstructural category "*Lenticularida*" of Komar (1976). *Conophyton miloradovici* Raaben (1964; also see Komar et al., 1965) possesses lensoidal clots, less than 1 mm in diameter, but the laminae surrounding the clots are relatively thin and regular (Raaben, 1969, plate 18). *C. garganicus* Korolyuk (see Komar et al., 1965) has a similarly laminated microstructure but the dark layers are continuous, as is well displayed by specimens from the Amelia Dolomite in Northern Territory, Australia (Cloud and Semikhatov, 1969). In addition, the axial zone of the Jubaylah *Conophyton* is similar to, though not identical with, that of *C. garganicus*. The peaks of the cones, however, and those of its individual conical laminae are definitely blunt as compared to the more tapered profile of *C. garganicus*.

The small calcitic clots are not a primary feature of our *Conophyton* or even crystalline replacements of primary features, for they are found also in the enclosing matrix and are unevenly distributed within the *Conophyton* (Figs.3A—C). They seem to represent either zones of secondary calcification or islands of nonsilicification in the generally silicified rock. In relative size and internal structure, these clots resemble cross sections of the problematical tubular carbonate structure *Nuia* described by Maslov from Ordovician rocks (Toomey and Klement, 1966).

No nannofossils have been found within the *Conophyton* or in its enclosing matrix.

Occurrence. In samples 93786 and 93788, Hadley's Station BFT-10 from limestone float of the Jubaylah Group, Jabal Umm al 'Aisah, northeastern Saudi Arabia.

Microbial fossils

In the following descriptions and discussions we use the traditional terms cyanophyte (Cyanophyta) and blue-green algae to refer to procaryotes that photosynthesize utilizing chlorophyll-*a* rather than the new and in some ways more logical term cyanobacteria (Cyanobacteriales) of Stanier (in Gibbons and Murray, 1978; see also Stanier and Cohen-Bazire, 1977, and Waterbury and Stanier, 1978). We do this because it would be impossible to follow the rules of bacteriological nomenclature in dealing with these microbial fossils. We can, however, treat them with a degree of consistency within the rules of botanical nomenclature applicable to blue-green algae without denying their procaryotic nature and bacterial affinities.

Genus *Obruchevella* Reitlinger 1948

Obruchevella parva Reitlinger 1959 (Figs.5I—K)

Description. Oscillatorialean cyanophytes consisting of springlike spirally coiled tubular filaments that are helically twisted around an open center. A complete helix is nearly circular in cross section, straight or slightly curved along its length. The coiled tube is circular in cross section, ~ 8.2 µm across, with feeble external wall. No cross-partitioning observed. Shape and dimensions of coil and tube show little change along the helix but vary from speciment to specimen, perhaps as a result of differences in preservation (e.g., Fig.5J). External diameter of helix from 19 to 38 µm (22 measured); internal diameter from 13.9 to 19.6 µm, averaging 16.2 µm (22 measured). Coiling loose, adjacent coils not touching. Length of a single coil along coiling axis averages 10.8 µm per 360° rotation.

Discussion. Obruchevella was first described, named, and assigned to the Foraminifera by Reitlinger (1948) based on specimens from the Lower Cambrian *Protolenus* zone in Yakutia, USSR. Later Reitlinger (1959, p.8) referred the genus to a group of "... organic remains of vague systematic position ..." but still later (Reitlinger, 1960, p.142) considered either a foraminiferal or an algal origin possible. Loeblich and Tappan (1964) listed *Obruchevella* with other problematica that have at one time or another been considered to be foraminifers. Luchinina (1975, p.11) compared *Obruchevella* to *Spirulina*, an oscillatoriacean blue-green alga, and grouped it with *Girvanella* and *Razumovskia* in a problematical family of fossil oscillatoraceans, the Girvanellaceae.

The Jubaylah *Obruchevella* are morphologically very similar to *O. parva* Reitlinger (1959), although with a greater inner coil-diameter, a wider range of outer coil-diameter, and a thinner filament wall. Their dimensions depart more widely from those of the other so-far-described species, as shown in Table I. *O. parva* Reitlinger is known from the Tinnovsk Suite of Yudomian age from the Aldan Shield, U.S.S.R. (Reitlinger, 1959, p.21; Dolnik and Vorontsova, 1974, p.48). *Obruchevella* larger than *O. parva* seem to be limited to Cambrian and Ordovician rocks in the U.S.S.R. and North America (Table I). A large *Obruchevella*, similar to the Cambrian and Ordovician forms, is also reported by Kline (1977) from calcareous strata ∿150 m below the top of the Tindir Group of eastern Alaska (Figs.4E,F) — and Kline's assignment of a Cambrian age to these rocks is consistent with the previously expressed view of Cloud et al. (1976) that beds of probable late Tindir age from the Washington Creek area of east-central Alaska are probably Cambrian, based on the presence in them of distinctive sponge spicules and a probable metazoan shell fragment.

Obruchevella cf *O. parva* from Jubaylah sediments is preserved in a partially silicified calcitic microbreccia (Fig.3E) as black, finely particulate material of undetermined nature. In one specimen (Fig.5J) a thin straight rodlike structure runs directly down the center of the coiled filament. As we do not see such a structure in other specimens it may be fortuitous. Perhaps it is

TABLE I

Characteristics and occurrence of known *Obruchevella*

CLASSIFICATION	EXTERNAL COIL DIAMETER	INSIDE COIL DIAMETER	FILAMENT DIAMETER	WALL THICKNESS	STRATIGRAPHY	LOCALITY
OBRUCHEVELLA PARVA REITLINGER (SIBERIAN FORM)	30-34μm	10μm	6.8-8.5μm	3.4μm	YUDOMIAN, TINOVSK SUITE	SIBERIA; LENA RIVER UPSTREAM FROM OLEKMINSK
OBRUCHEVELLA PARVA REITLINGER (ARABIAN FORM)	19-38μm	13-20μm	8.2μm	1μm (observed on one spec. only)	EDIACARIAN (?) JUBAYLAH GROUP	NORTHERN PART OF ARABIAN SHIELD
OBRUCHEVELLA DELICATA REITLINGER	36-49μm	18-24μm	12-18μm	1.7-3.4μm	LOWER CAMBRIAN, SINSK SUITE AND KUTORGINA BEDS	SIBERIA, SINEI AND BOTOMA RIVERS
OBRUCHEVELLA DELICATA VAR. *ELONGATA* REITLINGER	37μm	18μm	12-18μm	3.4μm	LOWER CAMBRIAN, KUTORGINA BEDS AND OLEKMINSK SUITE	SIBERIA, NOCHTUISK REGION, SINEI AND BOTOMA RIVERS
OBRUCHEVELLA spp. ? (ALASKAN FORMS)	5 specs. from 37μm to 252μm	2 specs. 32μm, 130μm	2 specs. 14μm - 43μm	7μm observed on one spec. only	LOWER CAMBRIAN, UPPERMOST PART OF TINDIR GROUP	EAST-CENTRAL ALASKA
OBRUCHEVELLA SIBIRICA REITLINGER	57-68μm	35-46μm	14-17μm	–	UPPER CAMBRIAN OR ORDOVICIAN	NORTHERN PART OF SIBERIAN PLATFORM
OBRUCHEVELLA SPIRALIS LEWIS	66-96μm (mean 85μm)	?	~22μm (internal diam 8-12μm)	4-6μm	LOWER AND MIDDLE ORDOVICIAN, PHILIPSBURG GROUP	QUEBEC, CANADA

another species of filamentous alga or bacterium — if so it is the only one of its kind we have seen in the Jubaylah material.

We agree with Luchinina (1975) and Voronova (1976) in comparing *Obruchevella* to coiled oscillatorialeans like *Spirulina*. We cannot determine, however, whether the Jubaylah nannofossils are preserved as sheaths or trichomes. No fine morphological details such as septae or tapered ends which could be interpreted as trichomes have been observed. Modern spiralled cyanophytes, such as *Spirulina* or *Arthrospira*, exhibit variability in coiling within each species (Ralph, 1975). *Obruchevella delicata* Reitlinger (1948, 1959, 1960) also exhibits variable coiling, which prompted Reitlinger to establish the variety *O. delicata* var. *elongata*. Caution must be exercised in the evaluation of the coiling habit. Understanding of variation within populations should precede taxonomic distinction. A mixture of coiling and noncoiling of tubes within the same specimen in Ordovician rocks, for instance, has been cause for confusion with *Girvanella* (Guilbault, 1975).

Except perhaps for the lone central filament in Fig.5I, no other nannofossils are known to be associated with the Jubaylah *Obruchevella*.

Occurrence. In BCL thin sections SR012(1—5) and C-540(2) from sample 93790, Hadley's Station BFT-10, limestone of Jubaylah Group, Jabal Umm al 'Aisah, northeastern Saudi Arabia. Occurs in matrix of siliceous carbonate microbreccia. Not found in samples with *Conophyton*.

Larger spheroids (Figs. 5D, F—H)

Description. Amber to brown spheroids 15.8—69.5 μm in diameter; averaging 39.6 μm (96 measured). Habit solitary. Generally circular in cross section, rarely oval. Surface texture varies from finely pitted to an irregular meshwork of ridges and pits. External envelopes not observed. These larger unicells, however, are commonly ruptured (Figs.5D, F, G), as if to release cell contents and, rarely, they are observed to contain small, colorless, sporelike spheroids 3.7—9.5 μm across, within the size range of the smaller forms described below (Fig.5H).

Discussion. These larger nannofossils are known only from the chert lenses at Mashhad and as poorly preserved HCl residues from Jabal Umm al 'Aisah. The composite, pluricellular, or sporangiate forms (containing small spheroids) observed are smaller (∿30 μm) than average (∿40 μm) and may not even belong to the same species. We judge, however, from the commonly ruptured state of empty cells that the latter contained sporelike cells before rupturing and that all variants of the larger unicells belong to the same species. Assuming they do represent a single species, their affinities remain uncertain. We know morphologically similar forms of both procaryotic and eucaryotic origin. Comparison of Fig.5E with Figs.5D, F, and G shows their similarity to a procaryotic pleutocapsalean. In all respects except size, in fact, they fit the definition of the Order Pleurocapsales as emended by Waterbury and Stanier (1978). A maximum diameter of ∿30 μm before multiple fission is indicated by Waterbury and Stanier, however. Contrariwise, our fossils, with maximal diameters up to 70 μm, are in the size range expectable of eucaryotic species, and similar composite, spore-bearing forms are known among vegetatively reproducing representatives of four phyla of eucaryotic algae and the fungi.

From evidence available, therefore, we cannot place our species even as to phylum, although it is most likely a eucaryote of some sort and perhaps a green alga. Among described fossils it is closest to *Favosophaeridium* of Timofeev (1966), in particular *F. favosum* Timofeev. Vidal (1976), however, in his revision of the genus excludes the pluricellular or sporangiate forms, referring such forms to the genus *Bavlinella* of Shepeleva (1962), which, among specimens so far described, includes a size range of only 15—24 μm and may well be a procaryote.

We can neither solve this riddle nor see how the adoption of an existing name or the coining a new one would do more than camoflauge our ignorance. A scientifically useful solution, if one is possible, can come only from a comprehensive analysis of similar forms based on research collections that are larger and more comprehensive than any now known to us.

Finally we note the similarity between the sporelike bodies or vegetative cells of Fig.5H and the smaller spheroids described below. We do not exclude the possibility that they are the same. But the smaller and larger spheroids form two distinct and largely separated size classes and we find it advisable to discuss them separately.

Occurrence. In BCL thin sections SR06 (1, 3, 4, 7, 18) from sample 116083 and SR09(2) from sample 116085, Hadley's Station JCT-2, lower Muraykhah Formation, Jubaylah Group, Mashhad area, northern Saudi Arabia.

Smaller spheroids (Figs.5A—C)

Description. Tiny, clear to light-yellowish or rarely amber spheroids; diameter 3.7—17.5 μm, averaging 8.2 μm (685 measured). Present singly or in groups of 2 to 28 cells. Pairs or dyads make up only ∿5% of cell population. Spheroids smoothly rounded to irregular and commonly overgrown with microcrystalline matter that produces polyhedral outlines and may bind them into irregularly arranged clusters. Walls less than 0.4 μm thick, consisting of a single layer as seen under the light microscope. Some spheres have small internal dark spots (Fig.5C). No envelopes, either single or multiple, were observed around individual cells or clusters.

Discussion. As a group these smaller spheroids exhibit morphological characteristics unlike that of other so far described nannofossils known to us. In size, shape and wall structure individual cells resemble *Huroniospora microreticulata* Barghoorn (Barghoorn and Tyler, 1965; Muir, 1976). However, the commonly loosely aggregated habit is more suggestive of *Sphaerophycus* Schopf (1968). But *Sphaerophycus* cells have a smaller size range, 2.1—3.6 μm, and occasionally are enclosed in an envelope. The presence or absence of an envelope is not critical in the characterization of ancient microbiotas;

but, where present, an envelope may provide useful supplementary data for the characterization of otherwise featureless spheres. For example, single or multiple envelopes around individual cells are characteristic of *Entophysalis*, whereas a common envelope around many cells is typical of *Aphanocapsa*. Nevertheless, the microcrystalline encrustations on these small spheroids and aggregates of them obscure their primary characteristics and would make us reluctant to propose a new and possibly superfluous name for them even if we were otherwise inclined to do so.

These tiny nannofossils are known so far only from thin sections of chert lenses. They are largly segregated within the rock from the larger Jubaylah nannofossils described above (Figs.4C, D). Were they not so segregated we would be inclined to suggest that they were the freshly ejected spores or vegetative cells of the sporulate or pluricellular phase of the larger unicells described above. Unless it represents some kind of seasonal and local phenomenon, however, this segregation suggests to us a taxonomic distinction.

Occurrence. In BCL thin sections SR06(1, 3, 4, 8, 18) from sample 116083 and thin section SR09(2) from sample 116085, Hadley's Station JCT-2, lower part of the Muraykhah Formation, Jubaylah Group, Mashhad area, northern Saudi Arabia.

CONCLUSIONS

(1) Fossils obtained imply that the stratigraphic position of the Jubaylah Group is very close to the boundary of or within the transition from Phanerozoic to pre-Phanerozoic, with perhaps a slightly greater probability of an earliest Phanerozoic (Ediacarian) age considering the apparent range of *Obruchevella* and the radiometric numbers.

(2) The strata of the Jubaylah Group, therefore, may represent a very critical and inadequately known interval in Earth history, in terms both of biological evolution and of their bearing on the initiation of large crustal and perhaps plate tectonic motions represented by the Najd fault system.

(3) *Obruchevella parva* Reitlinger may imply an Ediacarian age and the larger species of *Obruchevella* a Cambrian or younger age.

(4) The Jubaylah historical episode deserves more extensive study.

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