PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Triassic Stratigraphy of the Southern North Sea Basin

M. E. Geiger and C. A. Hopping

Phil. Trans. R. Soc. Lond. B 1968 **254**, 1-36
doi: 10.1098/rstb.1968.0012

TRIASSIC STRATIGRAPHY OF THE SOUTHERN NORTH SEA BASIN

By M. E. GEIGER

Shell U.K. Exploration and Production Limited, London

AND C. A. HOPPING

Bataafse Internationale Petroleum Maatschappij N.V., The Hague

(*Contribution to a Discussion Meeting on* 29 *June* 1967—
Communicated by K. C. Dunham, F.R.S.—Received 2 *August* 1967—
Revised 9 *October* 1967)

[Plates 1 to 4]

CONTENTS

Intensive drilling activity, particularly in the United Kingdom part of the North Sea, has greatly increased our knowledge of the subsurface geology of north-west Europe. The Triassic, perhaps more than any other system, has provided results of a special interest.

In this paper a stratigraphical study of the Triassic System of the southern North Sea basin has been undertaken by lithological and palynological analysis. The type Germanic Triassic and the dated Alpine Triassic are briefly reviewed. The facies development of the Germanic Triassic is traced by means of subsurface data from north-west Germany and the northern Netherlands into the North Sea. Further studies of the onshore Triassic of England from subsurface well data and surface outcrop sections are discussed.

The results, particularly those from wells in the North Sea, provide a lead to the understanding of the position of the English Triassic of Keuper and Bunter within the framework of the Germanic Triassic.

1. Introduction

The discovery in 1959 of a large accumulation of natural gas in the northern Netherlands triggered one of the great petroleum exploration ventures. This venture led to an evaluation of the geologically unknown area of the North Sea, where since 1962 geologists from many companies have participated in a vigorous exploration effort, primarily in the fields of geophysics and regional geology.

The sequel to this initial phase of exploration work has been the recent and continuing intensive drilling activity in the United Kingdom part of the North Sea. Many of the wells drilled have penetrated rocks of Palaeozoic, Mesozoic and Cenozoic age. The information which has accrued, particularly from the Triassic System, has yielded results of especial interest in that the type Germanic Triassic was found to be present in the southern North Sea basin, thus providing an important link between this facies development and that of the English Triassic.

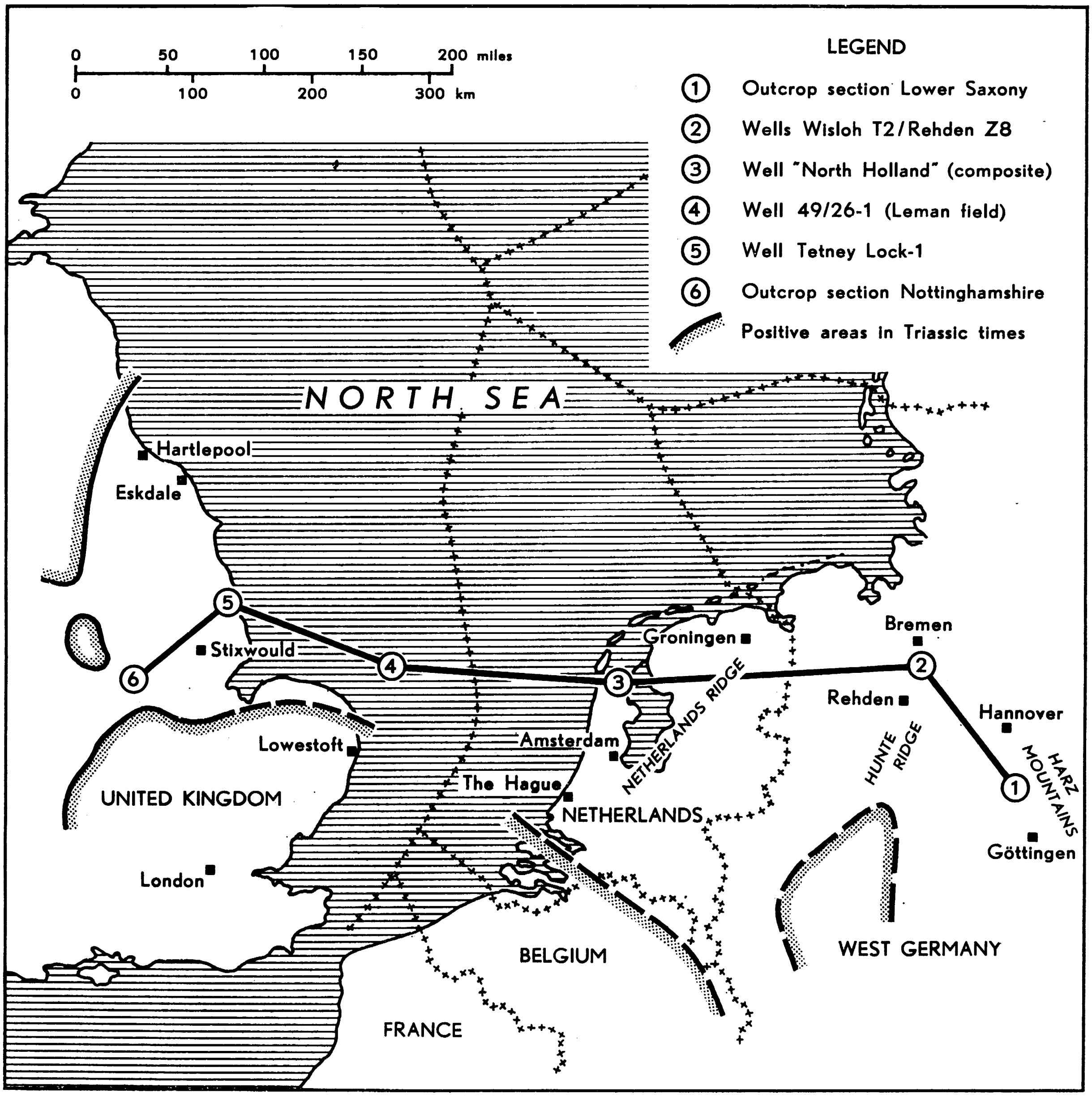


FIGURE 1. Situation map.

The present paper discusses results that have been obtained from routine operational work, which was not particularly concentrated on the Triassic System. The available rock material consists mainly of cutting samples which have been lithologically and palynologically examined while the wells were being drilled, in order to provide day-to-day stratigraphical control. On completion of a well and after a careful study of the wireline

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

logs, the recorded lithological column is corrected to the log information. In this respect the gamma ray–sonic curves, and to a lesser degree the resistivity devices, were found to be the most suitable. The distribution of the palynomorphs, which is particularly affected by the quality of the cuttings, is checked by sidewall samples wherever possible. Finally, an evaluation is made of the nature, depositional environment and age of the rocks penetrated.

The scope of this paper can be seen from the situation map shown in figure 1. The sections discussed in the following chapter include two outcrop areas representing the type Germanic Triassic in Lower Saxony and the English Triassic in Nottinghamshire as well as four well sections linking the two extremes. Finally, a stratigraphic correlation, both lithological and palynological, of these six sections is presented. It must be stressed that this correlation concentrates on the major units and only touches on the problems of local correlation from a regional point of view.

The results presented here are intended as a base for discussion and future work. Notwithstanding the limitations which are of necessity imposed upon operational petroleum geology, it is felt that the methods applied give a lead which should be further developed by detailed studies of additional sample material especially from onshore wells and surface sections in the United Kingdom. Such a study would undoubtedly yield much valuable information and ultimately lead to a generally acceptable subdivision and terminology of this most enigmatic of geological systems, the Triassic.

2. Stratigraphy

Each of the above-mentioned sections is treated separately. A detailed discussion is given of the lithology and palynology of the type Triassic or Germanic facies as studied from sampled outcrop sections in the region of Lower Saxony, together with data compiled from literature. These results are correlated with studies of the dated Triassic in Alpine facies of central and southern Europe (figure 3). The palynological part of this standard section is of particular importance in that the ranges of the selected palynomorphs established from investigation of collected field sample material and from literature are applied to the other sections examined and discussed.

The subsurface development of the Germanic Triassic in the type area is traced to the following three wells; Gewerkschaft Brigitta well Wisloh T2 in north-west Germany (figure 4), a composite of N.A.M. wells from North Holland (figure 5) and the Shell/Esso Leman Field well 49/26–1 in the North Sea (figure 6). The latter is presented in some detail in view of its importance in showing the westernmost extension of the Germanic Triassic and yet containing characteristics of the English Triassic.

The English Triassic has been studied in the subsurface from cutting samples and logs in the B.P. well Tetney Lock-1 in east Lincolnshire (figure 7) and from sampled outcrop sections in the Nottinghamshire area together with data compiled from literature (figure 8).

It must be stressed that the stratigraphical terminology used in this paper is the one which is commonly accepted in the areas concerned. Although it is realized that some of these terms have unfortunately acquired a time connotation, they are used here in a strictly rock-stratigraphical sense.

The Rhaetic deserves special attention. Rock-stratigraphically, it marks the start of the

Jurassic sedimentary cycle after a period of unrest and erosion, the early Kimmeric phase. Biostratigraphical criteria from the Tethys, however, favour the inclusion of the Rhaetian within the Triassic as the youngest stage of this system. In areas where an obvious truncation can be observed, as in the Netherlands and in the United Kingdom, the former attitude generally prevails. In those areas where a gradual transition to marine conditions can be seen as in central Germany, the latter viewpoint is adopted. For the rock-stratigraphical part of this paper the interval is excluded from the Triassic but its lithological development is, nevertheless, recorded for palaeontological reference.

It has been stated many times that in north-west Europe in general and in the United Kingdom in particular, rocks of the Triassic System are non-fossiliferous. These statements are all the more difficult to comprehend when it is realized that for several years published work has been available of the results of palynological studies undertaken in Austria, Switzerland, Germany, the Netherlands and the United Kingdom. These studies have shown that both the Germanic Triassic and the Alpine Triassic contain an abundance of microfossils in the form of acid-resistant palynomorphs. These microfossil assemblages are not only useful in supplying additional correlation data but can also be used to tie in the Germanic Triassic with the ammonite zones and the stages of the Alpine Triassic.

Thus palynology has been the time-stratigraphical method used to date the Triassic rocks of the North Sea area. The purpose of this paper is primarily stratigraphical with the palynological data serving as an applied method rather than being a derived result. However, it is necessary to discuss the palynological criteria in some detail.

From the total palynomorph assemblages studied from the late Permian, through the Triassic and into the early Jurassic the following twenty-five species have been selected as palynomorph marker types or 'guide fossils' and are discussed in §4.

1. *Perisaccus granulatus* Klaus
2. *Lueckisporites virkkiae* Potonié & Klaus
3. *Endosporites papillatus* Jansonius
4. *Gardenasporites heisseli* Klaus
5. *Taeniaesporites noviaulensis* Leschik
6. *Protohaploxypinus jacobii* (Jansonius) Hart
7. *Spinotriletes echinoides* Mädler
8. *Illinites kosankei* Klaus
9. *Aequitriradites minor* Mädler
10. *Microcachryidites sittleri* Klaus
11. *Striatoabieites balmei* Klaus
12. *Illinites chitonoides* Klaus
13. *Minutosaccus potoniei* Mädler
14. *Monosulcites perforatus* Mädler
15. *Aratrisporites scabratus* Klaus
16. *Camerosporites secatus* Leschik
17. *Enzonalasporites vigens* Leschik
18. *Conbaculatisporites longdonensis* Clarke
19. *Ovalipollis ovalis* Krutzsch
20. *Ricciisporites tuberculatus* Lundblad
21. *Zebrasporites interscriptus* (Thiergart) Klaus
22. *Perinosporites thuringiacus* Schulz
23. *Circulina meyeriana* Klaus
24. *Heliosporites altmarkensis* Schulz
25. *Classopollis torosus* (Reissinger) Balme

Only the qualitative distribution of these species has been considered in this paper. However, other Triassic palynomorphs, e.g. *Lueckisporites triassicus* Clarke, *Falcisporites zapfei* (Potonié & Klaus) Leschik, *Cingulizonates rhaeticus* (Reinhardt) Schulz etc., are also mentioned in the text but discussion of these species is restricted solely to their stratigraphical significance as additional evidence to that provided by the above-mentioned twenty-five 'guide fossils'.

(a) *Germany: Outcrop Section, Lower Saxony*
(Table 1, figures 1 to 3)

The type Triassic of central Germany disappears underneath the north German Plain south of Hannover. The composite lithological column summarized in figure 3 represents the outcrop sections lying to the west of the Harz Mountains and north of Göttingen. This column has been adapted from literature with the help of field notes of Gewerkschaft Brigitta and personal observations. Similarly, the distribution of the selected palynomorphs shown is based on their ranges recorded in literature and from the results of an investigation of samples collected in the field. Thus figure 3 may be regarded as a composite palynological range chart combining data obtained from the type Germanic Triassic and the dated Alpine Triassic.

A map of the above-mentioned area of Lower Saxony is shown in figure 2 indicating the locations and names of the intervals studied and the samples taken for palynological examination. It further shows the various colours of the palynomorphs observed, which is an indication of the degree of organic metamorphism of the sediments concerned (Gutjahr 1966). From these results it can be seen that the variation of metamorphism exhibited is not stratigraphical, i.e. due to the depth of burial of the strata, but is rather a late phenomenon linked to a late Kimmeric intrusion underneath the Hunte Ridge (south-eastern extension of the temperature aureole of the Brahmscher Massif according to Teichmüller 1964).

A schematic outline of the type Germanic Triassic is given in table 1. The following discussion, arranged under Group headings, concentrates on the general stratigraphical aspect of the main subdivisions of approximate formation rank, although most of these units could be further split into members or even individual beds.

Table 1. The major rock-stratigraphic units of the Germanic Triassic

Group	Formations/Members
Upper Keuper (Rhät)	Glimmersandstein Rhätschiefer Hauptsandstein & Pyritsandstein
Middle Keuper	Steinmergel Rote Wand Schilfsandstein Gipskeuper
Lower Keuper	Grenzdolomit Lettenkohlensandstein s.l.
Upper Muschelkalk	Ceratitenschichten (Tonplatten) Trochitenkalk
Middle Muschelkalk	Anhydrit Gruppe
Lower Muschelkalk	Wellenkalk
Upper Buntsandstein	Röt Folge with Röt Salinar
Middle Buntsandstein	Solling Folge Hardegsen Folge Detfurth Folge Volpriehausen Folge
Lower Buntsandstein	Obere Gruppe (Rogenstein) Untere Gruppe Bröckelschiefer

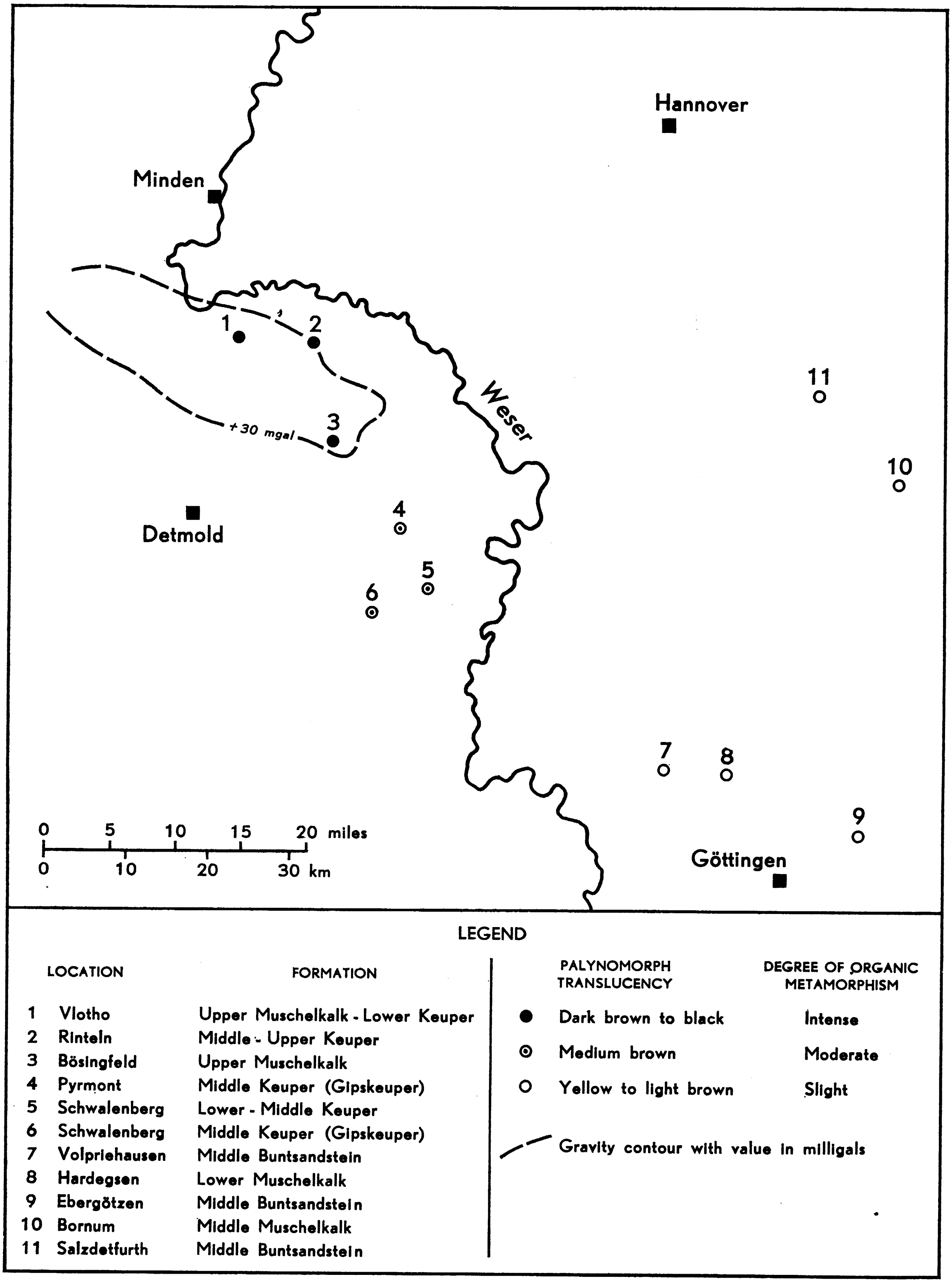


FIGURE 2. Degree of organic metamorphism of Triassic sediments in Lower Saxony.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

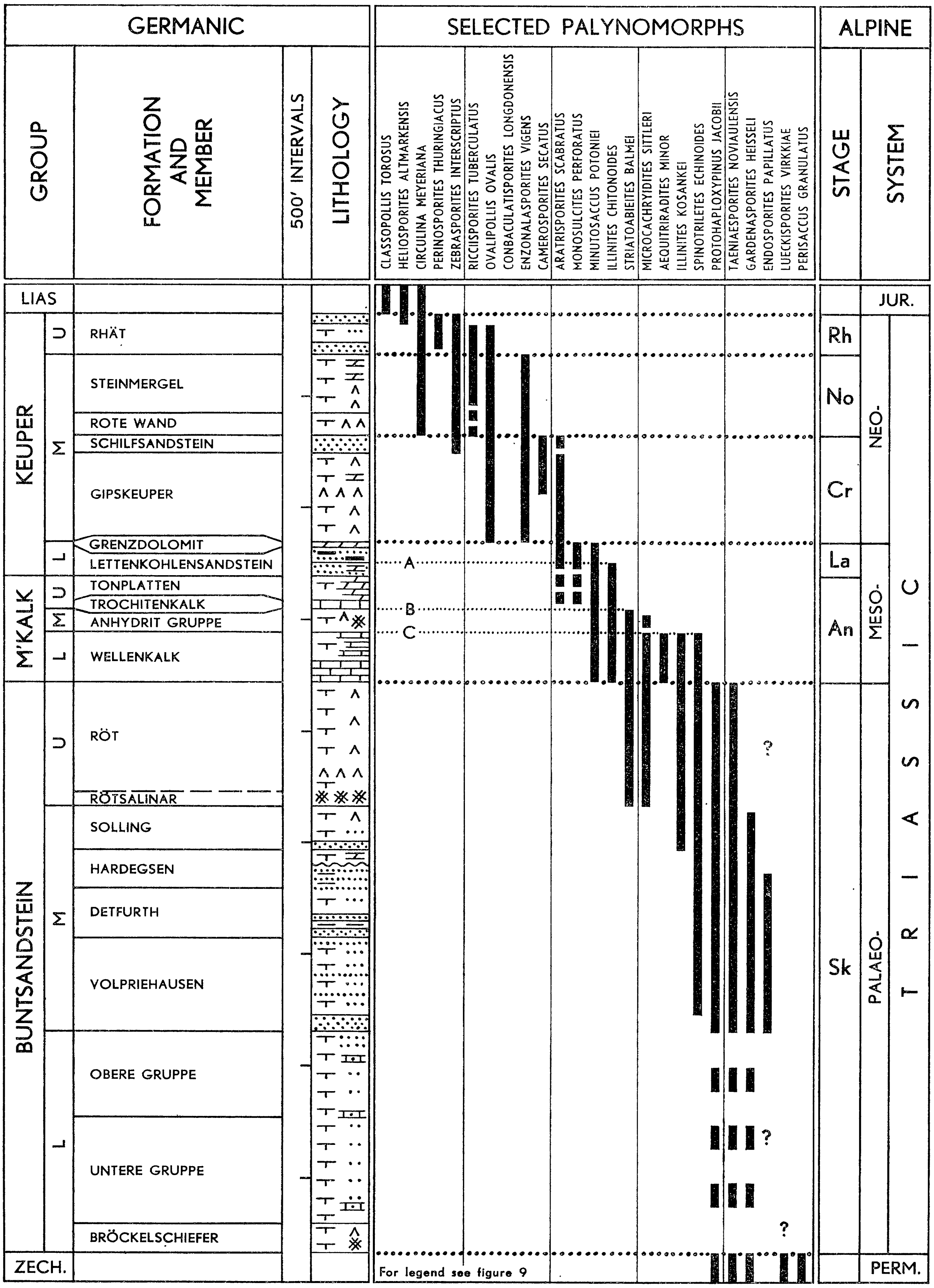


FIGURE 3. Outcrop section Lower Saxony—Germany.

(i) Lower Buntsandstein

The sequence starts with dark red silty mudstones containing abundant dolomite and anhydrite in the form of nodules and streaks and often displaying a brecciated appearance, the *Bröckelschiefer*. This interval represents the transition from the underlying Zechstein and its stratigraphic position is arguable (Boigk 1959; Trusheim 1963). Paleogeographically there are affinities with the uppermost Zechstein cycle IV but lithological considerations and especially past practice favour its retention in the Lower Buntsandstein.

The next unit or *Untere Gruppe* consists of a monotonous succession of red brown silty mudstones, slightly calcareous and anhydritic, with subordinate beds of grey to light red dolomitic sandstones, often ripple bedded and rarely oolitic.

The last unit or *Oberè Gruppe* is characterized by an increase in thin-bedded light-coloured sandstones with a calcareous matrix and abundant red brown calcareous ooliths, forming the so-called Rogenstein layers.

Early Triassic palynomorph assemblages have been reported from the north alpine Werfener Schichten by Klaus (1965), and from sediments of Skythian age in North America by Jansonius (1962). However, there are as yet no records of microfloras from the Lower Buntsandstein in north-west Europe.

(ii) *Middle Buntsandstein*

The Middle Buntsandstein consists of four consecutive sequences (Folgen), each with a prominent sandstone member at the base followed by an alternation of mudstones and fine sandstones.

The first two sandstone members, those of the *Volpriehausen* and the *Detfurth*, are very similar. They consist of light red to purple friable quartzsand, often cross-bedded, with alternating well sorted laminae of fine and coarse commonly frosted grains. Between these thick-bedded clean sands thinner beds of micaceous sandstone and layers of clay are found.

The third sandstone member, that of the *Hardegsen*, is a more sandy development of the mudstone–sandstone alternation with a few prominent sandstone banks.

The last sandstone member, that of the *Solling*, is separated from the underlying succession by a disconformity which is indicated, apart from an erosional hiatus, by a weathered zone and soil formation. The Solling Sandstones are light coloured, slightly dolomitic and anhydritic with commonly a high mica content.

The majority of German authors are in agreement that these sequences represent depositional cycles but the interpretation of the sandstone members and their position with respect to the cycle breaks is not yet clear (Boigk 1959; Wolburg 1961; Herrmann 1962). Several disconformities have been observed but one of them, the H (Hardegsen) disconformity, appears to be of regional importance and indeed is taken by Trusheim (1963) as the base of the Upper Buntsandstein, thus incorporating the Solling sequence within the Upper Buntsandstein.

Schulz (1964) has reported palynomorphs from Middle Buntsandstein samples from two wells in Germany. He recorded the occurrence of *Verrucosisporites morulae* Klaus, *?Nuskoisporites dulhuntyi* Potonié & Klaus, *Platysaccus leschiki* Hart and *Lueckisporites cf. noviaulensis* and described several new species like *Punctatisporites triassicus* Schulz, *Cycloverrutriletes presselensis* Schulz and *Lundbladispora nejburgii* Schulz.

Samples recently collected at the type localities of the various formations of the Middle Buntsandstein have yielded an abundance of well preserved palynomorphs. The overall impression of these assemblages is of a Permian flora, lacking however both the marker species and the predominance of striate bisaccates. Samples from the mudstone–sandstone alternation of the type Volpriehausen and from intercalated shales of the Volpriehausen, Detfurth and lowermost Hardegsen units at Salzdetfurth contain *Falcisporites zapfei* (Pontonié & Klaus) Leschik, *Klausipollenites schaubergeri* (Potonie & Klaus) Jansonius, *Protohaploxypinus jacobii*, *Taeniaesporites noviaulensis* and *Nuskoisporites dulhuntyi*, which are known to range from late Permian to early Triassic. These samples also contain *Endosporites papillatus*, which has been reported from early Triassic rocks in Canada (Jansonius 1962). Shales from the Solling sequence on the other hand yielded a rather higher percentage of striate bisaccates, especially *Taeniaesporites noviaulensis* together with *Verrucosisporites morulae*. In addition the following species also known from the Upper Buntsandstein and the Lower Muschelkalk are present: *Illinites kosankei*, *Spinotriletes echinoides*, *Reticulatisporites bunteri* Mädler and species of *Sulcatisporites*, *Inflatosaccus* and *Cyclotriletes*. *Endosporites papillatus*, however, has not been observed.

Thus there is also good palynological evidence for a break between the Solling sequence and the rest of the Middle Buntsandstein as discussed above.

(iii) *Upper Buntsandstein*

The boundary between the Middle and the Upper Buntsandstein has been drawn conventionally at the base of the evaporites or *Röt Salinar*. However, in the outcrop the salt is often dissolved and the underlying mudstones of the Solling sequence show the typical Röt aspect of mottled brick-red and green-grey colours and an increased anhydrite content.

Mädler (1964*a*), Klaus (1964, 1965) and Reinhardt & Schmitz (1965) have given excellent descriptions of the Upper Buntsandstein palynomorph assemblages. Of particular interest are the species *Protohaploxypinus jacobii* and *Taeniaesporites noviaulensis* persisting from the early Triassic with *Striatoabieites balmei*, *Microcachryidites sittleri* and *Illinites kosankei* which are also known from the Lower and Middle Muschelkalk.

The Buntsandstein of the type Germanic Triassic has been dated as Skythian on faunal evidence. The palynomorph assemblages of the Middle and Upper Buntsandstein compare closely with those reported from the Alpine early Triassic (Klaus 1965). The micro-floral boundary between the Paleo- and Meso-Triassic may not be precisely coincident with that of the established faunal boundary but lies probably within the older part of the Anisian.

(iv) *Lower Muschelkalk*

The most characteristic development of the Lower Muschelkalk is a grey argillaceous limestone, the *Wellenkalk*, which derives its name from the wavy appearance of its bedding planes. At the base it is often dolomitic and towards the top it becomes more marly.

Mädler (1964*a*) has given a detailed account of the palynomorphs found in the Lower Muschelkalk. The following selected species are considered to be representative: *Illinites chitonoides*, *Illinites kosankei*, *Striatoabieites balmei*, *Microcachryidites sittleri* and *Aequitriradites minor*. *A. minor* appears to be restricted to this interval and its top occurrence marks boundary ‘C’ indicated in figure 3.

Possibly the most interesting facet of the microfloral assemblages of the Lower Muschelkalk is the rapid incoming of a high percentage of microplanktonic organisms, mainly species of *Microhystridium*, *Tasmanites*, *Cymatiosphaera* and especially *Veryhachium*, characteristic of an open marine environment.

(v) *Middle Muschelkalk*

The *Anhydrite Gruppe* consists mainly of grey dolomitic mudstones with anhydrite and salt layers which, however, are rarely found in the outcrop. It often contains cavernous dolomite caused by the leaching of the original gypsum or salt content (Rauchwacke).

Klaus (1964, 1965) has reported the following palynomorphs from the Middle Muschelkalk: *Illinites chitonoides*, *Jugasporites renalis* Klaus, *Alisporites progrediens* Klaus, *Sulcosaccispora minuta* Klaus, *Tsugaepollenites oriens* Klaus and species of *Triadispora* and *Chordasporites*.

Shale samples from this interval collected at Bornum near the Göttingen–Hannover autobahn contained among others: *Microcachryidites sittleri*, *Illinites chitonoides*, *Minutosaccus potoniei*, *Ellipsovelatisporites* spp., *Triadispora* spp., *Tsugaepollenites oriens* and *Striatoabieites balmei*. The top occurrence of the latter marks boundary 'B' indicated in figure 3. A further point of interest is the absence of microplankton, suggesting a return to a more restricted saline environment.

These Middle Muschelkalk microfloras show close affinities to those described from the Lower Muschelkalk. The Upper Muschelkalk assemblages on the other hand are distinctly different but are in turn similar to the ones found in the Lower Keuper. This floral break is, however, not matched by the faunal boundary between the Anisian and the Ladinian stages which is placed at the contact Upper Muschelkalk–Lower Keuper.

(vi) *Upper Muschelkalk*

The base of the upper Muschelkalk is made up of massive crinoidal limestones, the *Trochitenkalk*. The remainder of the sequence, the *Ceratitenschichten*, consists of alternating thin limestones and marl beds, the so-called Tonplatten. These beds are particularly rich in pelecypods, hence the name Muschelkalk.

As stated above the microflora of the Upper Muschelkalk is closely comparable to the overlying Lower Keuper assemblages and will be discussed fully in the following subsection.

Samples collected from the Upper Muschelkalk again contain an abundance of microplanktonic organisms, indicating a second period of open marine conditions.

(vii) *Lower Keuper*

The bulk of the Lower or Kohlenkeuper consists of light coloured micaceous and slightly dolomitic sandstones with coaly films and particles, the *Lettenkohlensandstein*. There are also some prominent sandy dolomite beds especially at the top of the unit, i.e. the *Grenzdolomit*. Mädler (1964*a*) has quoted the following species from the Lower Keuper: *Minutosaccus potoniei*, *Monosulcites perforatus*, *Illinites chitonoides* and *Aratrisporites saturni*.

A similar assemblage was found in samples collected at Vlotho and Schwalenberg. Of particular interest is the absence of typical Neo-Triassic markers, e.g. *Ovalipollis ovalis*, *Enzonalasporites vigens*, *Patinasporites iustus* Klaus, *Taeniaesporites kraeuseli* Leschik and

Camerosporites secatus. The top occurrence of *Illinites chitonoides* marks boundary 'A' indicated in figure 3. It has not been observed in sediments younger than the 'Anoplophora-Sandstein', i.e. the top of the lower subdivision within the Lettenkohlensandstein. No microplankton has been found in the Lower Keuper.

The fact, already mentioned above, that many palynomorphs which make their first appearance in the Upper Muschelkalk occur in abundance in the Lower Keuper lends strong palynological support to the inclusion of the Lower Keuper in the Meso-Triassic.

(viii) *Middle Keuper*

In the lower part of the Middle Keuper variegated mudstones with gypsiferous and anhydritic nodules dominate. This *Gipskeuper* has been further subdivided on minor lithological variations. There are also several dolomitic marker horizons present which are useful for local correlation.

The *Schilfsandstein* is a thick-bedded argillaceous and micaceous sandstone which is locally rich in plant impressions.

The following unit of predominantly dark red gypsiferous mudstones, the *Rote Wand*, is very similar to the Gipskeuper. It also grades into the overlying variegated part of the Steinmergel.

The *Steinmergel* proper consists of thin-bedded green-grey calcareous and slightly anhydritic mudstones which are often very hard.

The Middle Keuper is of Carnian and Norian age and together with the Upper Keuper or Rhät comprises the Neo-Triassic. The palynomorph assemblages of this period have been competently described and documented by Leschik (1955), Klaus (1960, 1964), Schulz (1962), Reinhardt (1961, 1964*a*) and Mädler (1964*b*).

An interesting and important aspect of the microfloras of the Middle Keuper lies in the palynological differentiation of the Carnian and Norian stages. Klaus (1960) has discussed the stratigraphical distribution of the genera and species of the subturma *Circumpolles* within the Neo-Triassic. This subturma he subdivided into the infraturmae *Singulipollenites* and *Tetradopollenites*. The infraturma *Singulipollenites* with the genera *Duplicisporites*, *Praecirculina*, *Paracirculina* and *Discisporites* originates in the Carnian. The infraturma *Tetradopollenites* with genera *Circulina* originating in the Norian and *Classopollis* in the Rhaetian–Early Jurassic is being considered as post-Carnian.

Leschik (1955) and Mädler (1964*b*) have described *Camerosporites secatus* from the Schilfsandstein. This species has also been found in samples collected from the underlying Gipskeuper but not as yet in the overlying Rote Wand or Steinmergel which contain *Circulina meyeriana*. This latter species is not known from the Schilfsandstein. Klaus (1960) in his detailed account of the Carnian microfloras from the Austrian Alps does not metion *C. secatus*. However, the sediments examined are most probably an older part of the Carnian stage, as *C. secatus* apparently has a rather short range but is otherwise fairly widely known. Thus in operational palynology the top occurrence of *C. secatus* marks the boundary between the Carnian and the Norian stages.

The Norian may be readily distinguished from the overlying Rhaetian by the presence of *Enzonalasporites vigens*, *Conbaculatisporites longdonensis* and *Taeniaesporites kraeuseli* in addition to the absence of the typical Rhaetian markers.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

(ix) *Upper Keuper (Rhät)*

The Upper Keuper comprises a lower sandstone with a pyritic basal member and an upper mica-rich sandstone separated by dark grey shales, the Rhätschiefer. The German Upper Keuper has been equated with the English Rhaetic, the English Upper Keuper being thus part of the German Middle Keuper.

The Rhaetian is the youngest stage of the Triassic. It can be distinguished from the overlying Jurassic strata by the presence of *Ovalipollis ovalis*, *Perinosporites thuringiacus*, *Zebrasporites interscriptus*, *Ricciisporites tuberculatus*, *Rhaetipollis germanicus* Schulz, *Limbosporites lundbladii* Nilsson, *Cingulizonates rhaeticus* (Reinhardt) Schulz and by the absence of *Classopollis torosus* and *Heliosporites altmarkensis*. This microfloral boundary probably lies within the younger part of the Rhaetian as defined by faunal evidence.

(*b*) *Germany: Wells Wisloh T2/Rehden Z8*
(Figures 1 and 4)

The development of the north-west German Triassic at depth is represented by the two wells Wisloh T2 for the upper part of the sequence down to the Middle Buntsandstein and Rehden Z8 for the Lower Buntsandstein (after Boigk 1959). These wells are situated some 20 and 60 km south of Bremen (figure 1).

The following lithological and palynological discussion is restricted to variations of the development found in the outcrop. In addition the log characteristics of some of the members and of the more prominent marker-beds are pointed out. Boigk (1959) has shown that most of the fine subdivisions of the Buntsandstein established in the field can be recognized in wells by detailed log analysis. The palynological results from this and the following three well sections have been obtained mainly from the examination of drill cuttings. Thus it must be remembered that the most reliable boundaries are those which are established on extinction points of the species, i.e. 'top occurrences'. The points of origin, i.e. 'base occurrences' and the overall ranges of species are less reliable but by no means insignificant.

(i) *Buntsandstein*

Lithologically the three subdivisions of the Buntsandstein compare remarkably well with the outcrop sections. In the upper unit of the Lower Buntsandstein there is a marked increase in the number of Rogenstein layers as indicated by the sharp deflexions on the log. The Middle Buntsandstein can again be subdivided into four sequences on the character of the individual sand members. The most striking difference is the massive development of the Röt evaporites which shows up clearly on both logs.

The palynomorph assemblages of the Buntsandstein in Wisloh T2 are extremely poor and only a few diagnostic markers were observed.

(ii) *Muschelkalk*

The Lower and the Upper Muschelkalk are still predominantly calcareous but the Middle Muschelkalk comprises a thick salt member.

The microfloras obtained from the Muschelkalk are abundant and varied. Of particular interest is the distribution of the microplankton, e.g. *Veryhachium reductum*, which makes its

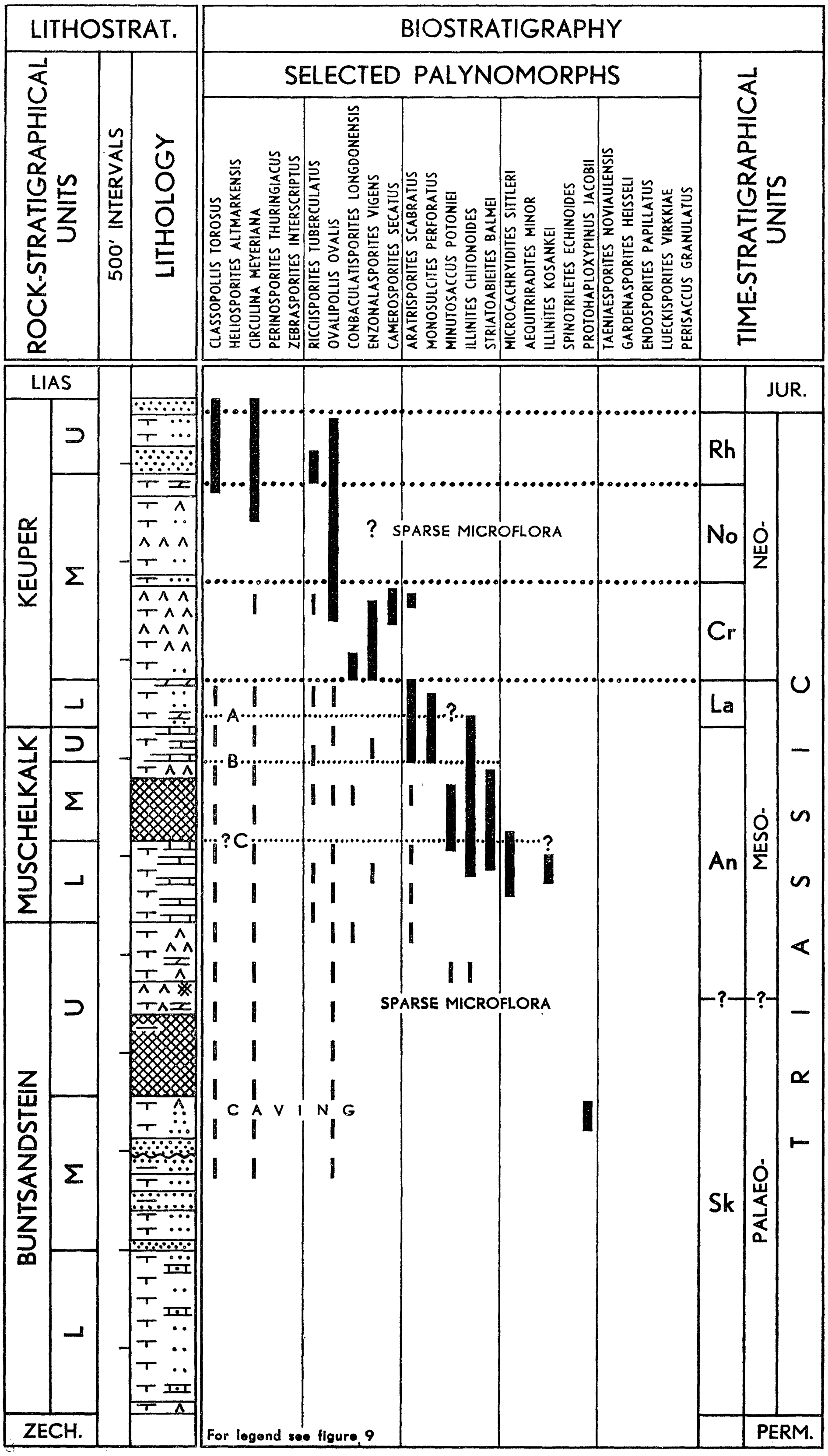


FIGURE 4. Wells Wisloh T2/Rehden Z8—Germany.

appearance in the Lower Muschelkalk and occurs regularly and in high quantities to the top of the Upper Muschelkalk. However, in view of possible contamination by caving the microplankton occurrences in the Middle Muschelkalk are suspect. The Meso-Triassic palynomorphs show a similar distribution pattern to that discussed in the outcrop section indicating an older (Lower to Middle Muschelkalk) and a younger (Upper Muschelkalk to Lower Keuper) assemblage. The marker horizons 'C', 'B' and 'A' occupy comparable stratigraphical positions as those indicated in the outcrop section (figure 3).

(iii) *Keuper*

The Lower or Kohlenkeuper can still be distinguished although it appears to be less sandy than in the outcrop. Nevertheless, most of the characteristic late Meso-Triassic microflora has been recognized.

In the absence of a properly developed Schilfsandstein the Gipskeuper and the Rote Wand are difficult to separate lithologically. The more calcareous upper part of the Steinmergel on the other hand stands out distinctly. However, in spite of the sparse microfloras encountered in this Middle Keuper sequence *Camerosporites secatus* was observed in samples near the top of the Gipskeuper and at the base of the Schilfsandstein, thus defining the Carnian–Norian boundary.

The three-fold subdivision of the Rhät is somewhat less clearcut than in the outcrop. Rhaetian palynomorphs *Ovalipollis ovalis* and *Ricciisporites tuberculatus* have their top occurrences within the sequence.

(*c*) *Netherlands: Wells North Holland* (*composite*)

(Figures 1 and 5)

The development of the Triassic discussed under the previous heading is recognizable over most of north-west Germany and also in parts of the eastern Netherlands (for the Buntsandstein see Boigk 1959, 1961). The section presented here is a composite from the Dutch province of North Holland situated between the IJsselmeer and the North Sea coast. Again only the dissimilarities within the sequence are pointed out.

(i) *Buntsandstein*

The Lower and the Upper Buntsandstein are still perfectly correlatable with their counterparts in Germany. However, the Middle Buntsandstein shows quite a different development with red-brown to grey-green slightly dolomitic and anhydritic micaceous sandstones at the base and a thin-bedded sandstone-silty mudstone alternation in the upper part. This difference is only partly the result of truncation over the Netherlands Ridge. The affinity of these deposits to the English-type Bunter of the North Sea rather suggests a different depositional regime in a separate sub-basin. Only the Upper Buntsandstein yielded palynomorphs of Skythian age.

(ii) *Muschelkalk*

The three subdivisions of Lower, Middle and Upper Muschelkalk are basically unchanged, but they, nevertheless, show signs of shallowing or restriction of the Muschelkalk

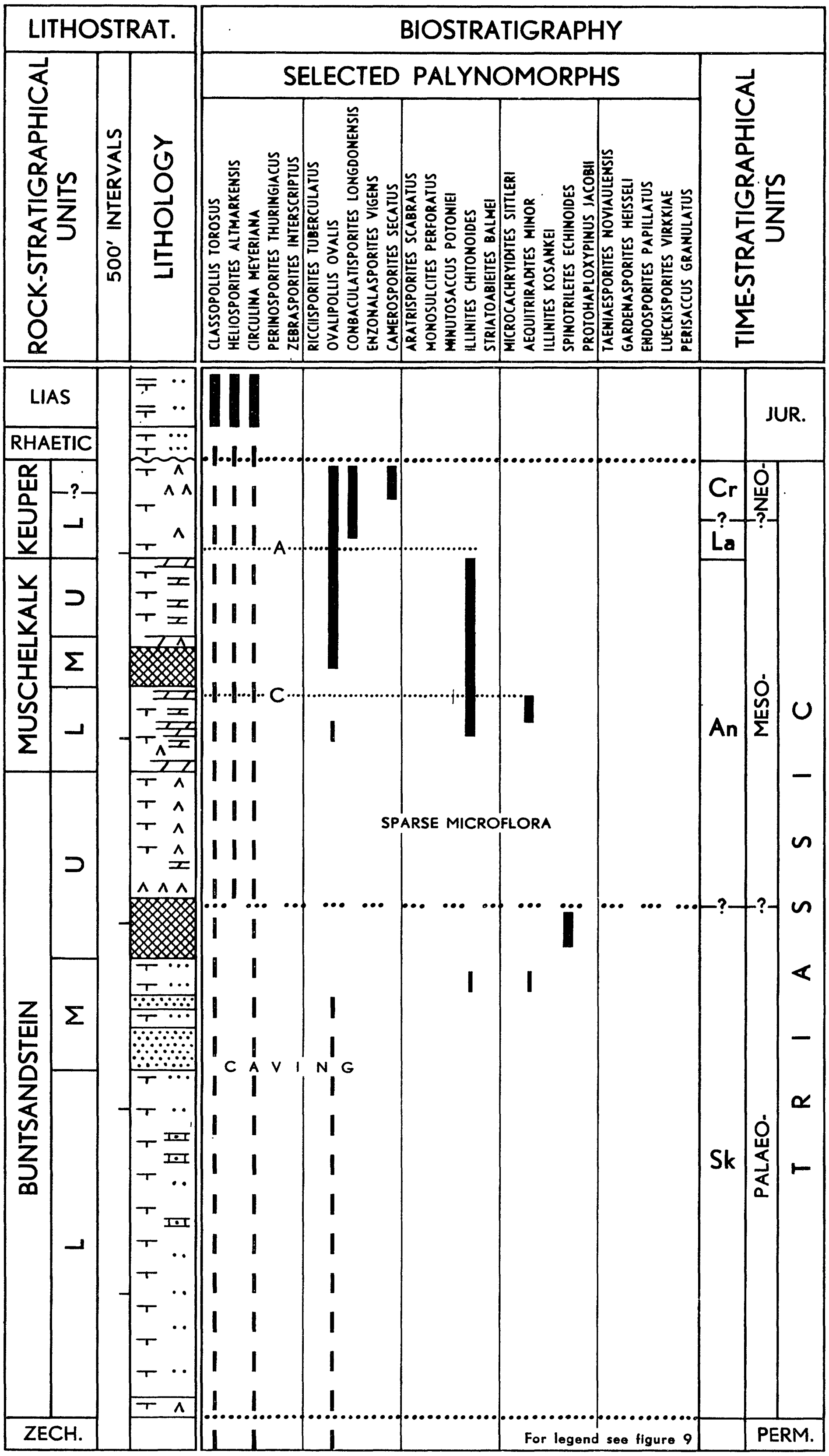


FIGURE 5. Well 'North Holland' (composite)—The Netherlands.

Sea in the slight increases in anhydrite content of the calcareous units and the appearance of reddish colours. The occurrence of the Meso-Triassic marker *Aequitriradites minor* in an otherwise poor assemblage indicates the approximate positions of horizon 'C'.

(iii) *Keuper*

A lithological differentiation into Lower and Middle Keuper is no more possible in the thin sequence of red-brown anhydritic claystones with anhydrite stringers which is left underneath the Rhaetic transgression. However, the top occurrence of *Illinites chitonoides* defining horizon 'A' suggests a normal succession. The co-occurrence of *Ovalipollis ovalis*, *Conbaculatisporites longdonensis* and *Camerosporites secatus* at the eroded top of the Keuper would indicate a Carnian age for the upper part of the interval.

The Rhaetic consists of dark grey silty shales containing mica and pyrites. No Rhaetian palynomorphs were observed, but it is, nevertheless, possible that this thin sequence represents only the youngest part of the stage which on palynological evidence compares better with the overlying Jurassic sequence.

(*d*) *North Sea: Well* 49/26–1 (*Leman Field*)

(Figures 1 and 6)

The development of the Triassic under the North Sea is represented by a section through the Shell/Esso Leman Field. In addition to the discovery well 49/26–1, there are at present four appraisal wells in this field. These wells have permitted a detailed study and close correlation of the Triassic sedimentary sequence. Thus, although the lithological column and the logs shown in figure 6 are from the discovery well, some of the stratigraphical information presented has been drawn from the other wells in the field. In view of the importance of this section, as a link between the Continental and the United Kingdom development of the Triassic, it has been treated in some detail.

(i) *Buntsandstein*

The *Lower Buntsandstein* is basically a monotonous sequence of red-brown silty and slightly anhydritic mudstones interbedded with micaceous siltstones and fine grained dolomitic sandstones containing calcareous oolithes often coated with hematite. Nevertheless, a three-fold subdivision can be distinguished which is comparable with the German Lower Buntsandstein in that there is a lowermost part with prominent anhydrite and thin beds of light grey calcareous sandstone (Bröckelschiefer), a middle part (Untere Gruppe) and an uppermost part which is characterized by the abundance of Rogenstein layers (Obere Gruppe).

Palynomorph assemblages of Permian age, including the species *Lueckisporites virkkiae*, have been observed in Bröckelschiefer samples. They must, however, be treated with extreme caution in view of the particular nature of the Bröckelschiefer, especially the widespread reworking of Zechstein sediments. At present we would therefore be reluctant to either place the Bröckelschiefer within the Permian or to extend the ranges of markers hitherto regarded as restricted to the Permian into the Triassic. Other beds of the Lower Buntsandstein have not yielded any palynomorphs.

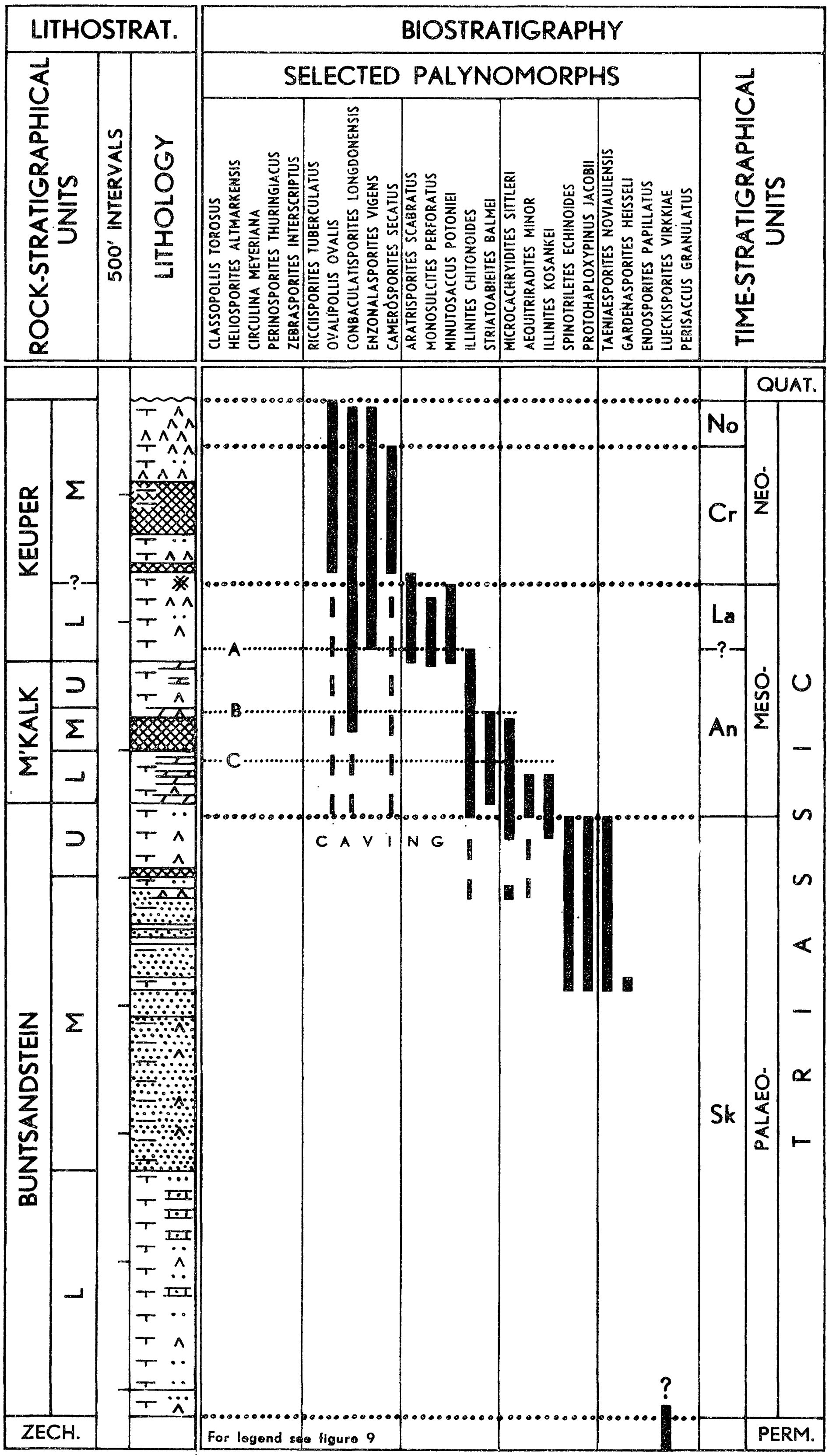


FIGURE 6. Well 49/26–1 (Leman field)—North Sea.

The *Middle Buntsandstein* is a succession of red-brown and grey-green fine to coarse grained sandstones and interbedded mudstones which can be subdivided into two major units on cuttings and log evidence. In the lower part the sandstones which alternate rapidly with silty mudstones are generally more argillaceous and micaceous containing various amounts of dolomite or anhydrite cement. There is a sharp contact above which the sands are more massive and cleaner, whereas the mudstone intervals are more pronounced. These sandstones resemble those of the English Bunter and have no counterpart east of the Netherlands Ridge.

Sidewall samples taken from the more prominent mudstones interbedded in the massive sandy upper part of the Middle Buntsandstein have yielded abundant microfloras containing *Falcisporites zapfei*, *Klausipollenites schaubergeri*, *Spinotriletes echinoides*, *Protohaploxypinus jacobii*, *Taeniaesporites noviaulensis*, *Gardenasporites heisseli*, *Nuskoisporites muelleri* Reinhardt and species of *Triadispora*, *Taeniaesporites*, *Chordasporites*, *Verrucosisporites*, *Alisporites* and *Limitisporites*. This combination of species, some of which are known from the Zechstein and others from the Upper Buntsandstein, appears to be typical for this interval.

The *Upper Buntsandstein* evaporites are poorly developed in the Leman Field area but elsewhere in the North Sea they are strikingly similar to the German Röt Salinar. The overlying mudstones, which are brick-red to red-brown, silty and anhydritic, also compare well with the German Röt sequence.

The palynomorph assemblages contain *Spinotriletes echinoides*, *Protohaploxypinus jacobii* and *Taeniaesporites noviaulensis*, and in addition *Illinites kosankei* and *Microcachryidites sittleri* which are also known from the overlying Muschelkalk.

(ii) *Muschelkalk*

The *Lower Muschelkalk* is here reduced to a thin-bedded alternation of pale grey and red-brown dolomites and silty mudstones.

Illinites kosankei and *Aequitriradites minor* have their top occurrence in the Lower Muschelkalk at horizon 'C'. These species occur in an assemblage containing *Illinites chitonoides*, *Microcachryidites sittleri*, *Striatoabieites balmei* and *Triadispora* spp. Microplanktonic organisms have been observed in sidewall samples taken from this interval.

The *Middle Muschelkalk* consists of a massive evaporite unit lying between the dolomitic sequences of the Lower and the Upper Muschelkalk. The microflora is similar to that of the Lower Muschelkalk except for the species *Aequitriradites minor* and *Illinites kosankei*. The species *Microcachryidites sittleri* and *Striatoabieites balmei* again define horizon 'B' near the top of the interval.

The *Upper Muschelkalk* has a lithology similar to the Lower Muschelkalk but here the mudstones dominate the dolomites and there are occasional anhydrite stringers. Just as in the outcrop section the palynomorphs of the Upper Muschelkalk compare better with those of the Lower Keuper than those of the Lower and Middle Muschelkalk. However, as in the Lower Muschelkalk, microplanktonic organisms have been observed in sidewall samples.

Whilst the stratigraphical development of the Muschelkalk in the North Sea area still shows clear affinities with the Continental Muschelkalk subdivisions, it also confirms the progressive shallowing and salinification of the Muschelkalk sea first observed in North Holland.

(iii) *Keuper*

The Keuper consists of variegated red-brown silty and grey-green dolomitic to anhydritic mudstones with laminae and thin beds of anhydrite and several salt layers, which often combine into a massive salt unit.

The microflora of the Keuper shows an interesting distribution. *Illinites chitonoides* again marks horizon 'A'. The Meso-Triassic assemblage of *Minutosaccus potoniei*, *Monosulcites perforatus* and *Aratrisporites scabratus* is clearly separated from the Neo-Triassic markers *Ovalipollis ovalis* and *Camerosporites secatus* by the boundary between the Ladinian and Carnian stages. The absence of such species as *Classopollis torosus*, *Heliosporites altmarkensis*, *Circulina meyeriana*, *Perinosporites thuringiacus*, *Zebrasporites interscriptus* and *Ricciisporites tuberculatus* would indicate that sediments of Norian age are missing with the possible exception of the uppermost 200 ft. of the interval in which, however, the lack of *Camerosporites secatus* may be due to poor recovery. Thus the bulk of the upper part of the Middle Keuper sequence corresponding to the Rote Wand–Steinmergel in Germany is missing in Leman Field. This sequence is, however, known from other wells in the North Sea area. The Rhaetic too has been removed by a later erosion.

(*e*) *England: Well Tetney Lock*-1
(Figures 1 and 7)

The well Tetney Lock-1 is situated near the Humber estuary about seven miles south-east of Grimsby. This well shows the typical two-fold subdivision of the English Triassic into Bunter and Keuper.

(i) *Bunter*

In keeping with the concept followed throughout this paper, the base of the Bunter has been drawn at the top of the evaporitic Zechstein. The interval between this boundary and the Bunter sands proper is locally referred to as the 'Upper Saliferous Marls'.

The sequence starts with bright red silty anhydritic mudstones and subordinate fine micaceous sandstones and continues with red-brown silty and slightly calcareous mudstones with only traces of anhydrite.

The overlying Bunter consist of red-brown fine to medium grained occasionally pebbly sandstones, with intercalations of red silty mudstones. Again there is evidence for a subdivision similar to that observed in Leman Field with the dirtier sands containing most of the pebbles in the lower part and the cleaner sands above.

No palynomorphs have been observed in samples from the Bunter in this well and indeed as far as is known none have as yet been reported from the surface or subsurface Bunter of England. In view of the good results obtained from equivalent intervals in the Leman Field, it is likely that a careful preparation and examination of selected sample material from the shale breaks in the Bunter would provide palynomorphs.

(ii) *Keuper*

The Keuper starts with a 'Basal Conglomerate', a white coarse-grained sandstone with pebbles, which is overlain by a thin interval of red-brown and purple silty mudstones

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

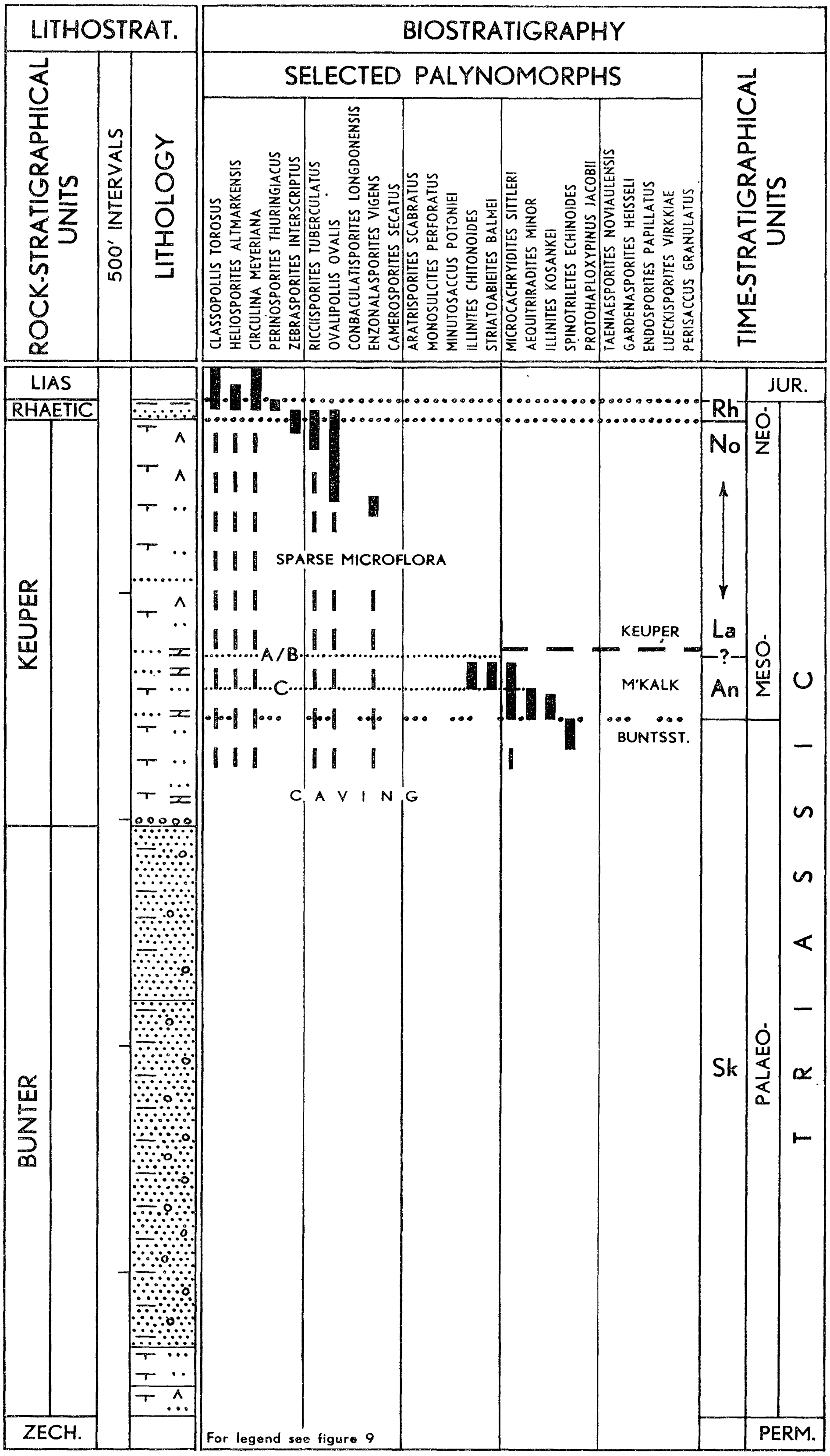


FIGURE 7. Well Tetney Lock–1—England.

grading into fine grained dolomitic sandstones, followed in turn by a sequence of red-brown silty mudstones. Near to the top of this sequence a microflora containing *Protohaploxypinus jacobii* and species of *Taeniaesporites* has been observed which is indicative of a Palaeo-Triassic age. It would appear therefore that the lower Keuper of England is synchronous with the Upper Buntsandstein of Germany.

The succession continues with an interval of alternating grey dolomitic sandstones and red-brown silty mudstones. The palynomorphs observed are of Meso-Triassic age and can be subdivided into two assemblages. There is a lower interval containing *Aequitriradites minor*, *Illinites kosankei*, *Microcachryidites sittleri*, *Lueckisporites triassicus* and *Triadispora* spp. The top occurrence of *Aequitriradites minor* (Horizon 'C') is comparable with the one found at or near the Lower-Middle Muschelkalk boundary in Germany. The upper interval contains *Illinites chitonoides*, *Striatoabieites balmei*, *Microcachryidites sittleri*, *Lueckisporites triassicus* and *Triadispora* spp., but without *Aequitriradites minor* and *Illinites kosankei*. The coincident top occurrences of *Striatoabieites balmei* (horizon 'B') and *Illinites chitonoides* (horizon 'A') does not necessarily prove that the younger Meso-Triassic is not represented in view of the sparse microflora recovered from the overlying interval.

The remainder of the Keuper sequence consists of variegated green-grey and red-brown silty and gypsiferous mudstones with subordinate siltstone beds. This interval contains few typical Neo-Triassic palynomorphs like *Enzonalasporites vigens* amongst the heavy contamination from the overlying Rhaetian and Jurassic intervals.

The thinly developed Rhaetic contains pale pyritic sandstones and dark fissile shales. In Tetney Lock-1 as in some of the North Sea wells Rhaetic or Upper Keuper rocks have yielded abundant well-preserved palynomorphs. *Perinosporites thuringiacus*, *Zebrasporites interscriptus*, *Stereosporites* sp. and *Cingulizonates rhaeticus* appear to have a higher top occurrence than *Ricciisporites tuberculatus*, *Ovalipollis ovalis*, *Rhaetipollis germanicus* and *Limbosporites lundbladii*.

(*f*) *England: Outcrop Section, Nottinghamshire*

(Figures 1 and 8)

Triassic outcrops cover a large area of England on either flank of the Pennines and across most of the Midlands, extending to the Channel coast. For this review our interest is focused on the belt running from Hartlepool to Nottingham representing the western margin of the North Sea basin at least in early Triassic times (Wills 1951). The area around Nottingham serves to illustrate this marginal development of the Bunter and also provides a detailed account of the Keuper which spread over a considerably larger area (Elliott 1961).

It is not within the scope of this paper to deal with the intricacies of English Triassic subdivision and correlation and to this end reference is made to a recent comprehensive study (Audley-Charles 1968). It would appear, however, that the restrictions imposed by the original terminology which often carried a somewhat arbitrary time connotation have rather complicated regional comparison. It is felt that the use of a neutral rock-stratigraphical terminology, combined with the increasing availability of reliable age-determinations by means of palynology, will improve the understanding of the English Triassic. In comparison with the Continent the number of palynological contributions is

BIOLOGICAL SCIENCES THE ROYAL B SOCIETY PHILOSOPHICAL TRANSACTIONS OF

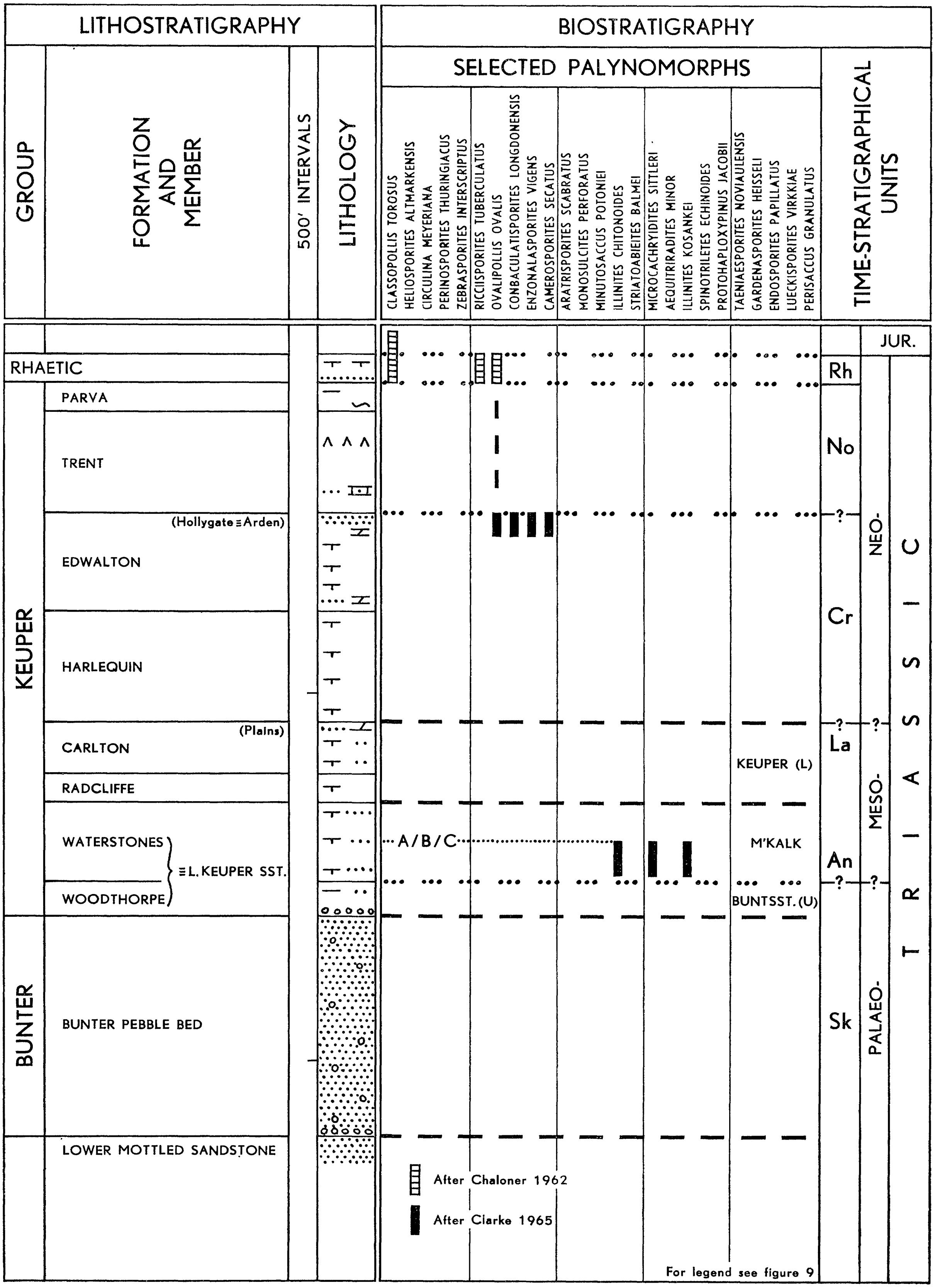


Figure 8. Outcrop section Nottinghamshire—England.

still rather small, nevertheless those by Chaloner (1962), Clarke (1965*a*) and Warrington (1967) have already shown promising results.

(i) *Bunter*

The Lower Mottled Sandstone of Nottinghamshire represents the clastic margin of a much attenuated Zechstein sequence (Edwards & Trotter 1954, fig. 23) and it should therefore not be included in the Bunter. The Bunter proper consists of mottled poorly sorted sandstones containing well-worn pebbles. These pebbles, the majority of which are quartzite and veinquartz, are believed to have a southern origin, possibly as far away as France.

As mentioned above no microfloras have as yet been described from the English onshore Bunter.

(ii) *Keuper*

Elliott (1961) subdivided the Keuper into eight formations, partly with the help of marker beds and by carefully evaluating all the observable sedimentary features.

The succession begins with a rhythmic alternation of variegated mudstones and sandstones (Woodthorpe). Locally a basal conglomerate occurs which is believed to be the result of winnowing of the underlying Bunter Pebble Beds.

The next unit consists of alternations of brown mudstones and buff to green-grey fine grained sandstones with abundant mudstone pebbles. The bedding planes are commonly ripple-marked and very micaceous giving a watered-silk appearance, hence the name of the formation (Waterstones). This interval has yielded the most abundant number of macrofossils indicative of aquatic life, *Lingula* sp., *Euestheria* sp., and fish-remains but also tetrapod footprints and plant impressions. Clarke (1965*a*) has recorded abundant well-preserved palynomorphs of Meso-Triassic age from the Waterstones of Worcestershire.

The remaining six formations are basically a succession of variegated mudstones, silty mudstones and siltstones with several prominent beds of pale coloured fine grained dolomitic sandstones, the so-called 'Skerries'. One of these skerries, the Hollygate of the Edwalton Formation, has been correlated lithologically with the Arden Sandstone of Worcestershire. From the latter Clarke (1965*a*) has recorded palynomorphs of a Carnian age including: *Enzonalasporites vigens*, *Ovalipollis ovalis*, *Conbaculatisporites longdonensis*, *Ellipsovelatisporites plicatus* Klaus and *Camerosporites secatus*. The occurrence of this last-named, short-ranging species suggests that the Arden Sandstone and the Hollygate Skerries are time stratigraphical equivalents of the German Schilfsandstein.

The upper part of the English Keuper is very gypsiferous, locally in sufficient concentration to be mined. At the top the mudstones are predominantly green and contain fishscales (Parva, with 'Tea Green Marls').

The Rhaetic beds, pale grey silty micaceous mudstones and fine sandstones followed by black fissile shales, lie on an irregular eroded surface of Keuper rocks (Kent 1953).

3. Correlation and palaeogeography

The six sections which have been discussed individually are now compared with each other unit by unit in stratigraphical order. It must be stressed again that the area covered by this paper is restricted to the southern North Sea basin. As far as north-west Germany is concerned this means that both the surface and the well sections reflect positions within this basin, but not necessarily its deepest part—as witnessed by the absence of Keuper salt. An overall picture of German Triassic palaeogeography is given by Wurster (1964). North-east England, on the other hand, constitutes the western edge of the basin for all but its latest phase and is therefore characterized by marginal deposits. The development of the Triassic in other parts of the British Isles is the subject of a paper to be published shortly (Audley-Charles 1968). North Holland and the North Sea represent intermediate stages between the two extremes.

Lithological correlation within the basin along its axis is rather straightforward but towards the margin it becomes more tentative, mainly in view of the predominantly clastic nature of the sediments and the numerous obvious or hidden hiatuses. Comparison then has to rely on palaeogeographical considerations supported by palynological dating.

The correlation of the major rock- and time- stratigraphical subdivisions in the southern North Sea basin is shown in figure 9.

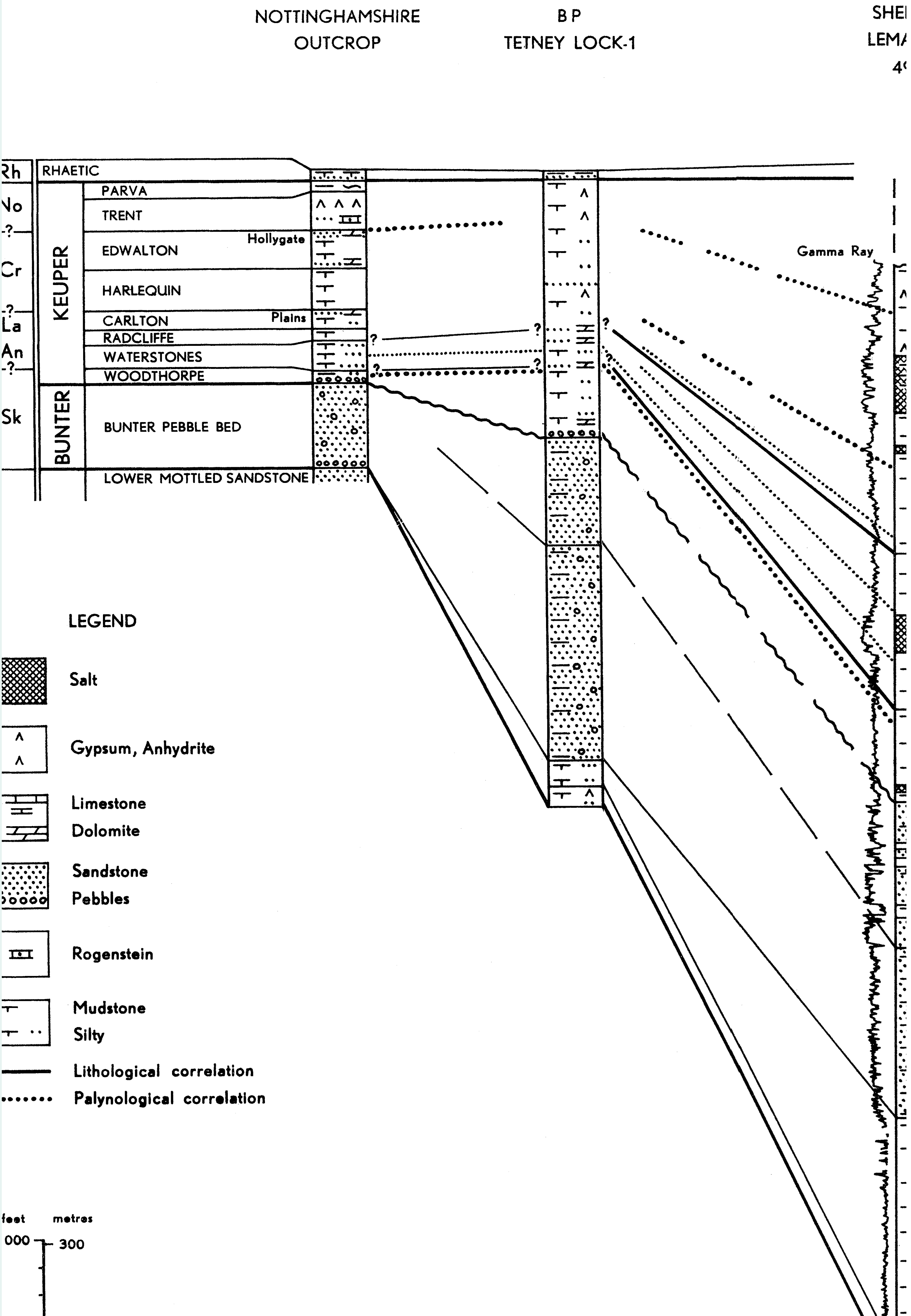
(i) *Buntsandstein*

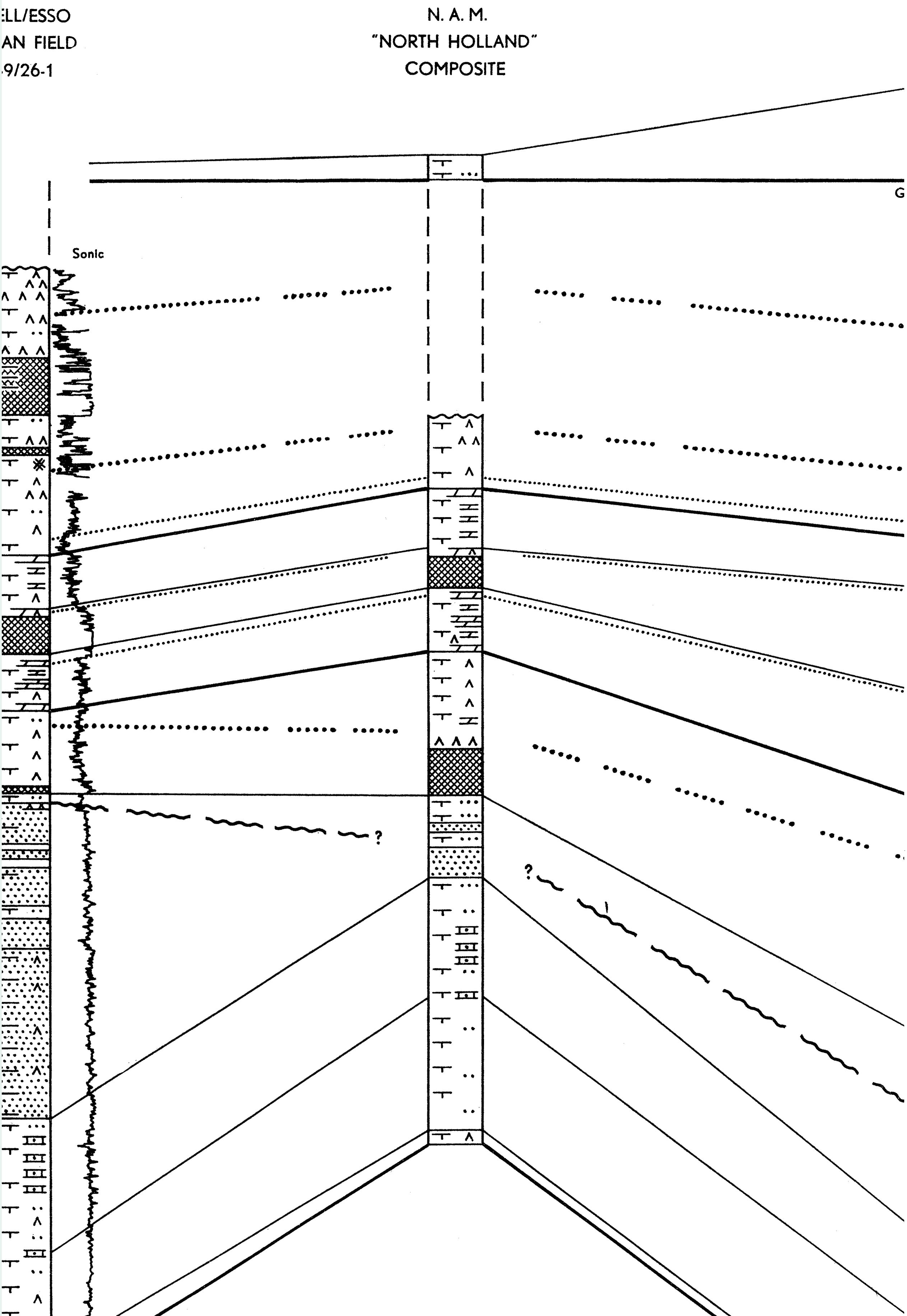
The Bröckelschiefer is a transitional sequence overlying the Zechstein in the centre of the basin. Towards the margins the evaporites and carbonates of the Zechstein were gradually replaced by pelites, the Upper Saliferous Marls and finally by coarse clastics, the Lower Mottled Sandstones. Some of the higher sandstone beds can be traced along the basin edge to the well Stixwould (Lees & Taitt 1945; Edwards & Trotter 1954) and as far out as Leman Field into the Bröckelschiefer proper. The age of this interval is still not satisfactorily established since the microfloras of Permian age found are not entirely above suspicion in view of the widespread reworking of Zechstein sediments.

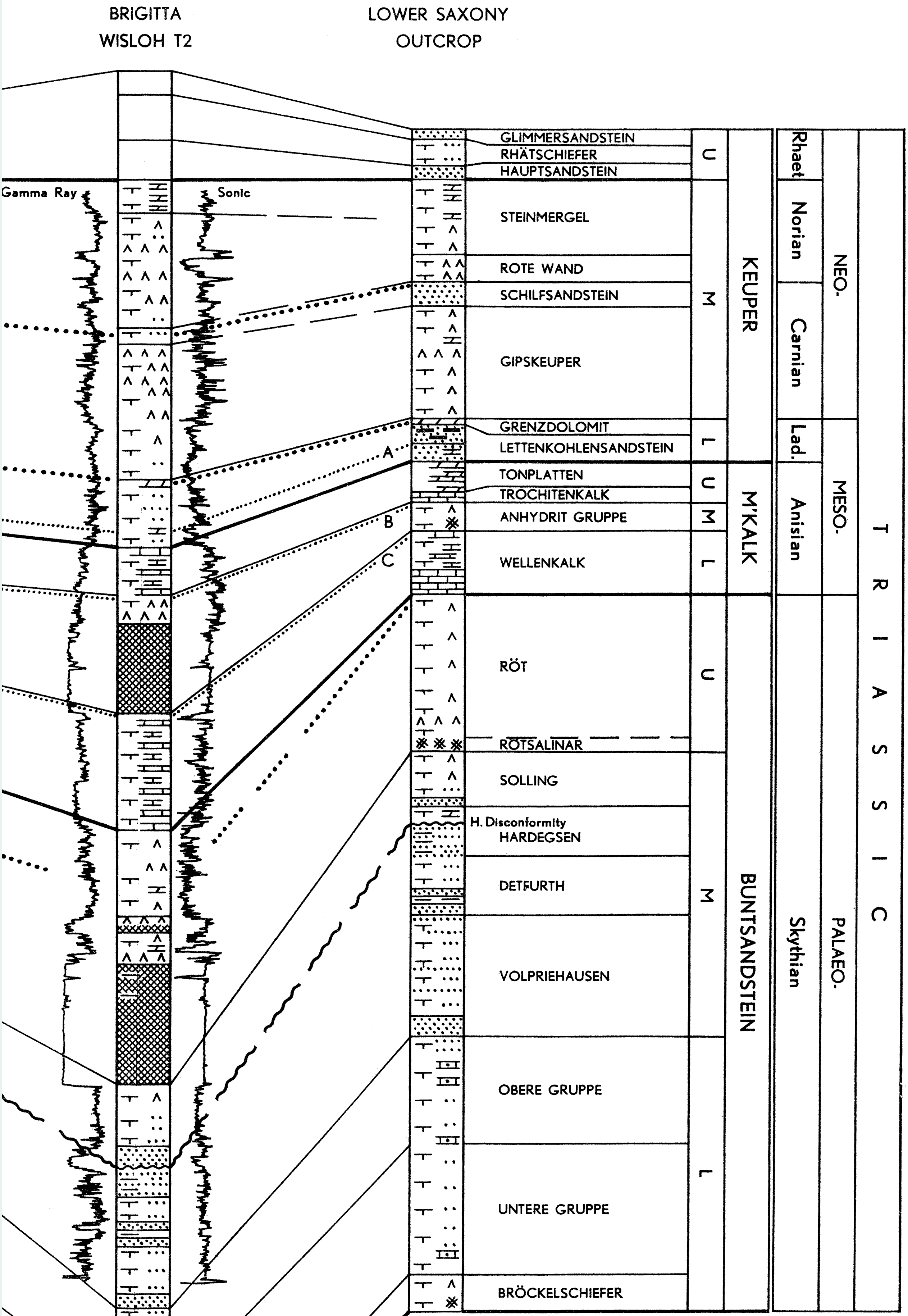
The *Lower Buntsandstein sensu strictu* shows a remarkable consistency over a large area, suggesting that sedimentation kept pace with subsidence in the flat, featureless basin inherited from Zechstein times. Towards the edges of the basin a rapid thinning occurs accompanied by the disappearance of the Rogenstein layers. It is believed that the fine clastic material was furnished by erosion of a low-lying source area and therefore the Lower Buntsandstein is probably not at all or only locally represented on land.

The *Middle Buntsandstein* owes its inception to uplift in the source areas resulting in an influx of coarser clastics. Whilst the pebbles were obviously restricted to the river fans, the bulk of the sands spread quickly over most of the basin with little evidence of diachronism either in the North Sea or in north-west Germany. A higher sand percentage in the former region confirms its closer proximity to the source area whereas only the major pulses reached the latter. The subdivisions observed in the Leman Field and in Tetney Lock-1 probably compare with the Bunter Pebble Bed and Upper Mottled Sandstones on land.

Towards the end of the interval renewed epirogenetic movements produced local uplifts like the Hunte Ridge in the continuation of the Rhenish Massif (Trusheim 1963), the


NOTTINGHAMSHIRE
OUTCROP
B P
TETNEY LOCK-1
Gamma Ray
Rh
No
Cr
La
An
Sk
RHAETIC
KEUPER
PARVA
TRENT
EDWALTON
Hollygate
HARLEQUIN
CARLTON
Plains
RADCLIFFE
WATERSTONES
WOODTHORPE
BUNTER
BUNTER PEBBLE BED
LOWER MOTTLED SANDSTONE
LEGEND
Salt
Gypsum, Anhydrite
Limestone
Dolomite
Sandstone
Pebbles
Rogenstein
Mudstone
Silty
Lithological correlation
Palynological correlation
feet
metres
000
300


ELL/ESSO
AN FIELD
9/26-1
N. A. M.
"NORTH HOLLAND"
COMPOSITE
Sonic
G


BRIGITTA
WISLOH T2
LOWER SAXONY
OUTCROP
Gamma Ray
Sonic
GLIMMERSANDSTEIN
RHÄTSCHIEFER
HAUPTSANDSTEIN
STEINMERGEL
ROTE WAND
SCHILFSANDSTEIN
GIPSKEUPER
GRENZDOLOMIT
LETTENKOHLENSANDSTEIN
TONPLATTEN
TROCHITENKALK
ANHYDRIT GRUPPE
WELLENKALK
RÖT
RÖTSALINAR
SOLLING
H. Disconformity
HARDEGSEN
DETFURTH
VOLPRIEHAUSEN
OBERE GRUPPE
UNTERE GRUPPE
BRÖCKELSCHIEFER
A
B
C
U
M
L
U
M
L
U
M
L
KEUPER
M'KALK
BUNTSANDSTEIN
Rhaet
Norian
Carnian
Lad.
Anisian
Skythian
NEO-
MESO-
PALAEO-
TRIASSIC

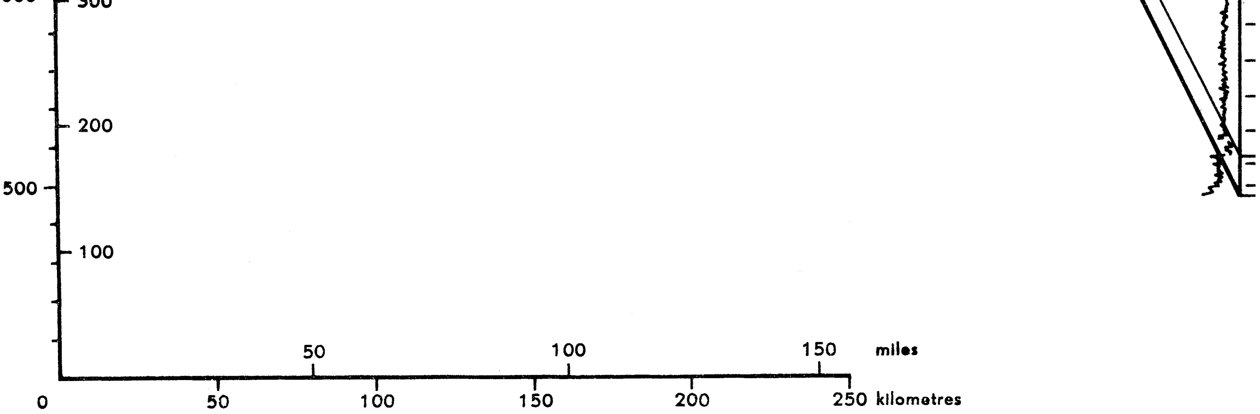
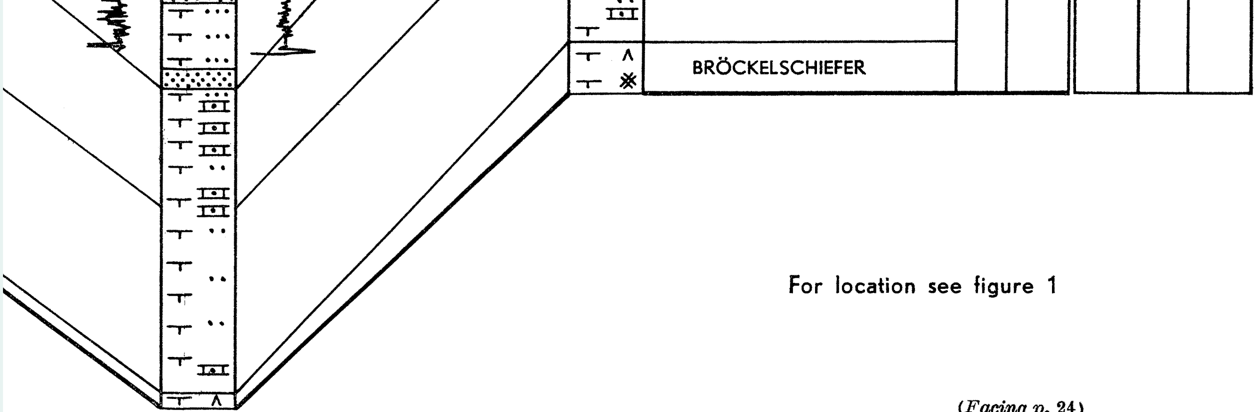

200
500
100
50
100
150
miles
0
50
100
150
200
250
kilometres

FIGURE 9. Correlation of Triassic strata from Central England to North-West Germany.



For location see figure 1

(*Facing p.* 24)

Netherlands Ridge and possibly also the rejuvenation of faults which had been active at the start of the interval in central England (Wills 1956). The positive areas suffered considerable truncation as witnessed by the reduced section in North Holland and the missing Upper Mottled Sandstones in Nottinghamshire, but even the intermediate low regions show evidence of a minor hiatus, suggesting that the whole of the basin had been at least for a short time above the erosion base. The points in question are the Hardegsen disconformity in north-west Germany, the varying stratigraphical position of the top of the sands in Leman Field and the conglomerate on top of the Bunter in Tetney Lock-1.

Palaeogeographically there is good reason for Trusheim's suggestion to take this event as the base of the Upper Buntsandstein. The Solling Sandstone and at least part of the English Keuper sandstones—the sandy equivalent of Elliot's Woodthorpe Formation—would then represent the clastic waste of the erosion period.

The *Upper Buntsandstein* with its conventional lower boundary indicates the return to flat basin conditions and also marks the beginning of the first evaporite sequence. The Röt Salt, which has the widest distribution of all Triassic salts, just reached England in Eskdale-11 (Audley-Charles 1968). Further south in Tetney Lock-1 there is no trace of evaporites left, only a slight increase in the dolomite content of the lower part of the interval.

The type Buntsandstein is of Skythian age. The English Bunter could not be dated on land but the succeeding lower part of the Keuper, the Woodthorpe Formation, was found to be the time equivalent of the German Upper Buntsandstein.

Further comparative studies of the Palaeo-Triassic microfloras will undoubtedly lead to the establishment of finer subdivisions, in particular the time-stratigraphical differentiation between the Middle and the Upper Buntsandstein.

(ii) *Muschelkalk*

The Muschelkalk is the result of a marine flooding over most of the area, interrupted by a period of evaporitic conditions in the Middle Muschelkalk. Evidence of this marine incursion is strongest in north-west Germany which was apparently closest to open sea conditions. In the shallow basin to the north and west a more saline environment prevailed judging from the facies of the Lower and Upper Muschelkalk in North Holland and in the North Sea. Nevertheless, the marine influence of this Muschelkalk sea reached England during the deposition of the Waterstones as evidenced by the fossils and microplankton (Rose & Kent 1955; Warrington 1967), and the intertidal aspect of the sedimentary features (Klein 1962).

The palynomorph assemblages of the Muschelkalk are of Anisian age and can be subdivided into two distinctive intervals, the older one covering the Lower and Middle Muschelkalk and the younger one the Upper Muschelkalk (and extending into the Lower Keuper). The Waterstones would appear to belong to the older interval. It is thus possible that at least part of the Keuper sandstones occurring in the English Midlands are contemporaneous with the marginal Muschelsandstein facies of the Continent.

(iii) *Keuper*

The Keuper is again characterized by a return to evaporitic conditions which persisted nearly to the end of the sequence and produced a rather monotonous succession in the centre of the basin. Towards the margins more varied conditions occurred making a subdivision possible.

The *Lower Keuper* in Lower Saxony is a predominantly clastic facies with abundant coal, but these lithological characteristics have already largely disappeared in Wisloh, south of Bremen, and are not traceable into the North Sea. Microfloras of Ladinian age extend, however, over most of the area thus proving the synchronal nature of the Lower Keuper deposits. In England this interval is represented by the Radcliffe and Carlton Formations with the Plains Skerry as a possible equivalent of the Grenzdolomit.

The *Middle Keuper* is the truly evaporitic unit. Along the margins of the basin it is subdivided by the occurrence of prominent clastic intercalations of Carnian age, the Schilfsandstein in Germany and the Arden Sandstone in central England which is represented in Nottinghamshire by the Hollygate Skerry. In the basin the only lithological indications of this subdivision are the prominence of salt in the lower part and concentration of gypsum or anhydrite in the upper part. Towards the top of the Middle Keuper there is increasing evidence of a new marine incursion of Norian age in the upper part of the Steinmergel in Germany and the 'Tea Green Marls' of the Parva Formation in England.

The *Upper Keuper* in the Germanic sense is the Rhaetic of England. The Rhaetic can be considered as the beginning of the Jurassic marine cycle after a period of unrest (Early Kimmeric phase), accompanied by widespread but mostly minor erosion.

The palaeogeographical implications drawn from these comparisons may be summarized briefly. The southern North Sea and adjoining areas formed a wide, flat and probably rather shallow basin in Triassic times. On the whole the deposition kept pace with more or less continuous subsidence. In the beginning clastic sediments prevailed, later the environment became increasingly evaporitic apart from a short period of less saline marine conditions. The most striking feature of this basin is its extraordinary flatness which meant that climatic fluctuations or tectonic disturbances affected large parts simultaneously and also made possible the practically instantaneous spread of the clastic units, thus allowing the correlation of even the finest stratigraphic subdivisions from one end to the other.

4. Selected palynomorph marker types

In this section the twenty-five selected palynomorph marker types or 'guide-fossils' are briefly discussed. It is not our intention to enter into the intricacies of palynological systematics, which is neither within the purpose nor the scope of this stratigraphical paper. It will have been noted that no new genera or species of palynomorphs have been proposed and that the palynological work which has been undertaken has been of a purely applied nature.

It is necessary, however, to discuss the above mentioned twenty-five palynomorphs in some detail in order to familiarize the reader with the nature and validity of the types used in §2. The palynomorphs are discussed in stratigraphical order and not in any supposed systematical relationship.

(*a*) *Perisaccus granulatus* Klaus 1963. Figure 10, plate 1,

Clarke (1965*b*) has given a concise and comprehensive account of the genus *Perisaccus* (Naumova 1953), as amended by Klaus (1963). Clarke, however, placed the species

Simplicesporites granulosus of Leschik (1955) within the genus *Perisaccus* as a new combination, *Perisaccus granulosus*. He further included the above species *P. granulatus* of Klaus as a synonym of his new combination *P. granulosus*.

Mädler (1964*a*) assigned the species *Simplicesporites virgatus*, which is the type species of Leschik's genus *Simplicesporites*, to the genus *Aratrisporites* also of Leschik (1955), thus invalidating the generic name of *Simplicesporites*. He further believed that Leschik's species *S. granulosus* belongs to the genus *Aequitriradites* of Delcourt & Sprumont (1955). In this paper we have taken the species *P. granulatus* of Klaus as the type.

P. granulatus has not as yet been reported from Palaeo-Triassic sediments and as a 'guide-fossil' it would appear to have a range restricted to the Permian. Thus in applied palynology its 'top occurrence' can be taken as an indication of strata of Permian age.

(*b*) *Lueckisporites virkkiae* Potonié & Klaus 1954 emend. Clarke 1965*b*. Figure 11, plate 1

L. virkkiae is the type species of the genus *Lueckisporites* of Potonié & Klaus (1954). The generic and specific description of *Lueckisporites* and *L. virkkiae* have since been emended by Klaus (1963). Clarke (1965*b*) has accepted the generic description of Klaus, but in view of the high variability of extreme forms, connected by many intermediate forms, he considered that the separation of many species was impossible to maintain. Thus he has emended the specific diagnosis to include these forms as variants A, B and C. The species *L. virkkiae* variant A has been taken as the type in this paper.

Specimens of *L. virkkiae* have been recorded from the Palaeo-Triassic. However, we regard the above species as being restricted to the Permian and indeed as a 'characteristic palynomorph of the late Permian' (Klaus 1964).

(*c*) *Endosporites papillatus* Jansonius 1962. Figure 12, plate 1

Jansonius (1962) defined and named the above species and assigned it to the genus of Wilson & Coe (1940). He shows specimens of *E. papillatus*, where the spore body has become detached from the saccus as shown above in figure 12.

Jansonius described his specimens from sediments of Skythian age in western Canada. In our study of the Buntsandstein microfloras *E. papillatus* has been found in sediments from the Volpriehausen, Detfurth and Hardegsen sequences but as yet not from the overlying Solling or Röt deposits. Thus *E. papillatus* of known Skythian age appears so far to be restricted to Middle Buntsandstein sediments of the Germanic Triassic.

(*d*) *Gardenasporites heisseli* Klaus 1963. Figure 13, plate 1

G. heisseli is the type species of the genus *Gardenasporites* of Klaus (1963).

This typically large species was first described from samples of late Permian age. Klaus (1965) has recently extended the stratigraphical range of *G. heisseli* into the early Skythian. We have found specimens of *G. heisseli* in samples from the Middle Buntsandstein at outcrop and well sections but not as yet from the Upper Buntsandstein, which is in agreement with Klaus's findings.

(*e*) *Taeniaesporites noviaulensis* Leschik 1956. Figure 14, plate 1

Leschik (1956) defined and named the species *T. noviaulensis* which he assigned to the genus *Taeniaesporites* (Leschik 1955). Klaus (1963) then emended the generic description of

Taeniaesporites. Clarke (1956*b*) accepted this emended description with the reservation that genus should be broadened to include all bisaccate miospores with four primary taeniae and which are haploxylonoid or diploxylonoid in outline. Some of the specimens described by Jansonius (1962) under the name of *Taeniaesporites novimundi* belong to *T. noviaulensis*.

T. noviaulensis was first described by Leschik from samples of late Permian age. Jansonius (1962) has since extended its range into the Skythian from his findings in North America. *T. noviaulensis* is present in the Upper Buntsandstein and may be considered as a characteristic species of the Palaeo-Triassic.

(*f*) *Protohaploxypinus jacobii* (Jansonius 1962), Hart 1964. Figure 15, plate 1

Jansonius (1962) defined and named the species *P. jacobii* which he placed in the genus *Striatites* of Pant (1955) as emended by himself. Hart (1964) later emended the generic description of *Protohaploxypinus* of Samoilovich (1953) and included Jansonius's species within this genus. The species *P. samolovichii* (Jansonius) Hart 1964 and *P. chaloneri* Clarke (1965) are very similar to *P. jacobii* and these and other forms are possibly all variants of a single species, as indeed has been suggested by Jansonius.

P. jacobii has been found in rocks of Permian and Palaeo-Triassic age. It is an extremely characteristic form and its 'top occurrence' has been taken as indicating deposits of Skythian age.

(*g*) *Spinotriletes echinoides* Mädler 1964. Figure 16, plate 2

The genus and species *S. echinoides* were defined and named by Mädler (1964*a*). Mädler has found *S. echinoides* in samples from the Upper Buntsandstein and the Lower Muschelkalk of Germany. Specimens of this species have also been found by us in samples from the Middle Buntsandstein in the outcrop section in Lower Saxony and in the North Sea wells. Thus we should like to extend the known range of *S. echinoides* from the Middle Buntsandstein to the Lower Muschelkalk.

(*h*) *Illinites kosankei* Klaus 1964. Figure 17, plate 2

Klaus (1964) defined and named the above species and assigned it to the genus *Illinites* of Kosanke (1950), having emended Kosanke's generic description. Mädler (1964*a*)

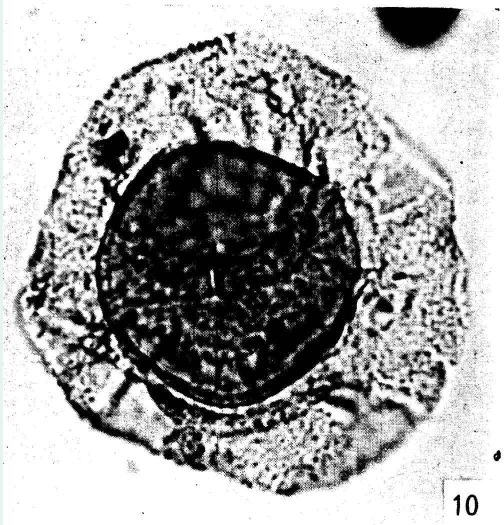
Plates 1 to 4

Selected palynomorph marker types

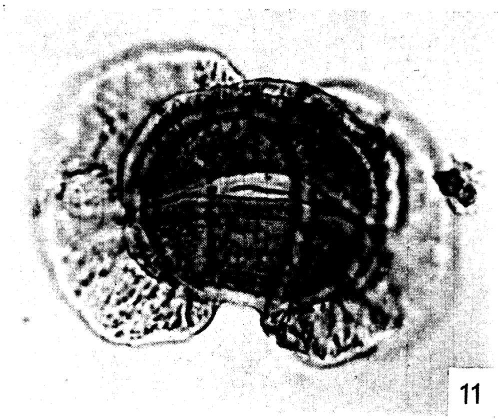
(Magnifications ×1000)

Description of plate 1

Figures 10. *Perisaccus granulatus* Klaus. Durham (England) Zechstein.
11. *Lueckisporites virkkiae* Potonié & Klaus. Durham (England) Zechstein.
12. *Endosporites papillatus* Jansonius. Salzdetfurth (Germany) Hardegsen.
13. *Gardenasporites heisseli* Klaus. Ebergötzen (Germany) Solling.
14. *Taeniasporites noviaulensis* Leschik. Ebergötzen (Germany) Solling.
15. *Protohaploxypinus jacobii* (Jansonius) Hart. Durham (England) Zechstein.

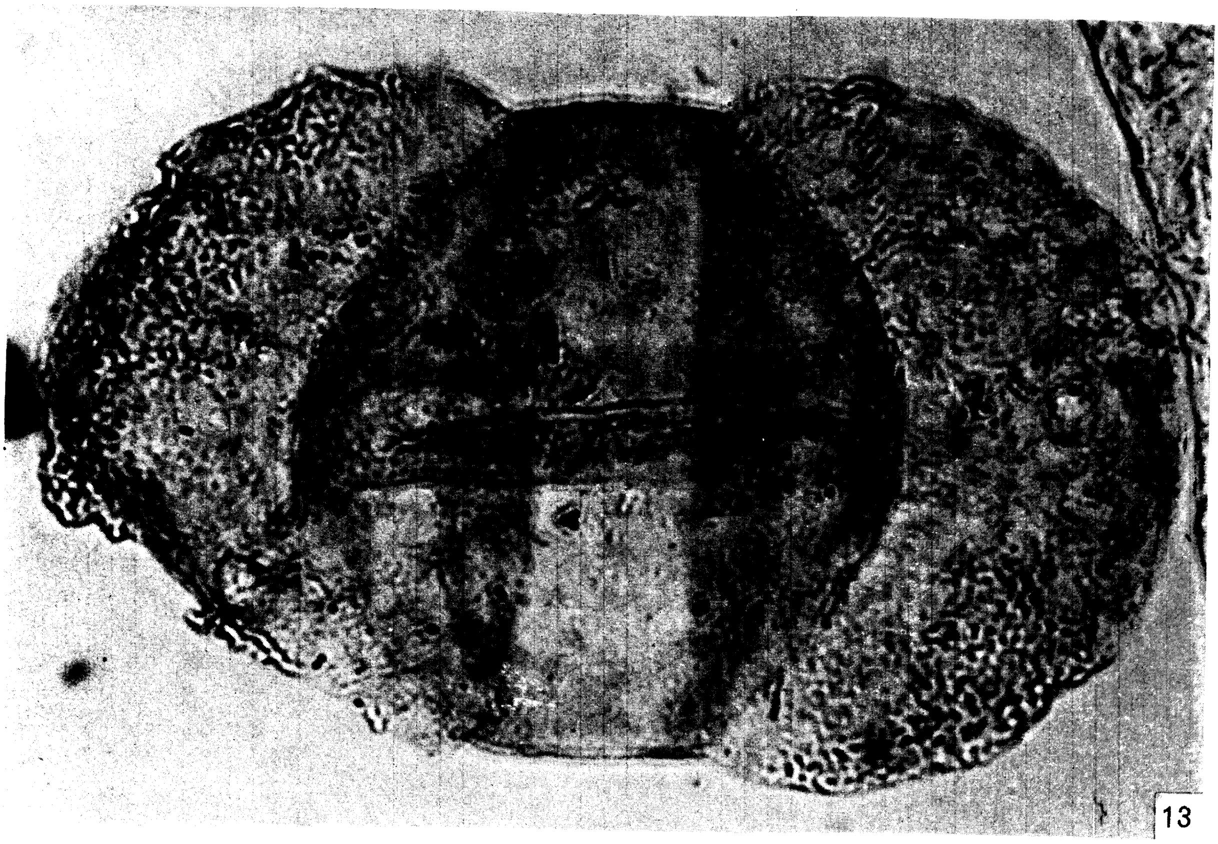


10

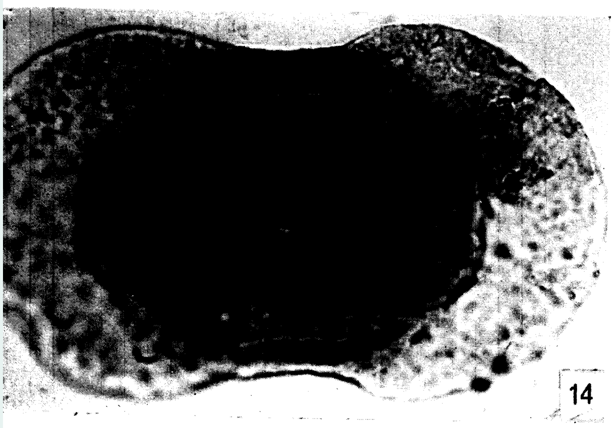


11

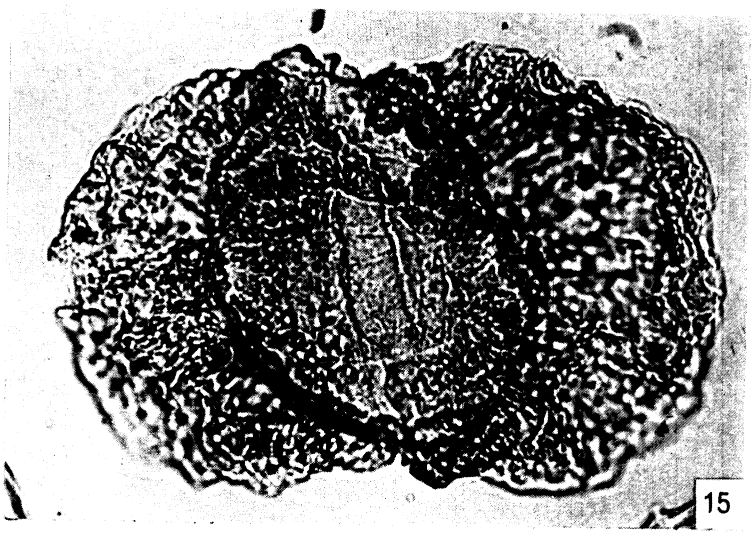
12



13

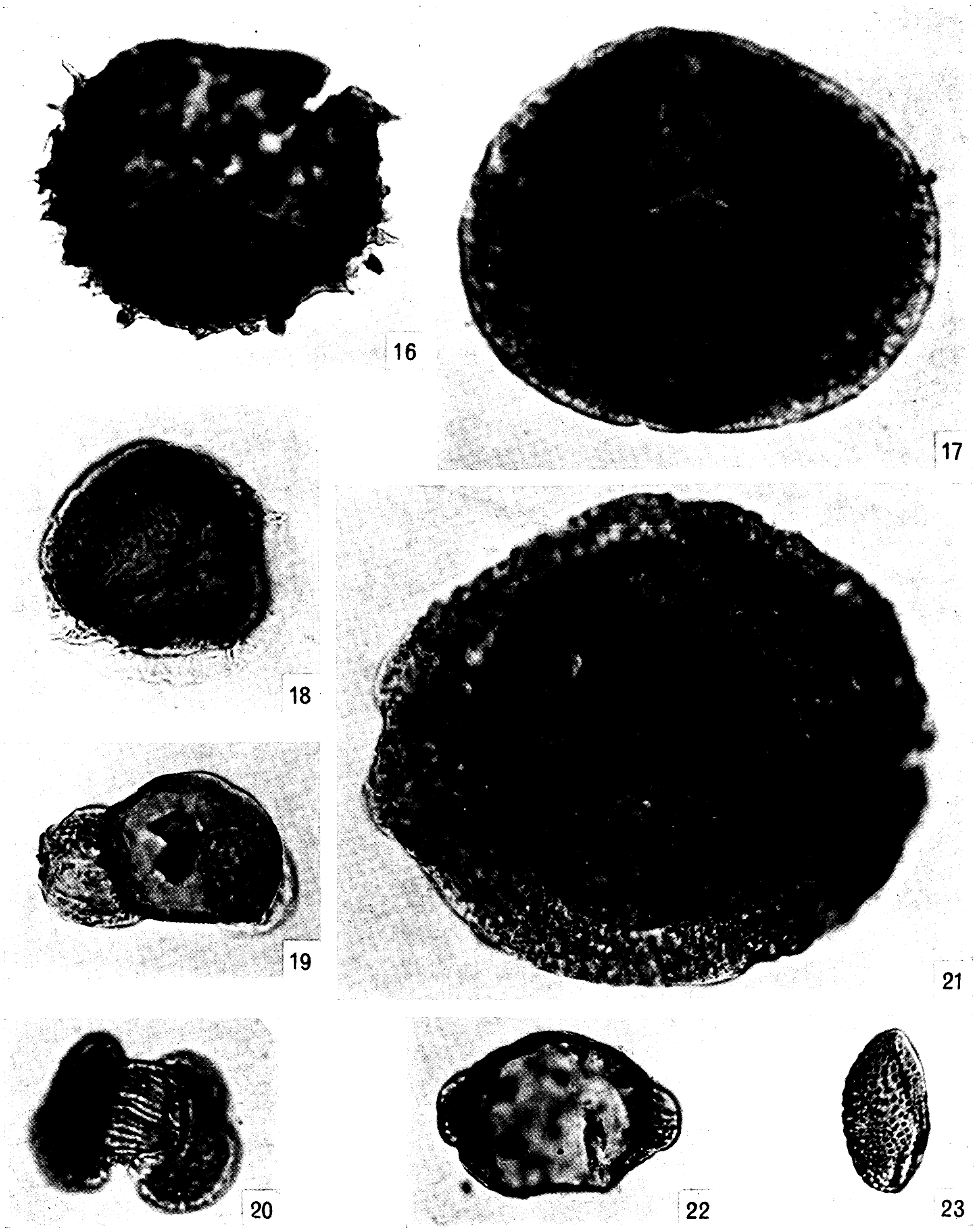


14



15

(*Facing p.* 28)


16
17
18
19
20
21
22
23

described a species which he named *Sahnisporities reticulatus* which is strikingly similar to *Illinites kosankei*. Clarke (1965*a*) has also assigned specimens which he has referred to *Chordasporites singulichorda* Klaus but which from his illustrations bear a strong affinity to the form *I. kosankei*. Well-preserved and typical specimens of *I. kosankei* are quite distinct from the species *I. chitonoides*, nevertheless it is often difficult to distinguish the specific identity of many specimens.

I. kosankei has been found in the lower Muschelkalk by Mädler (*S. reticulatus*), the Upper Buntsandstein by Klaus and in the Keuper Waterstones and Lower Keuper Sandstones by Clarke (*C. singulichorda*). We have also found specimens of *I. kosankei* in samples from the Solling sequence of Germany.

(*i*) *Aequitriradites minor* Mädler 1964*a*. Figure 18, plate 2

Mädler (1964*a*) defined and named the above species and assigned it to the genus *Aequitriradites of* Delcourt & Sprumont (1955).

Mädler described the above specimens of *A. minor* from a sample of the Lower Muschelkalk in Germany. He did not record the species from the underlying Upper Buntsandstein deposits. *A. minor* has been consistently found in Lower Muschelkalk sediments in all sections examined and indeed would appear to have a range restricted to this interval.

(*j*) *Microcachryidites sittleri* Klaus 1964. Figure 19, plate 2

Klaus (1964) defined and named the above species and assigned it to the genus *Microcachryidites* of Cookson (1947) as emended by Couper (1953). Mädler (1964*a*) has described specimens which he has assigned to the species *Minutosaccus acutus*. We believe that this species is synonymous with *M. sittleri* of Klaus.

Clarke (1965*a*) has described specimens of a palynomorph species from the Lower Keuper of England, which he named *Alisporites minutisaccus*. This species too is most probably closely related to, if not identical with, Klaus's *M. sittleri*.

Klaus has recorded *M. sittleri* from the Upper Buntsandstein of Germany and Mädler reported the same species from the Lower Muschelkalk, which is similar to its range as found in outcrop and well samples in this paper.

(*k*) *Striatoabieites balmei* Klaus 1964. Figure 20, plate 2

Klaus (1964) described the above species from the Muschelkalk of Italy, France and Germany and assigned it to the genus *Striatoabieites* of Sedova (1956). Later in the same

---

Description of plate 2

Figures 16. *Spinotriletes echinoides* Mädler. Shell/Esso 49/26–1 (North Sea) Upper Buntsandstein.
17. *Illinites kosankei* Klaus. Brigitta Wisloh T2 (Germany) Lower Muschelkalk.
18. *Aequitriradites minor* Mädler. Shell/Esso 49/26–1 (North Sea) Lower Muschelkalk.
19. *Microcachryidites sittleri* Klaus. Shell/Esso 49/26–1 (North Sea) Middle Muschelkalk.
20. *Striatoabieites balmei* Klaus. Shell/Esso 44/2–1 (North Sea) Muschelkalk.
21. *Illinites chitonoides* Klaus. Shell/Esso 44/2–1 (North Sea) Muschelkalk.
22. *Minutosaccus potoniei* Mädler. Shell/Esso 49/26–1 (North Sea) Upper Muschelkalk.
23. *Monosulcites perforatus* Mädler. Shell/Esso 49/26–1 (North Sea) Lower Keuper.

year Mädler (1964*a*) proposed a new generic and specific name, *Thuringisaccus multistriatus* for a species of palynomorph found in the Upper Buntsandstein of Germany. There is little doubt that Mädler's and Klaus's species are identical. In this paper we have adopted the name of *S. balmei* after Klaus.

S. balmei is commonly found in sediments of the Upper Buntsandstein, and the Lower and Middle Muschelkalk. Its 'top occurrence' has been taken in operational petroleum geology as marking the top of the Middle Muschelkalk.

(*l*) *Illinites chitonoides* Klaus 1964. Figure 21, plate 2

Klaus (1964) defined and named the above species assigning it to the genus *Illinites* of Kosanke (1950) as emended by himself. Mädler (1964) later in the same year described specimens of palynomorphs which he assigned to the genus and species *Succinctisporites grandior* of Leschik (1955). Mädler's specimens of *S. grandior* belong to the same species described by Klaus as *I. chitonoides*. However, we find it difficult to refer either Klaus's or Mädler's specimens to the type *S. grandior* as shown by Leschik. Thus at present we would prefer to relate these specimens and those found by ourselves to Klaus's *Illinites chitonoides*.

I. chitonoides has been found in samples of the Lower, Middle and Upper Muschelkalk and is fairly abundant in the lower part of the Lower Keuper in Germany. We have not found this species in younger horizons, e.g. Middle Keuper which may be another reason to exclude Leschik's form *S. grandior* from this species.

(*m*) *Minutosaccus potoniei* Mädler 1964*a*. Figure 22, plate 2

The genus and species *Minutosaccus potoniei* were defined and named by Mädler (1964*a*).

M. potoniei is an important palynomorph marker species for the Meso-Triassic interval.

(*n*) *Monosulcites perforatus* Mädler 1964*a*. Figure 23, plate 2

Mädler (1964*a*) described the above species and assigned it to the genus *Monosulcites* of Cookson (1947) as emended by Couper (1953).

M. perforatus has been found in sediments of the Upper Muschelkalk and Lower Keuper of Germany.

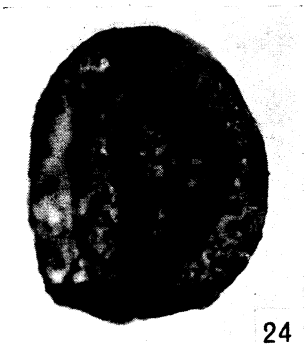
(*o*) *Aratrisporites scabratus* Klaus 1960. Figure 24, plate 3

Klaus (1960) has defined and named the above species from samples of Carnian age and assigned it to the genus *Aratrisporites* of Leschik (1955) as emended by himself. In the North

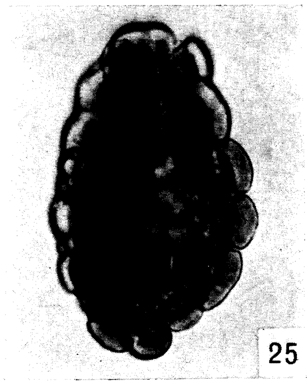
---

Description of plate 3

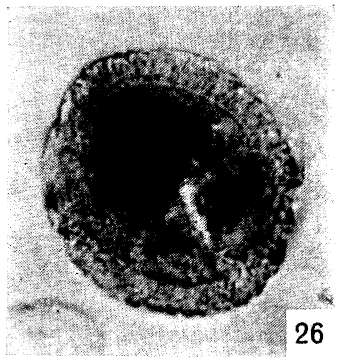
Figures 24. *Aratrisporites scabratus* Klaus. Shell/Esso 44/2–1 (*North Sea*) *Munschelkalk*.
25. *Camerosporites secatus* Leschik. Copesep SMB–201 (France) Middle Keuper.
26. *Enzonalasporites vigens* Leschik. Mount Triona (Sicily) Carnian.
27. *Conbaculatisporites longdonensis* Clarke. Shell/Esso 44/2–1 (North Sea) Muschelkalk.
28. *Ovalipollis ovalis* Krutzsch. Laneuvelle (France) Rhaetic.
29. *Ricciisporites tuberculatus* Lundblad. Shell/Esso 44/2–1 (North Sea) Keuper.
30. *Zebrasporites interscriptus* (Thiergart) Klaus. Shell/Esso 44/2–1 (North Sea) Keuper.



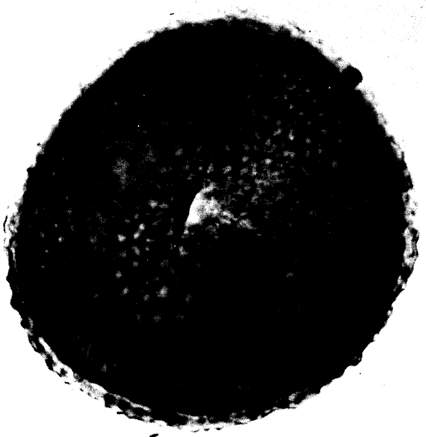
24



25

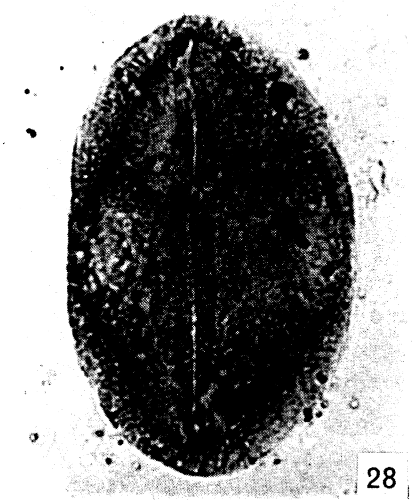


26

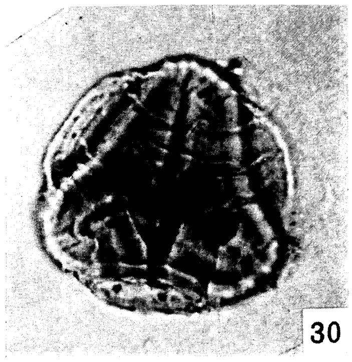


27

29



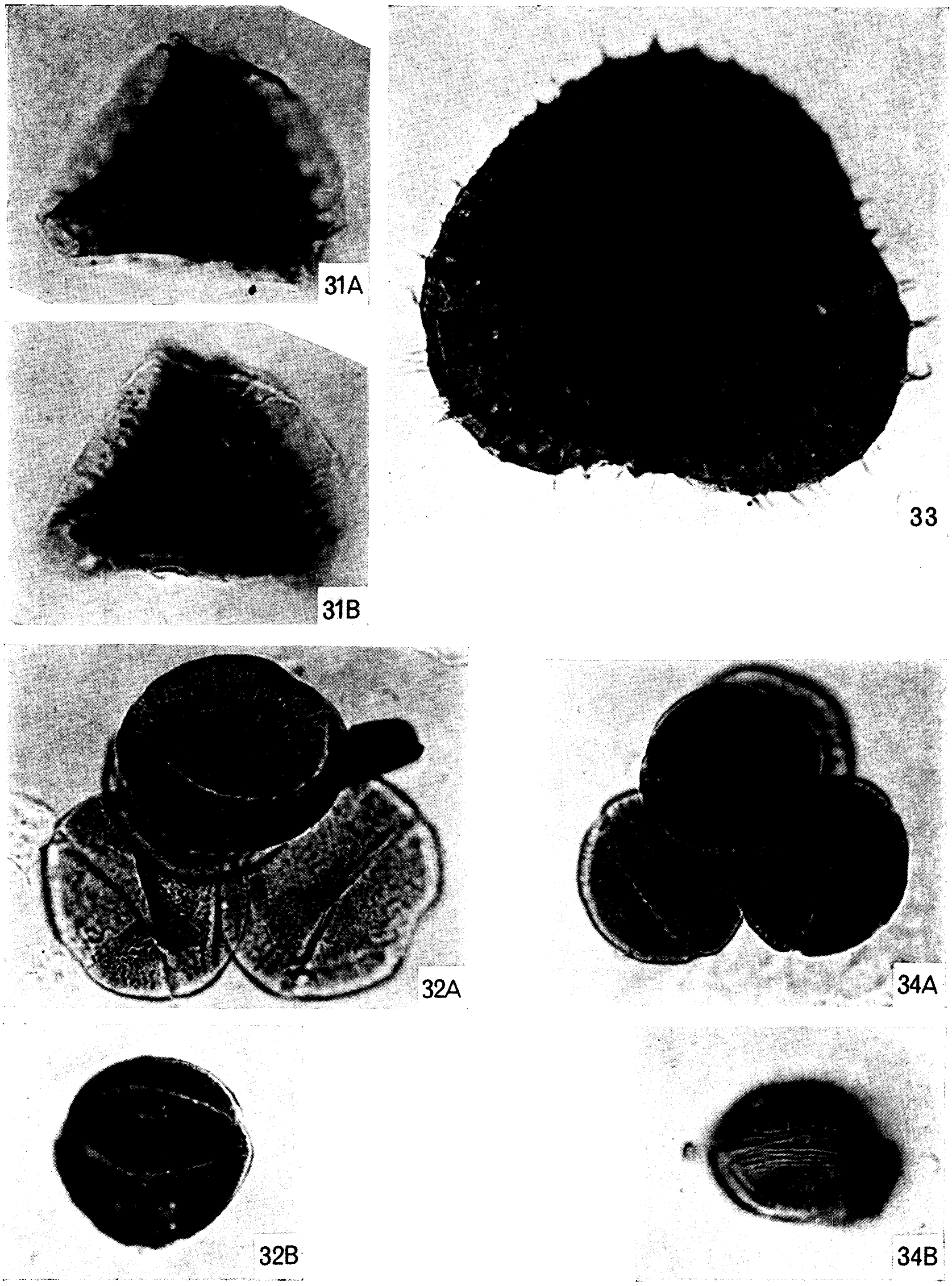
28



30

(*Facing p.* 30)

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES



PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Sea wells two forms of *Aratrisporites* have been observed: a smaller form with short echinae which appear to be easily removed, giving the specimens a somewhat perforate and granular appearance and a larger form with longer spines. The former we have referred to *A. scabratus* and the latter may be compared with Klaus's *Saturnisporites palettae*.

(*p*) *Camerosporites secatus* Leschik 1955. Figure 25, plate 3

The genus and species *Camerosporites secatus* was first described from specimens found in the Middle Keuper (Schilfsandstein) of Switzerland. Mädler (1964*b*) has referred to *C. secatus* as a species which is characteristic of the lower Middle Keuper of Germany. Clarke (1965*a*) has emended the generic description of *Camerosporites* and recorded specimens of *C. secatus* from the Arden Sandstones of Worcestershire.

The distribution of *C. secatus* is of stratigraphical importance. It has an extremely short range within the uppermost Gipskeuper and the Schilfsandstein in the Germanic facies of the Triassic. *C. secatus* is considered as being restricted to the Carnian Stage and indeed its 'top occurrence' is taken in this paper as demarcating the Carnian–Norian boundary.

(*q*) *Enzonalasporites vigens* Leschik 1955. Figure 26, plate 3

The genus and species of *Enzonalasporites vigens* were defined and named by Leschik (1955), who described specimens found in samples from the Middle Keuper (Schilfsandstein) of Switzerland.

E. vigens occurs throughout the Carnian and Nornian stages. It has not as yet been found in sediments of Rhaetian age. Its top occurrence has therefore been taken as indicating the Norian boundary.

(*r*) *Conbaculatisporites longdonensis* Clarke 1965*a*. Figure 27 plate 3

Clarke (1965*a*) defined and named the above species and assigned it to the genus *Conbaculatisporites of* Klaus 1960. The micro-baculate sculpture and small tri-radiate mark are in agreement with Clarke's specific diagnosis although the overall circular shape deviates somewhat from the triangular form given by Klaus in his generic description.

C. longdonensis is found in abundance in the Neo-Triassic and its 'top occurrence' would appear to demarcate the Norian–Rhaetian boundary.

(*s*) *Ovalipollis ovalis* Krutzsch 1955. Figure 28, plate 3

The genus and species *Ovalipollis ovalis* were first described from specimens found in the Rhaeto-Liassic of Germany. Leschik (1955) later described the same species from the Schilfsandstein of Switzerland under the name *Unatextisporites mohri*. Klaus (1960) emended the generic description of *Ovalipollis* as given by Krutzsch. He further named a new species, *O. lunzensis*, found in the Lunzer-schichten of known Carnian age. Clarke (1965*a*) has placed *O. lunzensis* of Klaus within the species *O. ovalis* as defined by Krutzsch.

Description of plate 4

Figures 31A and 31B. *Perinosporites thuringiacus* Schulz. Shell/Esso 44/2–1 (North Sea) Rhaetic.
32A and 32B. *Circulina meyeriana* Klaus. Laneuvelle (France) Rhaetic.
33. *Heliosporites altmarkensis* Schulz. Venary–les–Lanmes (France) Pliensbachian.
34A and 34B. *Classopollis torosus* (Reissinger) Balme. Laneuvelle (France) Rhaetic.

O. ovalis is an excellent guide-fossil of the Neo-Triassic as it has been reported from the Carnian, Norian and the Rhaetian stages and is known from the Middle and Upper Keuper of the Germanic Triassic. The 'top occurrence' of *O. ovalis* has been taken as indicating the top of the Triassic.

(*t*) *Ricciisporites tuberculatus* Lundblad 1959. Figure 29, plate 3

The genus and species *Ricciisporites tuberculatus* were first described from specimens from the Rhaeto–Liassic deposits of Sweden. *R. tuberculatus*, which is a large and easily identifiable palynomorph, shows a wide variety of forms within the limits of its specific diagnosis. In the North Sea wells some four variants have been observed, whose distributive patterns may yield further stratigraphical information in the future.

R. tuberculatus appears to be restricted to Norian and Rhaetian. It occurs in abundant numbers in the Rhaetic but may also be found in early Jurassic rocks as suggested by Schulz (1962).

(*u*) *Zebrasporites interscriptus* (Thiergart 1949) Klaus 1960. Figure 30, plate 3

Thiergart (1949) defined and named the species *Sporites interscriptus*. Klaus (1960) later assigned this species to his genus *Zebrasporites*. *Z. interscriptus* is very closely related to the species *Z. corneolus* (Leschik 1955) Klaus (1960).

Z. interscriptus has been reported from Keuper sediments of central Germany (Thiergart 1949). We have found specimens in late Carnian, Norian and Rhaetian deposits.

(*v*) *Perinosporites thuringiacus* Schulz 1962. Figures 31 *A*, *B*, plate 4

The genus and species *Perinosporites thuringiacus* was first described from specimens found in Rhaetic sediments of central Germany. This species may belong to the genus *Zebrasporites*.

P. thuringiacus is an excellent guide fossil for the Rhaetian and indeed would appear to be restricted to the interval.

(*w*) *Circulina meyeriana* Klaus 1960. Figure 32 *A*, *B* plate 4

The genera *Circulina* and *Classopollis* (*Corollina*) constitute the infraturma *Tetradopollenites* of Thomson & Pflug (1953) according to Klaus (1960). There is, we believe, good reason to make a generic distinction between forms assigned to *Circulina* and those assigned to *Classopollis* (*Corollina*). Klaus (1960) defined and named the above species and assigned it to the genus *Circulina* of Maljawkina (1949). It is quite possible that the form *Classopollis reclusus* cited by Mädler (1964) is identical with *C. meyeriana*.

Klaus (1960) has given the stratigraphical range of *C. meyeriana* as Norian, Rhaetian and early Jurassic. Certainly the species has not been found in association with *Camerosporites secatus* and Klaus in his extensive and thorough palynological studies of the Carnian has only recorded one specimen.

(*x*) *Heliosporites altmarkensis* Schulz 1962. Figure 33, plate 4

Heliosporites altmarkensis was first figured but not named by Reissinger (1950). Danzé-Corsin & Laveine (1963) named this species after Reissinger and placed it within the genus *Styzisporites* of Cookson & Dettman (1958) as *S. reissingeri*. However, Schulz (1962) had previously described, illustrated and named this species as *H. altmarkensis*, which has priority and is adopted in this paper.

Leschik (1955) has also described and illustrated a similar species as *Tuberculatisporites magnispinosus* from the Middle Keuper (Schilfsandstein) of Switzerland. This form is excluded by Schulz in his definition of the genus *Heliosporites*.

H. altmarkensis is regarded by most authors as a guide fossil for the Liassic and especially the early Liassic. Danzé-Corsin & Laveine (1963) and Levet-Carette (1964) have recorded *H. altmarkensis* from sediments of Hettangian age. Schulz (1962) has placed it within the Lias α. It would appear to have a possible range from Hettangian to Pliensbachian, i.e. early Liassic, although it perhaps cannot quite be excluded from Rhaetian sediments.

(*y*) *Classopollis torosus* (Reissinger 1950) Balme 1957. Figure 34 *A*, *B*, plate 4

The genus *Classopollis* (Pflug 1953) as emended by Pocock & Jansonius (1961) is preferred to that of *Corollina* (Maljawkina 1949) as emended by Klaus (1960). This preference is based solely upon the criteria of usage and familiarity and it is quite possible that the generic name *Corollina* may have priority. Thus the combination of *C. torosus* by Balme (1957) has been adopted in this paper.

Burger (1965) has recently reviewed the genus *Classopollis* and emended the specific description of C. *torosus* given by Couper (1958). Burger further maintains the specific identity and separation of *C. classoides* (Pflug 1953) Pocock & Jansonius (1961) from *C. torosus* on the intectate nature of the exine of *C. classoides*. Since however the sculpture of *C. torosus* is difficult to detect and may indeed be worn away together with the tectum giving the appearance of being intectate, there would appear to be no adequate reason to maintain *C. classoides* as a distinct species. Thus for practical purposes *C. classoides* is taken here as the same species as *C. torosus* as originally suggested by Couper (1958).

The majority of palynologists appear to favour a Rhaetian and younger age for *C. torosus*. Chaloner (1962) states that the species appears in the basal Rhaetian and extends into the Jurassic. *C. torosus*, however, is not so common in the Rhaetian and early Jurassic as *Circulina meyeriana* with which species *Classopollis torosus* has been confused by earlier writers.

The authors are grateful to the Royal Dutch/Shell Group and the Standard Oil Company (New Jersey) for permission to publish this paper.

They express their appreciation to the British Petroleum Company, who kindly made available geological data and sample material from their well Tetney Lock-1 and gave permission to present the results.

The authors would also like to acknowledge the authorization of the following companies to present their geological information:

Shell U.K. Exploration and Production Limited, London
N.V. Nederlandse Aardolie Maatschappij, Oldenzaal
Gewerkschaft Brigitta, Hannover.

They are also most grateful for the assistance and advice given by the staff of these companies and in particular they would like to thank the palynologists, G. A. Cramer, Th. Schröder and C. O. J. Diederix.

Finally, they are indebted to C. L. Slootweg and W. Geluk of Bataafse Internationale Petroleum Maatschappij N.V. The Hague for their respective efforts in the drafting of the figures and the preparation of the photographs shown in the text and plates.

References

Audley-Charles, M. G. Stratigraphic correlation of the Triassic Rocks of the British Isles. *Quart. J. Geol. Soc., Lond.* (In the Press.)

Balme, B. E. 1957 Spores and pollen grains from the Mesozoic of Western Australia. *Commonw. Sci. Industr. Res. Org. (Fuel Research) T.C.* **25.**

Boigk, H. 1959 Zur Bliederung und Facies des Buntsandsteins zwischen Harz und Emsland. *Geol. Jb.* **76**, 597.

Boigk, H. 1961 Ergebnisse und Probleme stratigraphischpalaogeographischer Untersuchungen im Buntsandstein Nordwest Deutschlands. *Geol. Jb.* **78**, 123.

Burger, D. 1965 Some new species of *Classopollis* from the Jurassic of The Netherlands. *Leidse Geol. Medl.* **33**, 63.

Chaloner, W. G. 1962 British Rhaetic and Triassic spores. *Pollen et spores* **4**, 2.

Clarke, R. F. A. 1965*a* Keuper miospores from Worcestershire, England. *Palaeontology* **8**, 294.

Clarke, R. F. A. 1965*b* British Permian saccate and monosulcate miospores. *Palaeontology* **8**, 322.

Cookson, J. C. 1947 Plant microfossils from the lignites of Kerguelen Archipelago. *B.A.N.Z. Antarctic Res. Exped.* 1929–1931 A, **2**, (8), 127.

Cookson, J. C. 1953 Difference in microspore composition of some samples from a bore at Comaum, South Australia. *Aust. J. Bol.* **1**, (3), 462.

Cookson, J. C. & Dettman, M. E. 1958 Some trilete spores from upper mesozoic deposits in the Eastern Australian Region. *Proc. Roy. Soc. Victoria* **70**, (2), 95.

Couper, R. A. 1953 Upper Mesozoic and Cainozoic spores and pollen grains from New Zealand. *N.Z. Geol. Surv. Palaeont. Bull.* **22.**

Couper, R. A. 1958 Mesozoic microspores and pollen grains, a systematic and stratigraphic study. *Palaeontographica* B **103**, 75.

Danze-Corsin, P. & Laveine, J. P. 1963 Flore infraliasique du Boulonnais. *Mém. Soc. Geol. Nord.* **13**, 1.

Delcourt, A. & Sprumont, G. 1955 Les spores et grains de pollen du Wealden du Hainaut. *Mém. Soc. Belge. Geol.* **5**, 1.

Edwards, W. & Trotter, F. M. 1954 The Pennines and adjacent areas. British Regional Geology. *Geol. Surv. G.B.*

Elliott, R. E. 1961 The stratigraphy of the Keuper Series in southern Nottinghamshire. *Proc. Yorks. Geol. Soc.* **33**, (2), 197.

Gutjahr, C. C. M. 1966 Carbonisation measurements of pollen grains and spores and their application. *Leidse Geol. Medl.* **38**, 1.

Haanstra, U. 1963 A review of the Mesozoic geological history in the Netherlands. *Verh. K. ned. geol. mijnb. Genoot.* **21**, (1), 35.

Hart, G. 1964 A review of the classification and distribution of the Permian miospore; *Disaccate striatiti. C.R. 5. Congr. Int. Carb.* **3**, 1171.

Herrmann, A. 1962 Epirogene Bewegungen im germanischen Buntsandsteinbecken und deren Bedeutung für lithostratigraphische Parallelisierungen wischen Nord–und Süddeutschland. *Geol. Jb.* **81**, 11.

Jansonius, J. 1962 The palynology of Permian and Triassic sediments; Peace River area, Western Canada. *Palaeontographica* B **110**, 35.

Kent, P. E. 1953 The Rhaetic Beds of the North-East Midlands. *Proc. Yorks. Geol. Soc.* **29**, (2), 117.

Klaus, W. 1960 Sporen der karnischen Stufe der Ostalpinen Trias. *Jb. Geol. Bund. Anst. Wien* **5**, 107.

Klaus, W. 1963 Sporen aus dem südalpinen Perm. *Jb. Geol. Bund. Anst. Wien.* **106**, 229.

Klaus, W. 1964 Zur sporenstratigraphischen Einstufung von gipsführenden Schichten in Bohrungen. *Erdöl* (Wien) **80**, (4), 119.

Klaus, W. 1965 Zur Einstufung alpiner Salzstone mittels Sporen. *Verh. Geol. Bund. Anst. Wien G.* 288.

Klein, G. de 1962 Sedimentary structures in the Keuper Marl. *Geol. Mag.* **99**, (2), 137.

Kosanke, R. M. 1950 Pennsylvanian spores of Illinois and their use in correlation. *Illinois State Geol. Surv. Bull.* **74**, 1.

Krutzsch, W. 1955 Uber einige liassiche angiospermide Sporomorphen. *Z. Geol.* **4**, 65.

Lees, G. M. & Taitt, A. H. 1945 The geological results of the search for oilfields in Great Britain. *Quart. J. Geol. Soc. Lond.* **101**, 255.

Leschik, G. 1955 Die Keuperflora von Neuewelt bei Basel. 2. Die Iso- und Mikrosporen. *Schweiz. Paläont.* **72**, 1.

Leschik, G. 1956 Sporen aus dem Salzton des Zechstein von Neuhaf (bei Fulda). *Palaeontographica* B **100**, 122.

Levet-Carette, J. 1964 Microflore Infraliasique du Boulonnais (carriere Napoleon). *Ann. Soc. Geol. Nord.* **84**, 1.

Lundblad, B. 1959 On *Ricciisporites tuberculatus* and its occurrence in certain strata of the 'Hollviken 11' boring in S. W. Scania. *Grana Palynologica*, **2**, (1), 77.

Mädler, K. 1964*a* Die geologische Verbreitung von Sporen und Pollen in der Deutschen Trias. *Beih. Geol. Jb.* **65.**

Mädler, K. 1964*b* Bemerkenswerte Sporenformen aus dem Keuper und unteren Lias. *Fortschr. Geol. Rheinld. Westf.* **12**, 169.

Maljawkina, W. S. 1949 Bestimmungsschlüssel der Sporen und Pollen von Jura und Kreide. *Arb. Erdölgeol. Inst. Wnigri* **33.**

Naumova, S. N. 1953 Sporo-pollen complexes of the Upper Devonian of the Russian platform and their stratigraphical value. *Tr. Inst. geol. nauk. Akad. SSSR* **143.**

Nilsson, T. 1958 Über das Vorkommen eines mesozoischen Sapropelgesteins in Schonen. *Lunds. Univ. Arsskr. Adv.* (2), **54**, 10.

Pannekoek, A. J. 1956 Geological history of the Netherlands. The Hague: *Gov. Print. and Stat. Office.*

Pant, D. D. 1955 On two disaccate spores from the Bacchus Marsh Tillite, Victoria (Australia). *Ann. Mag. Nat. Hist.* **8**, 757.

Pflug, H. D. 1953 Zur Entstehung und Entwicklung des angiospermiden Pollens in der Erdgeschichte *Palaeontographica* B **95**, 60.

Pocock, S. J. & Jansonius, J. 1962 The pollen genus *Classopollis* Pflug 1953. *Micropaleontology* **7**, (4), 439.

Potonie, R. & Klaus, W. 1954 Einige Sporengattungen des alpinen Salzgebirges. *Geol. Jb.* **68**, 317.

Reinhardt, P. 1961 Sporae dispersae ans dem Rhät Thüringens. *Mber. dt. Akad. Wiss. Berl.* **3**, 704.

Reinhardt, P. 1964*a* Über die Sporae dispersae der Thüringer Trias. *Mber. dt. Akad. Wiss. Berl.* **6**, (1), 46.

Reinhardt, P. 1964*b* Einige Sporenarten aus dem Oberen Buntsandstein Thüringens. *Mber. dt. Akad. Wiss. Berl.* **6**, (8), 609.

Reinhardt, P. & Schmitz, W. 1965 Zur Kenntnis der Sporae dispersae des mittel-deutschen Oberen Buntsandsteins. *Freiberger Forschungshefte*, C **182**, (Paläont.) 19.

Reissinger, A. 1950 Die Pollenanalyse ausgedehnt auf alle Sedimentgesteine der geologischen Vergangenheit. II. *Palaeontographica B*, **90**, 99.

Rose, G. N. & Kent, P. E. 1955 A *Lingula* bed in the Keuper of Nottinghamshire. *Geol. Mag. Lond.* **92**, 476.

Samoilovich, S. R. 1953 Pollen and spores from the Permian deposits of the Cherdinsk and Aktjubinsk Ural Regions. *Trudy Vnigri*, *N.S.*, **75**, (in Russian). (Trans. M. K. Elias., *Okla. Geol. Surv. Circ.* **56.**)

Schettler, H. 1962 Untersuchungsmethoden und stratigraphische Ergebnisse von Trias- und Zechstein-Bohrungen im Weser/Emsgebiet. *Z. Dtsch. Geol. Ges.* **115**, (1), 215.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

Schulz, E. 1962 Sporenpaläontologische Untersuchungen zur Rhät-Lias Grenze in Thüringen und der Altmark. *Geologie* **11**, (3), 308.

Schulz, E. 1964 Sporen und Pollen aus dem Mittleren Buntsandstein des germanischen Beckens. *Mber. dt. Akad. Wiss Berl.* **6**, (8), 597.

Sedova, M. A. 1956 Four new genera and type species. In: Materials for Palaeontology. New families and genera. *Trudy Vsesojuzn Geol. Inst.* **12.**

Sherlock, R. L. 1926 A correlation of the British Permo-Triassic rocks I. North England, Scotland and Ireland. *Proc. Geol. Ass. Lond.* **37**, 1.

Sherlock, R. L. 1948 The Permo-Triassic formations. London: Hutchinsons.

Shotton, F. W. 1956 Some aspects of the New Red Desert in Britain. *Lpool. Manchr. J.* **1**, (5), 450.

Teichmüller, R. 1964 Zur Stratigraphie and Inkohlung des jüngsten Oberkarbons (Silesium) in Nordwestdeutschland. *C.R.* 5 *Congr. Int. Carb.* **2**, 813.

Thiergart, F. 1949 Der stratigraphische Wert mesozoischer Pollen and Sporen. *Palaeontographica* B, **89.**

Thomson, P. W. & Pflug, H. D. 1953 Pollen and Sporen des mitteleuropäischen Tertiärs. *Palaeontographica* B **94**, 1.

Trusheim, F. 1963 Zur Gliederung des Buntsandsteins. *Erdöl. Z.* **79**, (7), 277.

Warrington, G. 1967 Correlation of the Keuper Series of the Triassic by miospores. *Nature, Lond.* **214**, 5095.

Wills, L. J. 1951 *Paleogeographical atlas.* London: Blackie & Son.

Wills, L. J. 1956 *Concealed coafields.* London: Blackie & Son.

Wilson, L. R. & Coe, E. A. 1940 Descriptions of some unassigned plant microfossils from the Des Moines series of Iowa. *Am. Midland Nat.* **23**, 182.

Wolburg, J. 1961 Sedimentations-Zyklen and Stratigraphie des Buntsandsteins in NW-Deutschland. *Geotekt. Forsch.* **14**, (I–II), 7.

Wolburg, J. 1962 Uber Schwellenbildungen in Mittleren Buntsandstein des Weser-Ems Gebietes. *Erdöl Z.* **78**, (4), 183.

Wurster, P. 1964 Krustenbewegungen, Meeresspiegel–Schwankungen und Klimaänderungen der Deutschen Trias. *Geol. Rundschau* **54**, 224.

PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

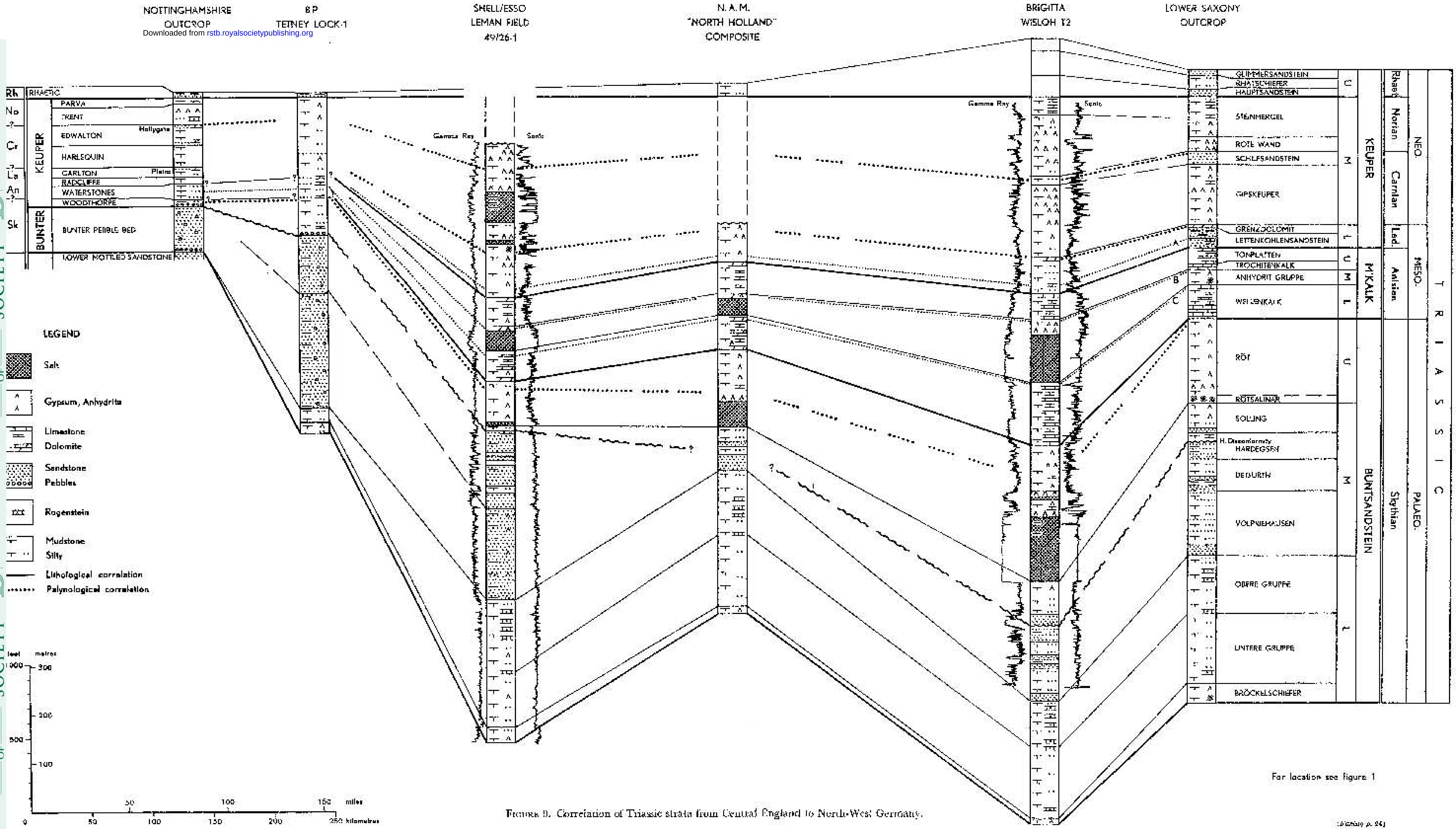
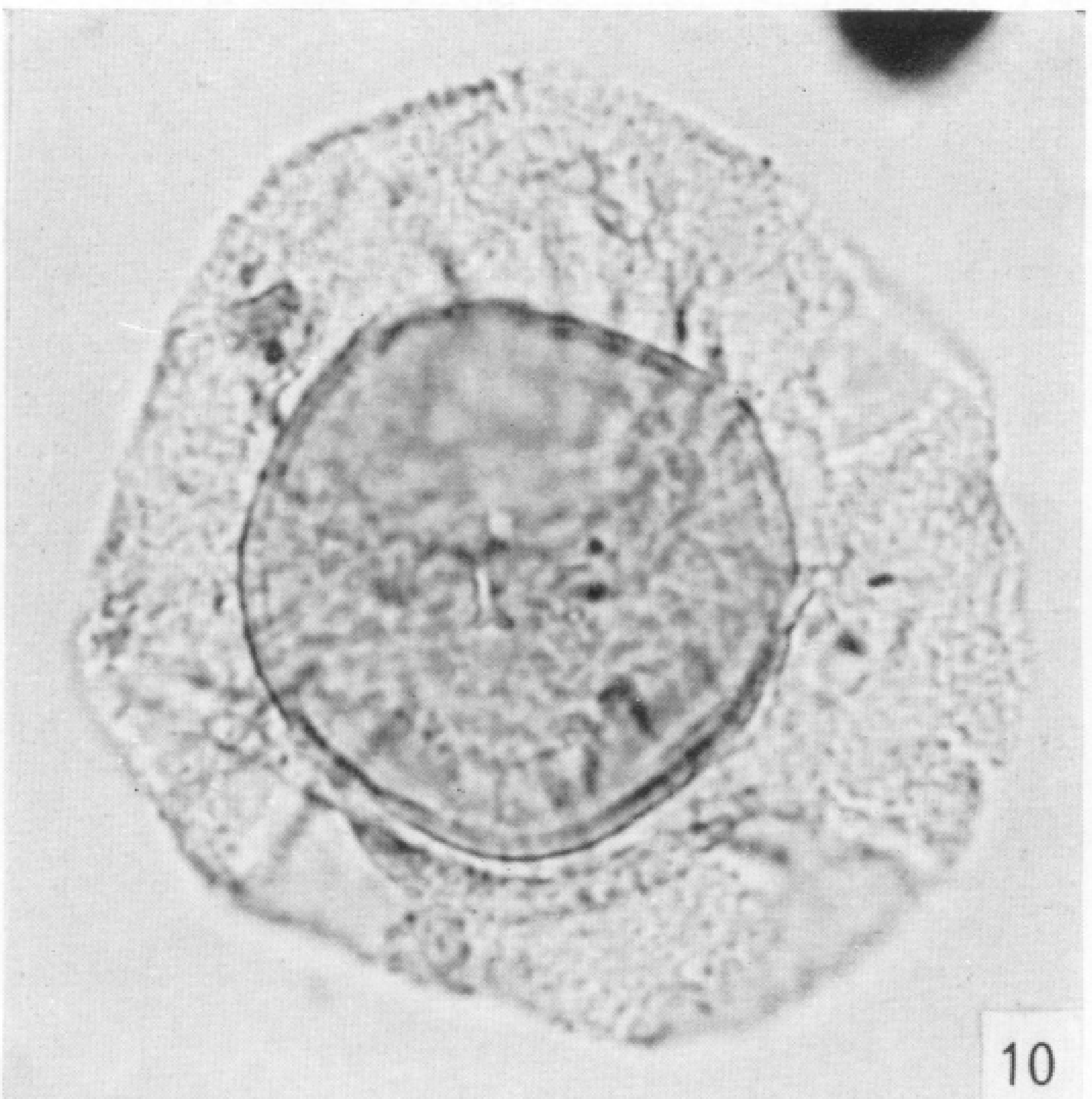
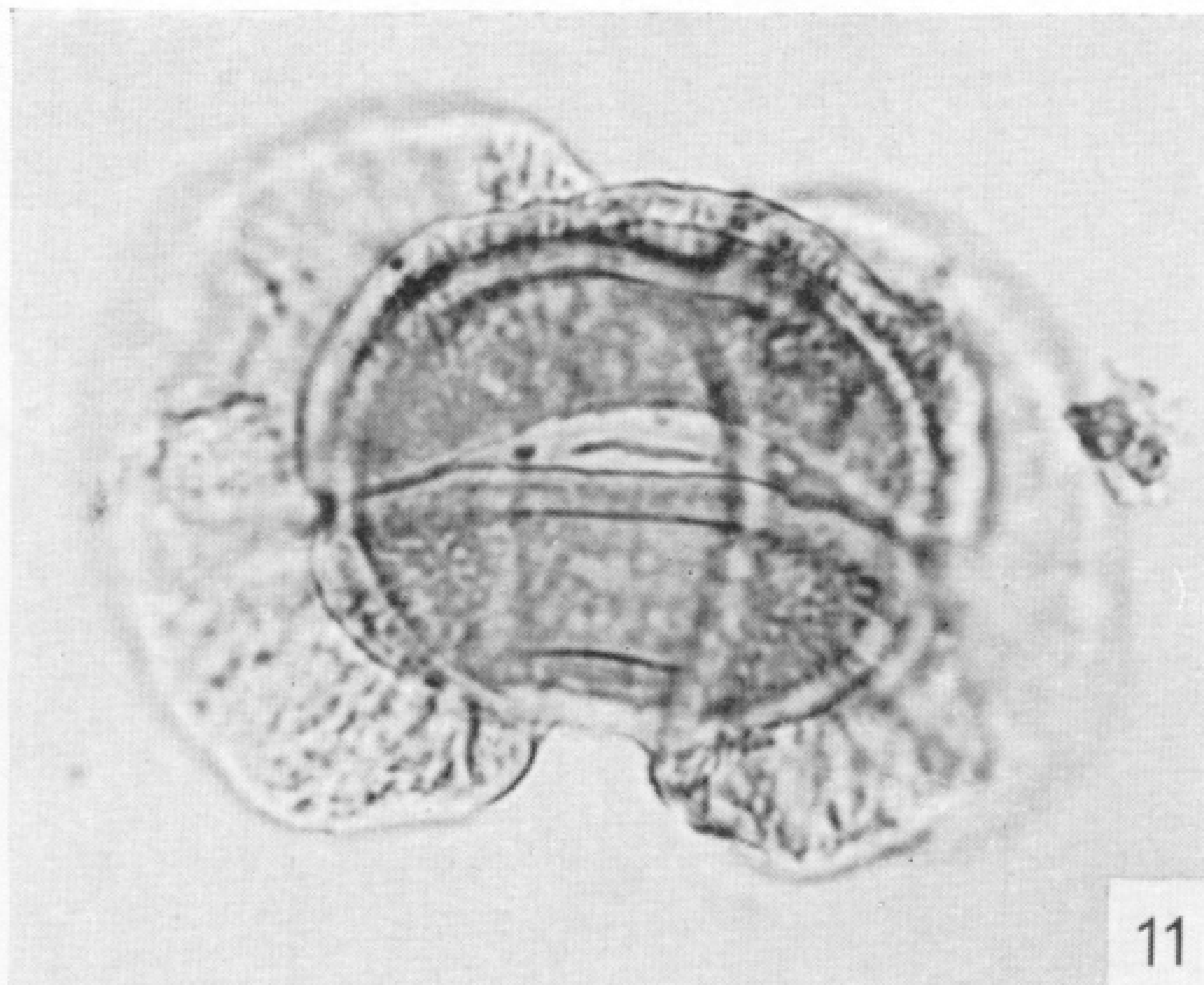
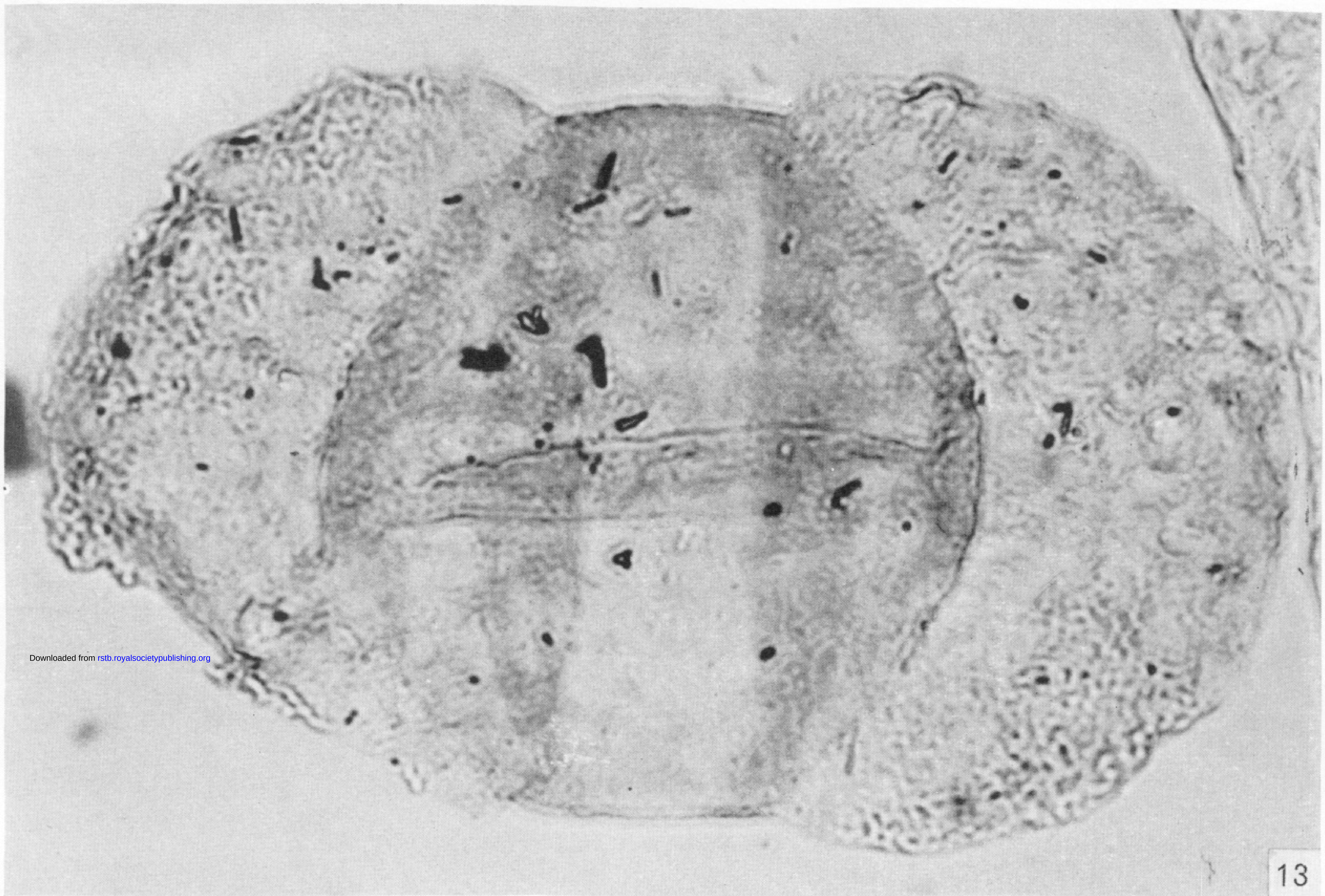


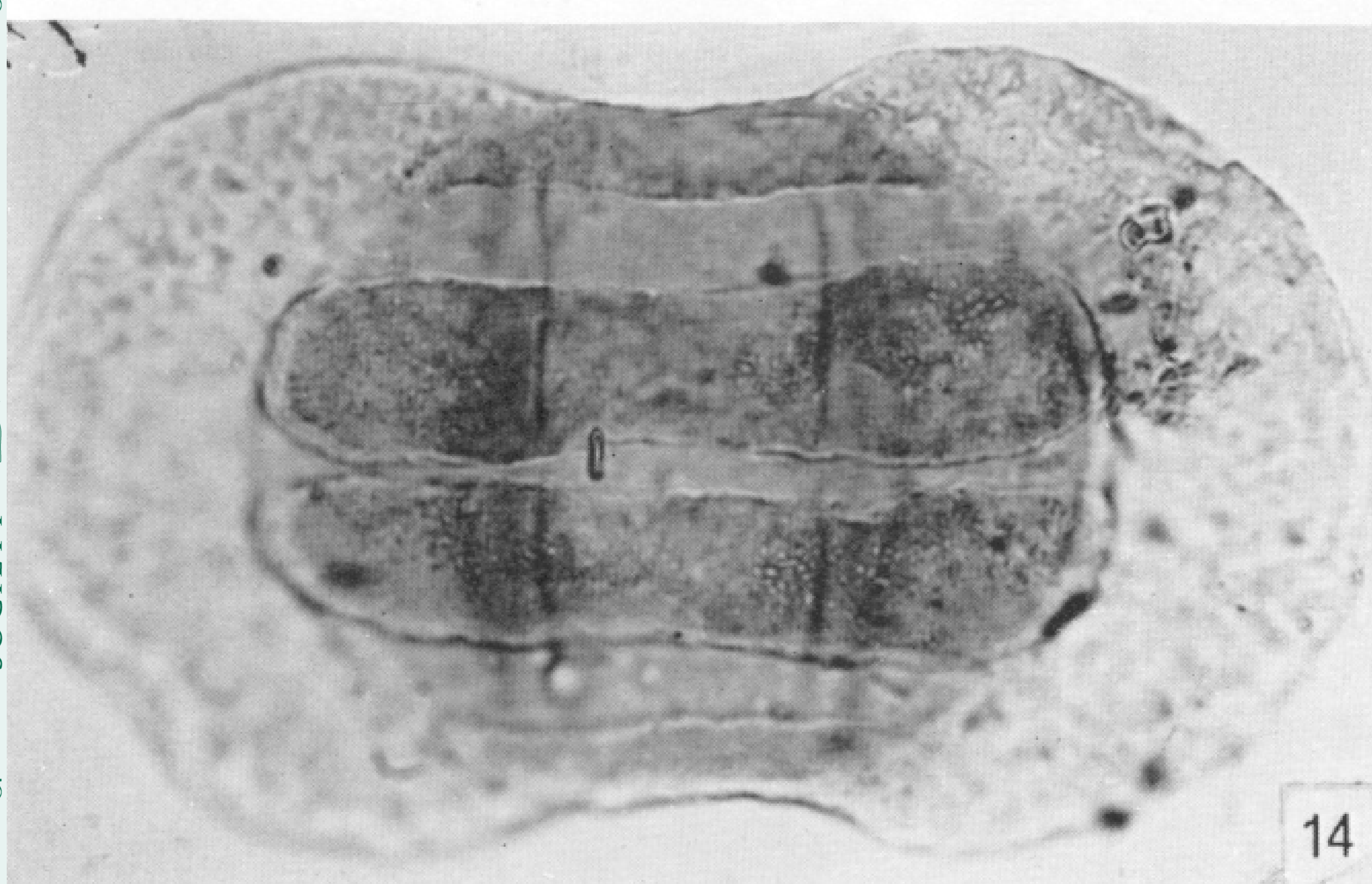
FIGURE 9. Correlation of Triassic strata from Central England to North-West Germany.

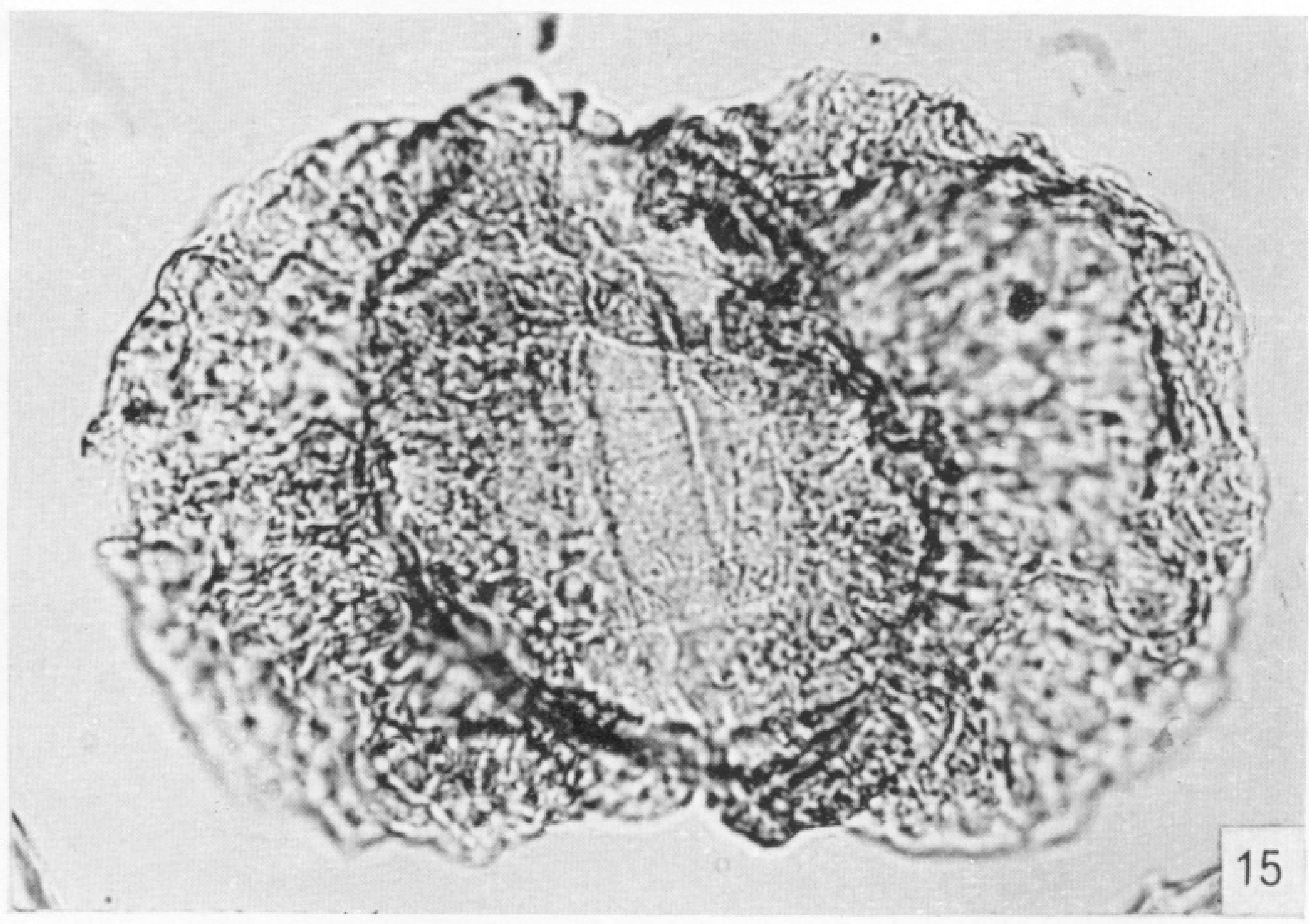

10

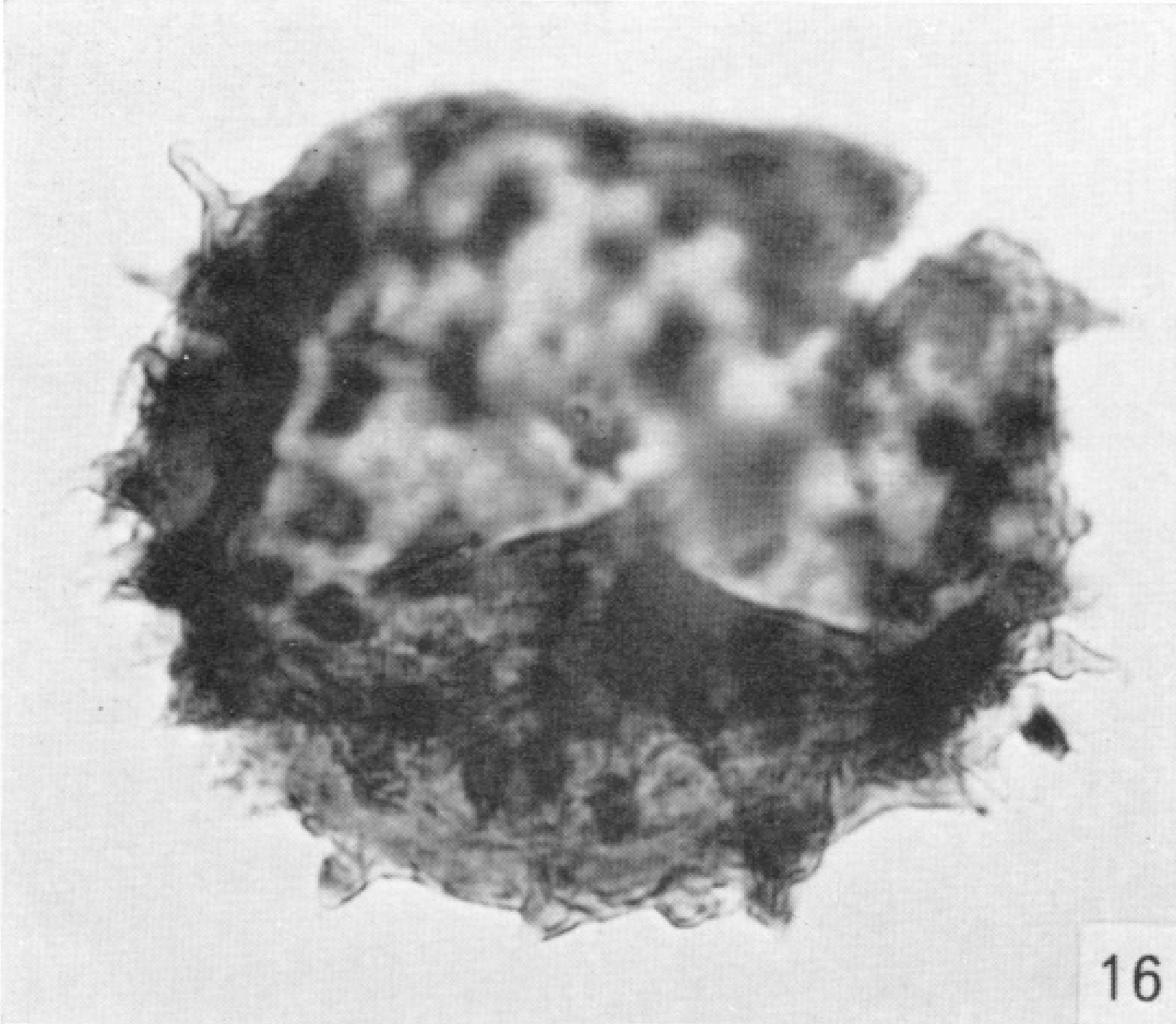

11

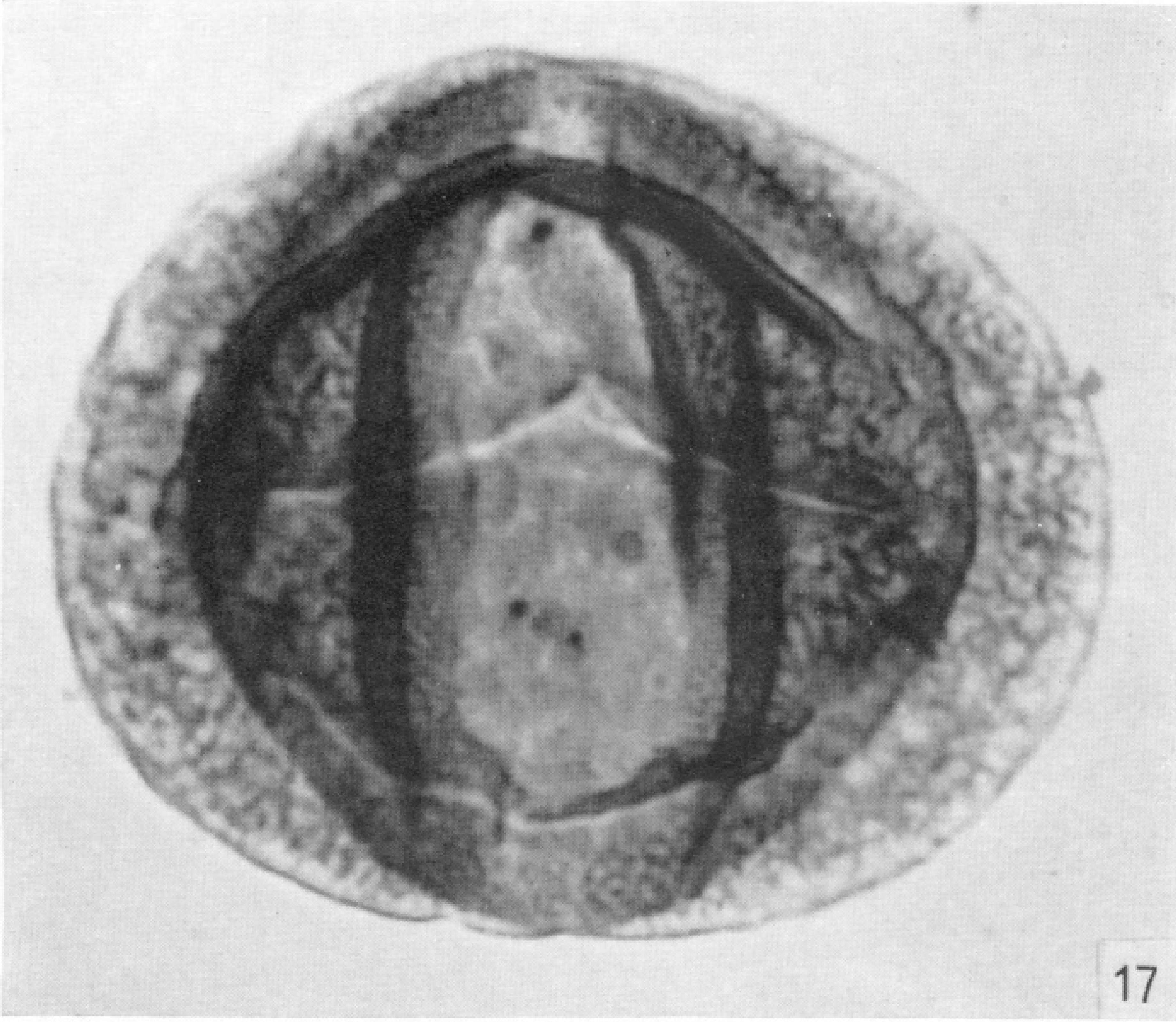

12

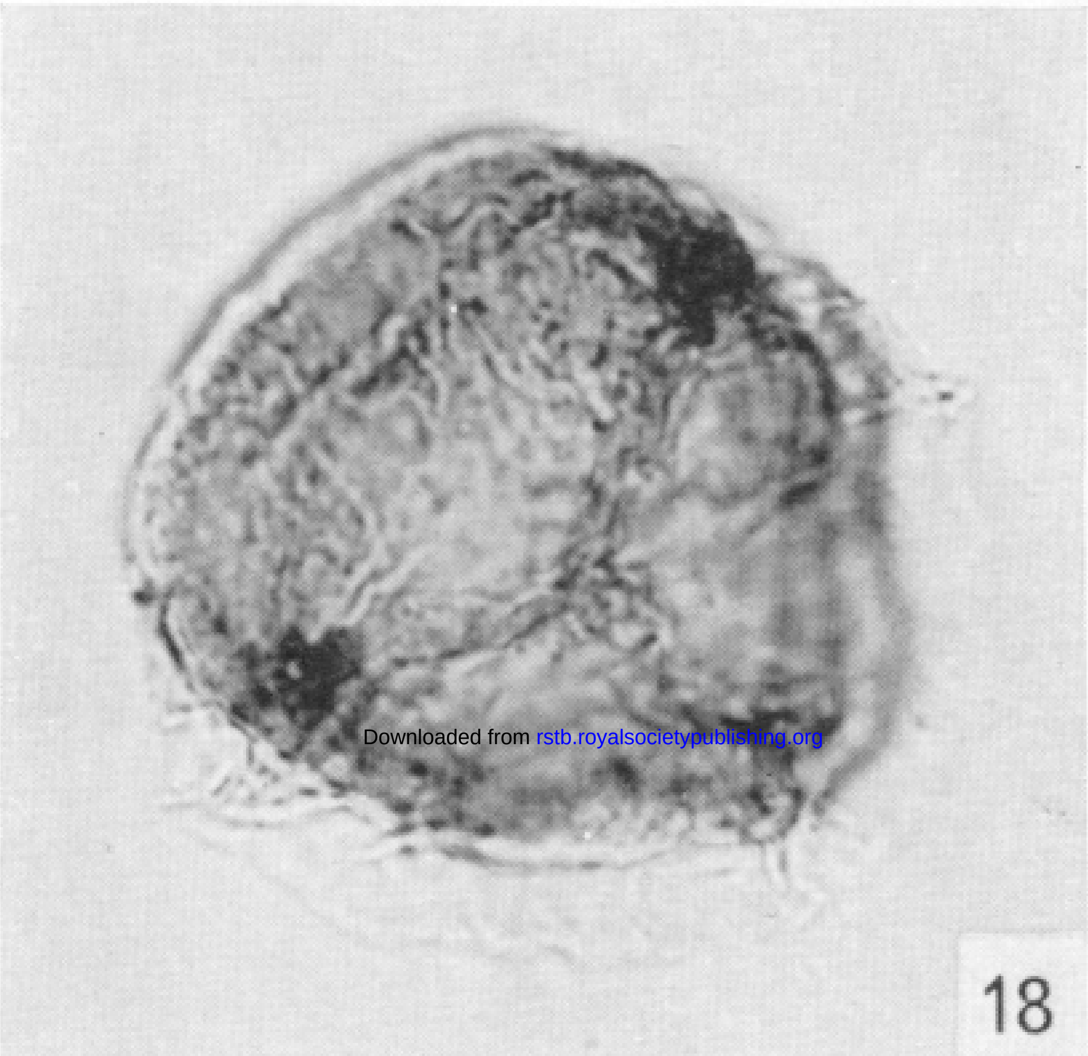

13

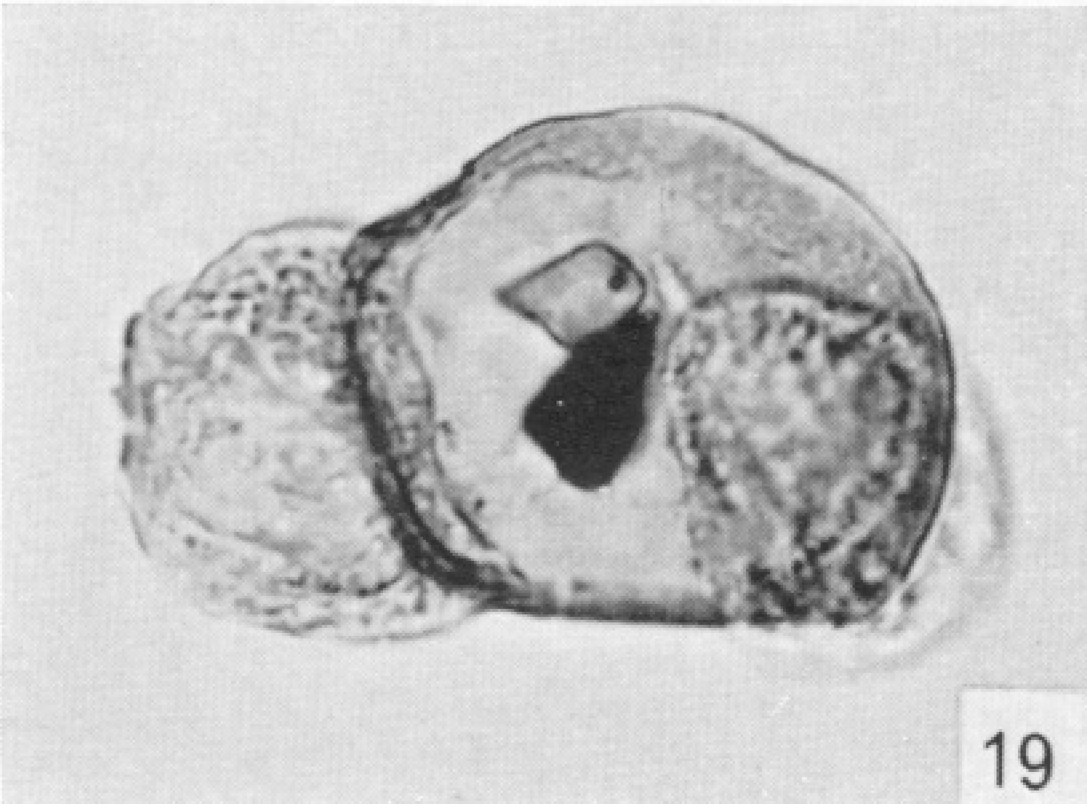

14

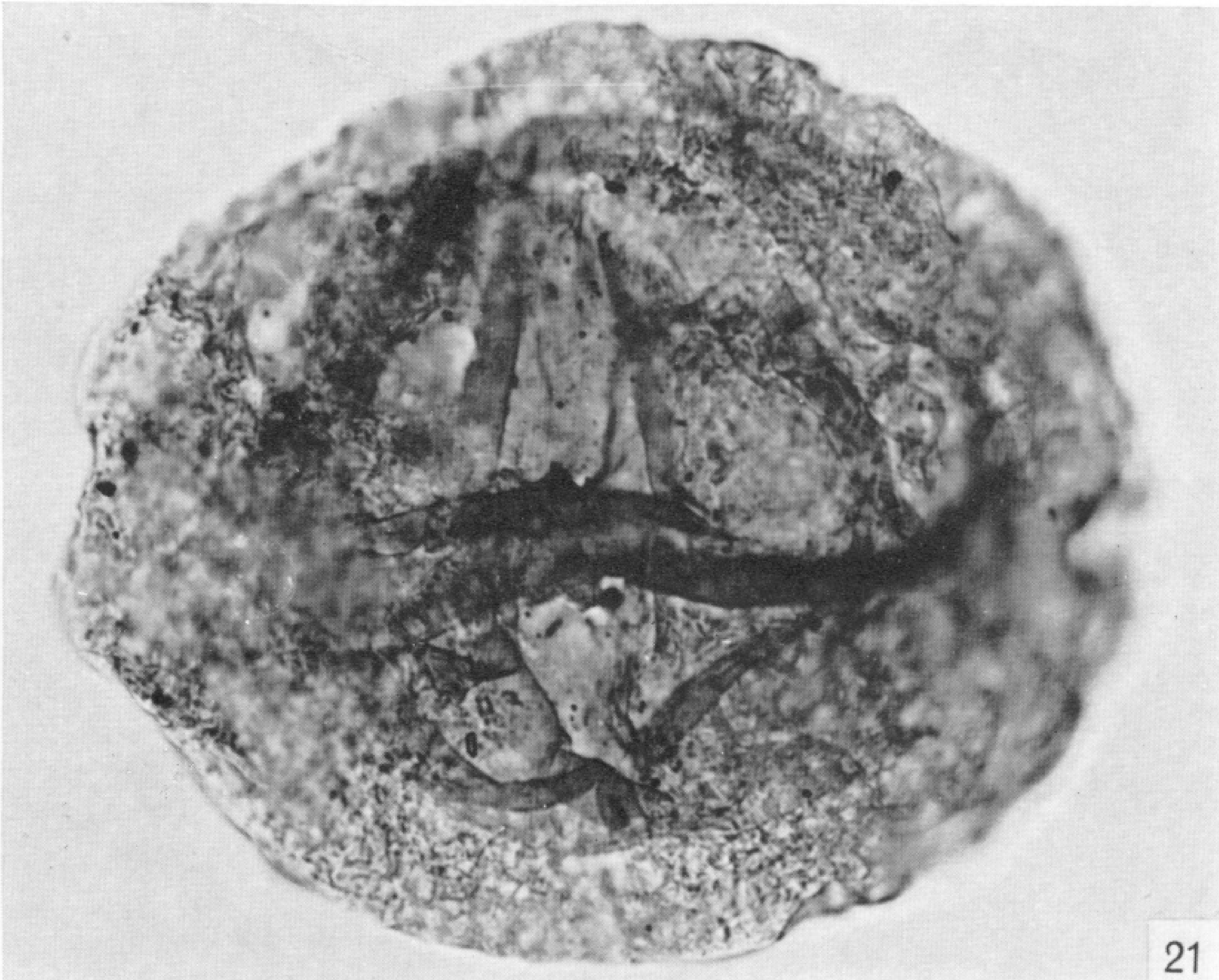

15

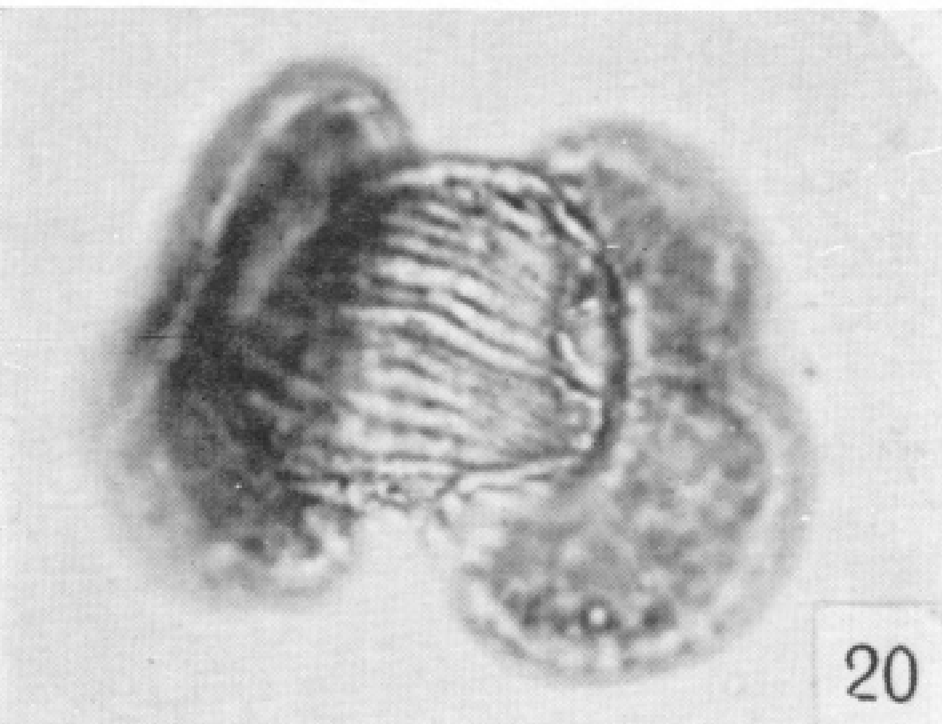

16

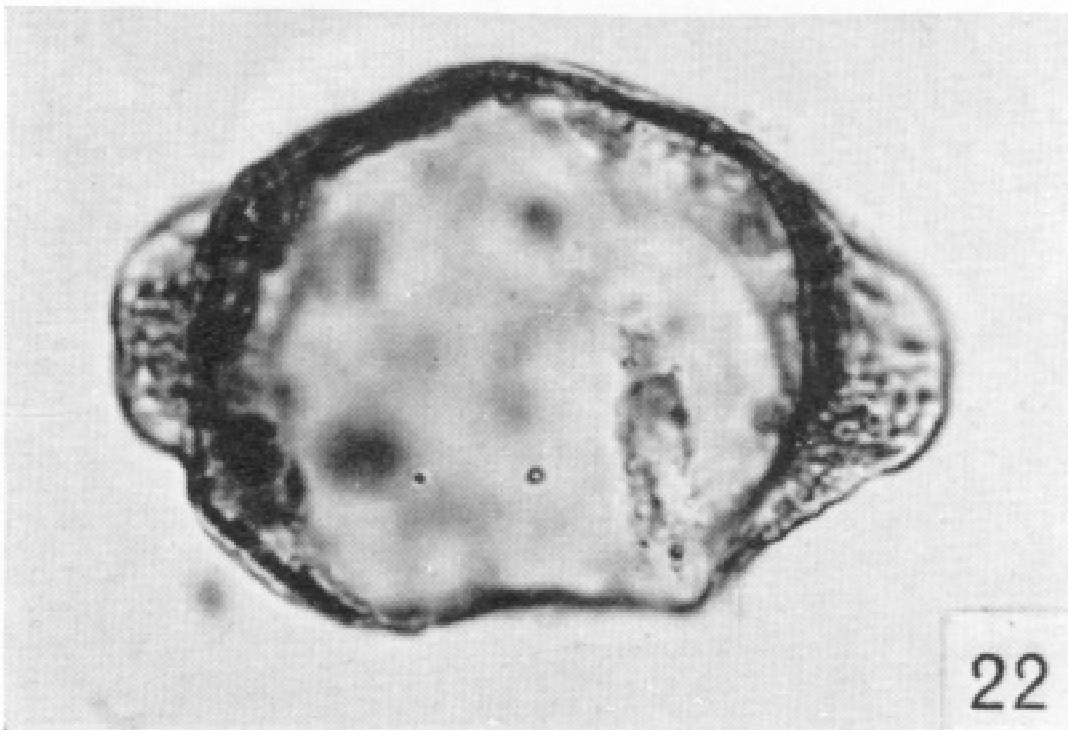

17


18


19

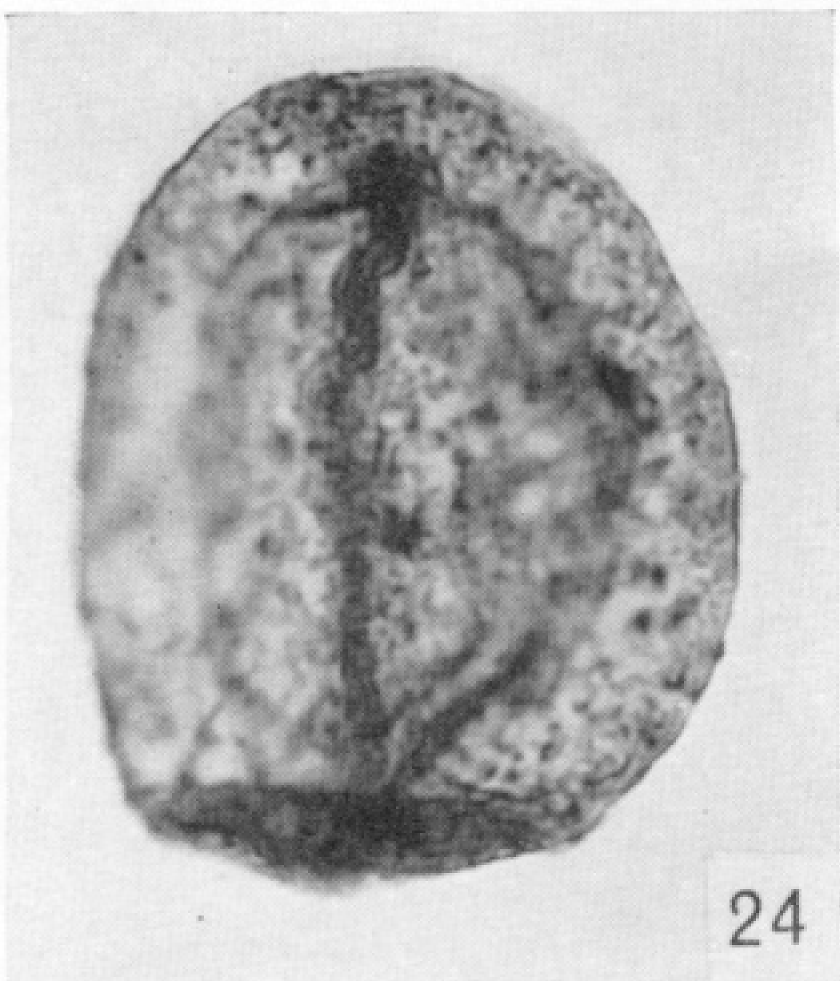

21

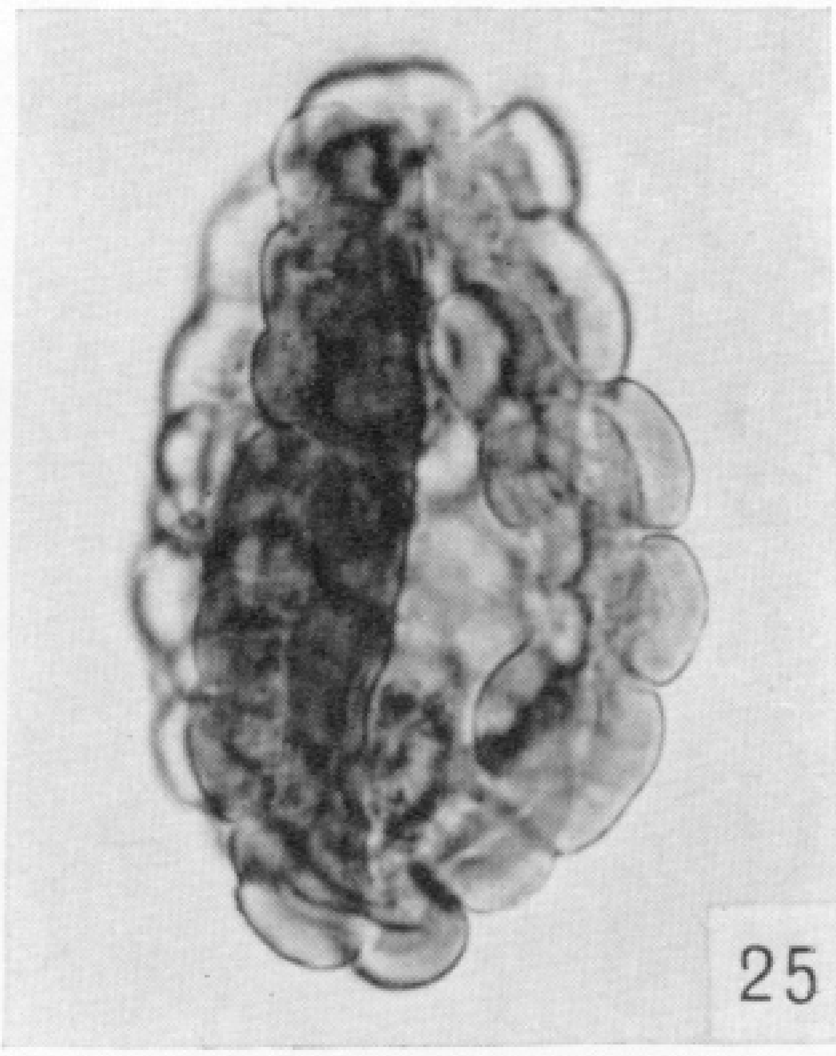

20

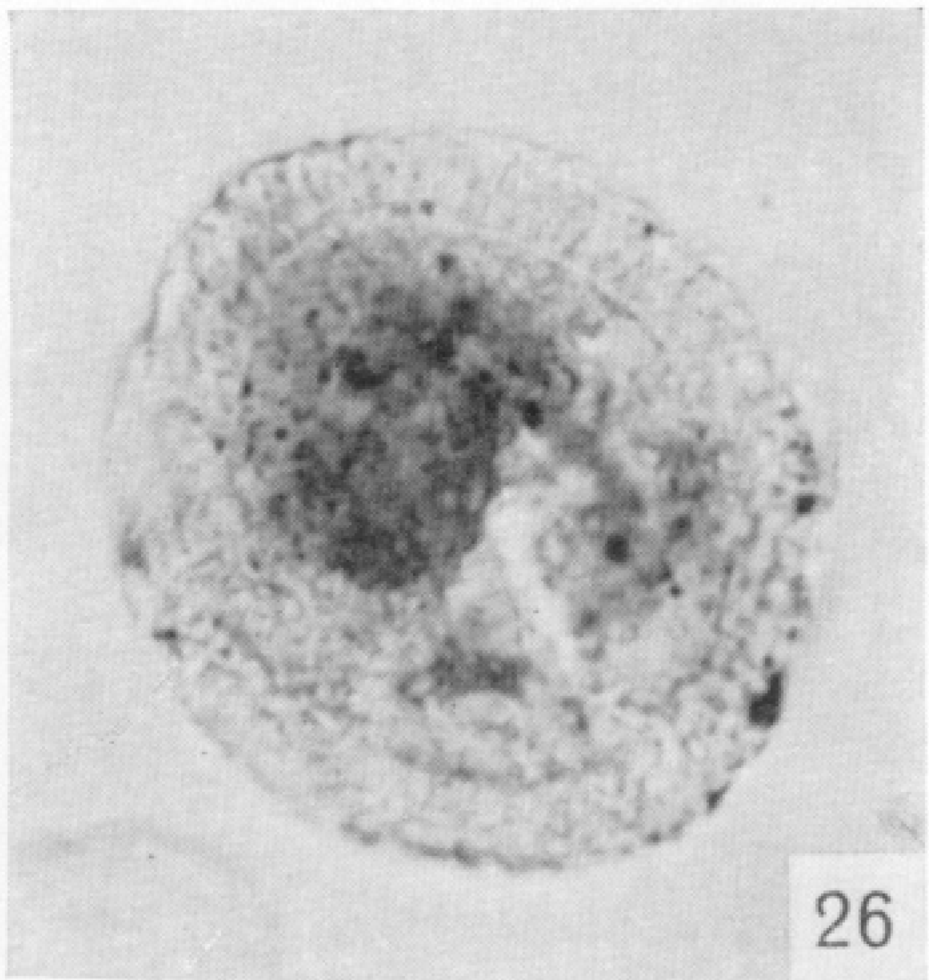

22

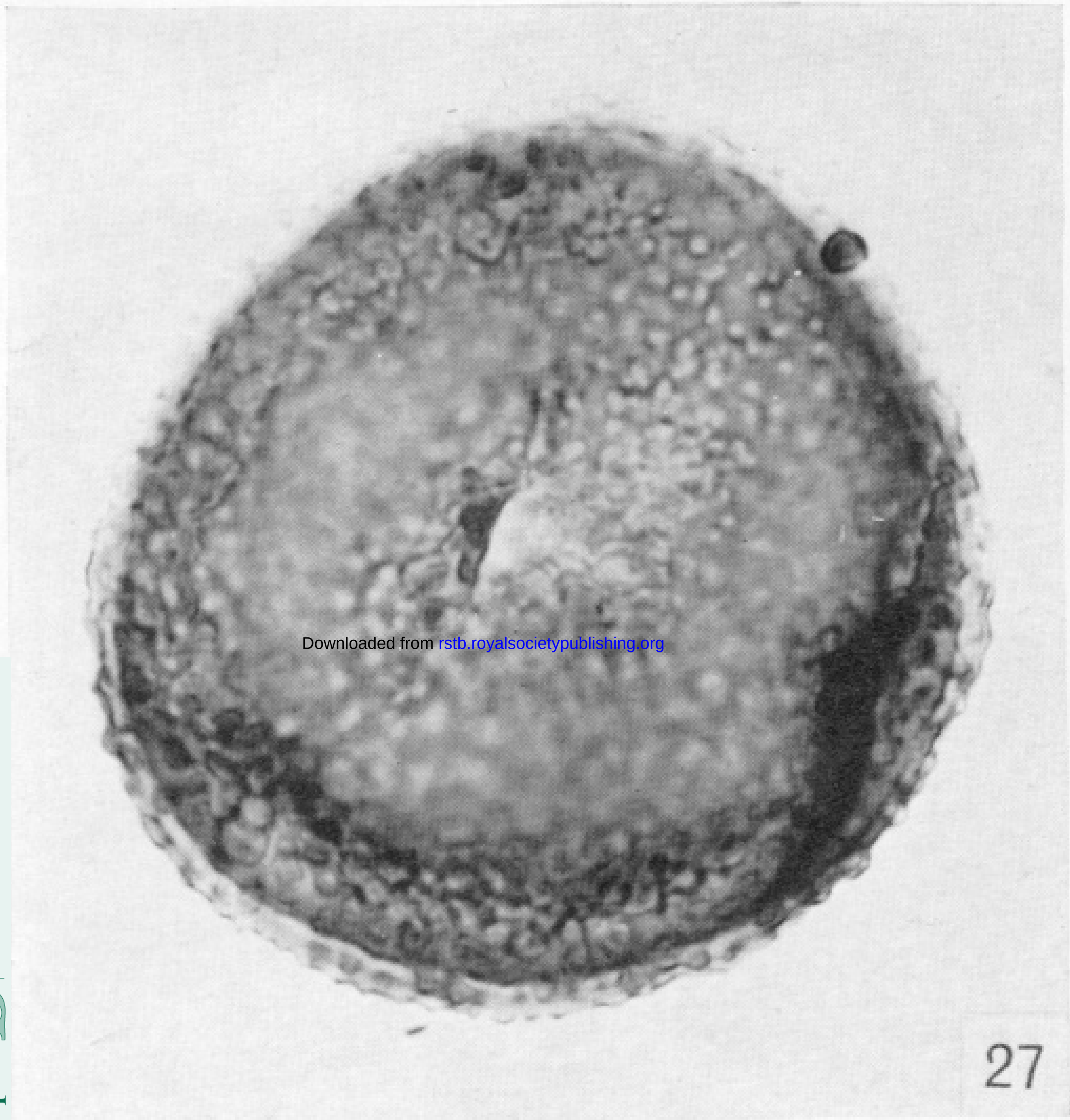

23

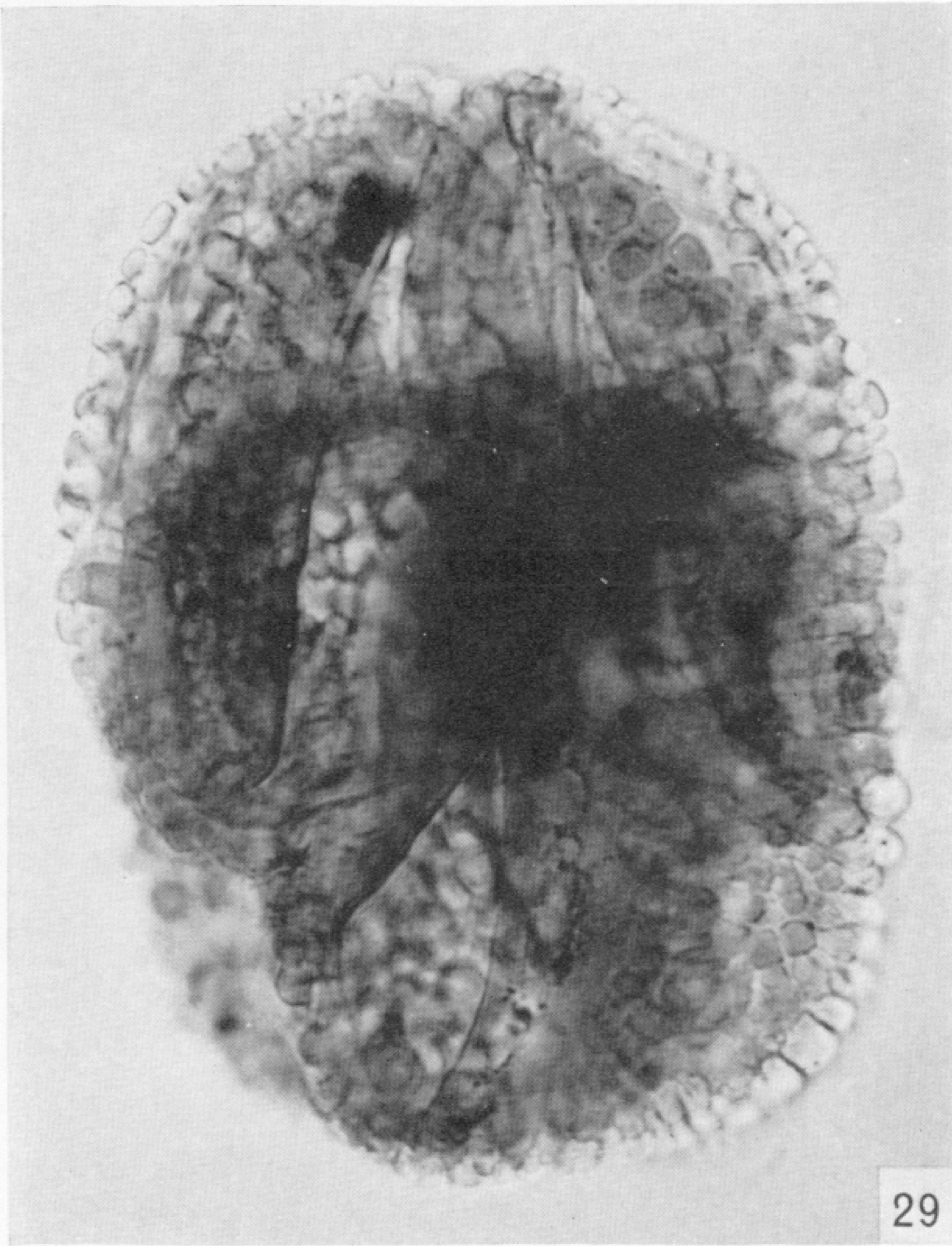
PHILOSOPHICAL TRANSACTIONS OF THE ROYAL SOCIETY B BIOLOGICAL SCIENCES

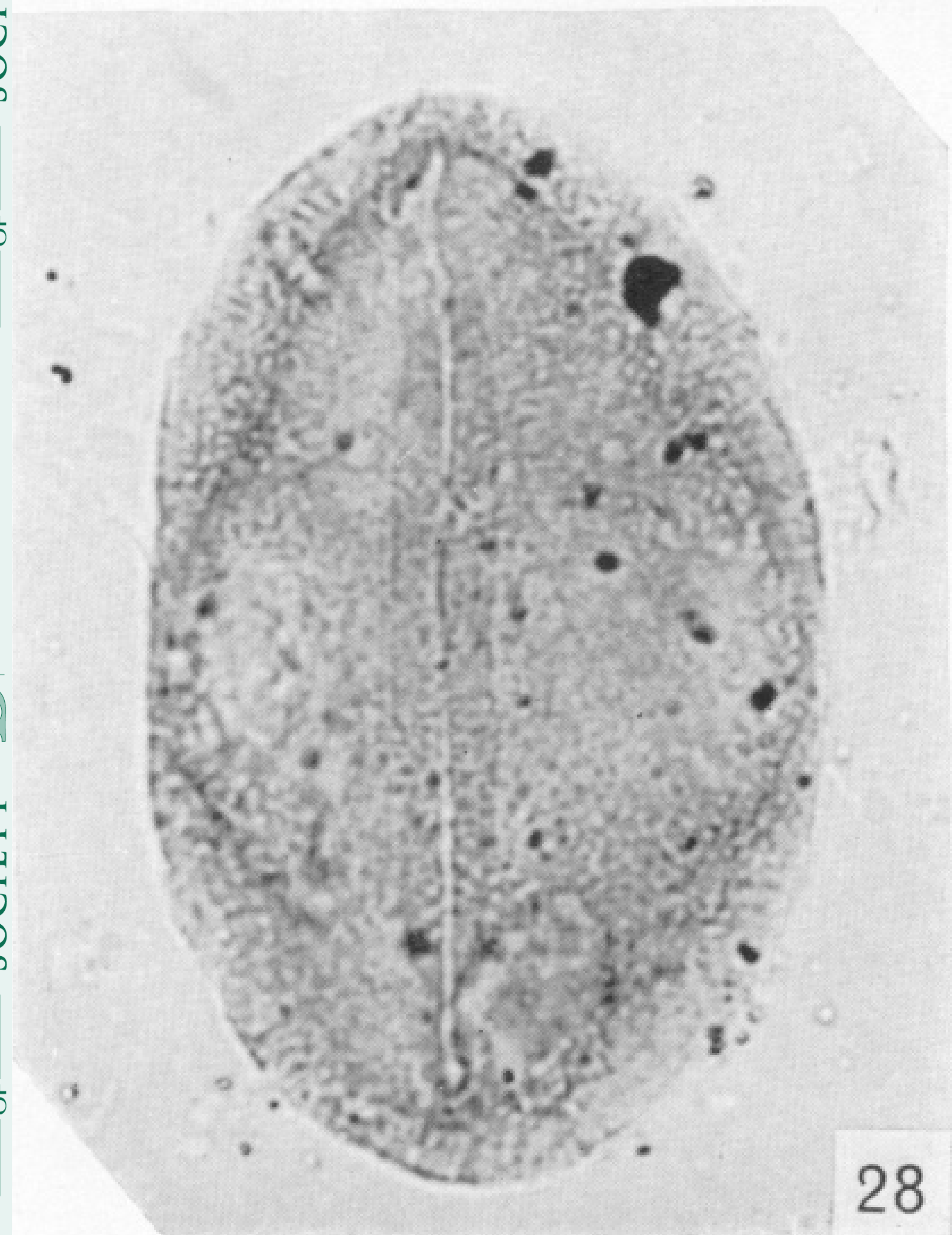

24

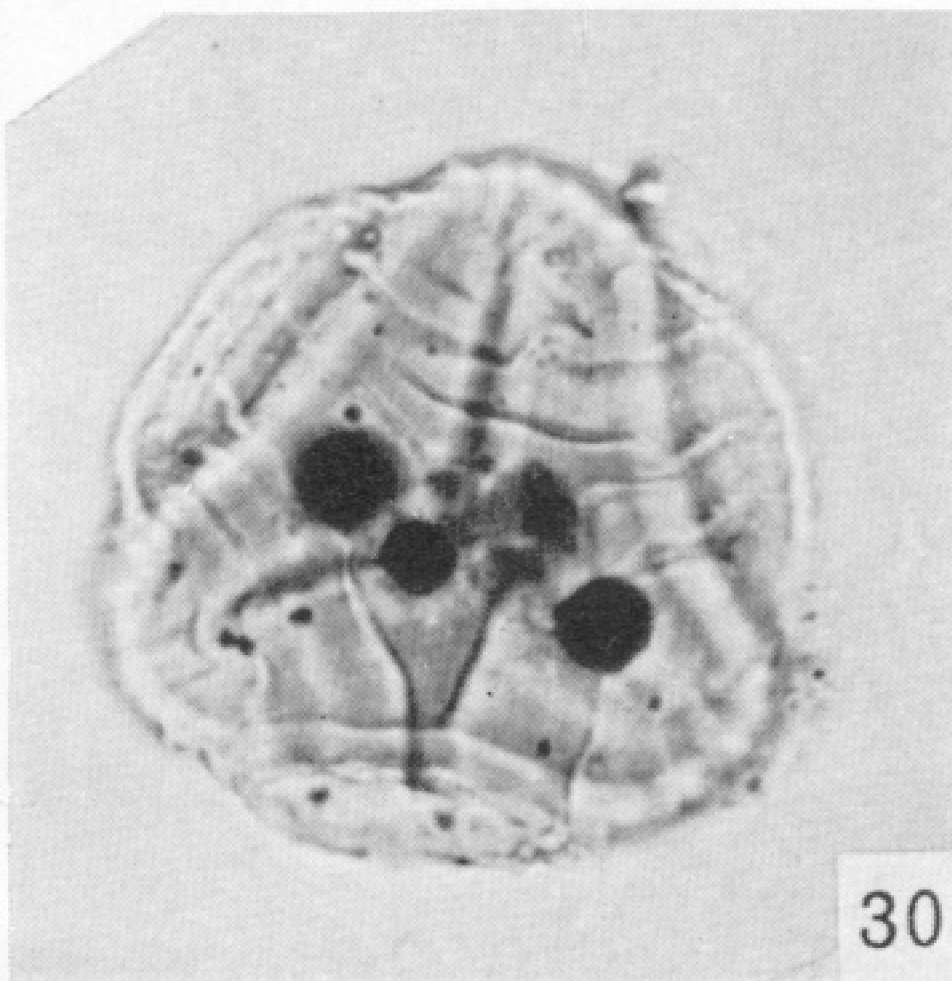

25

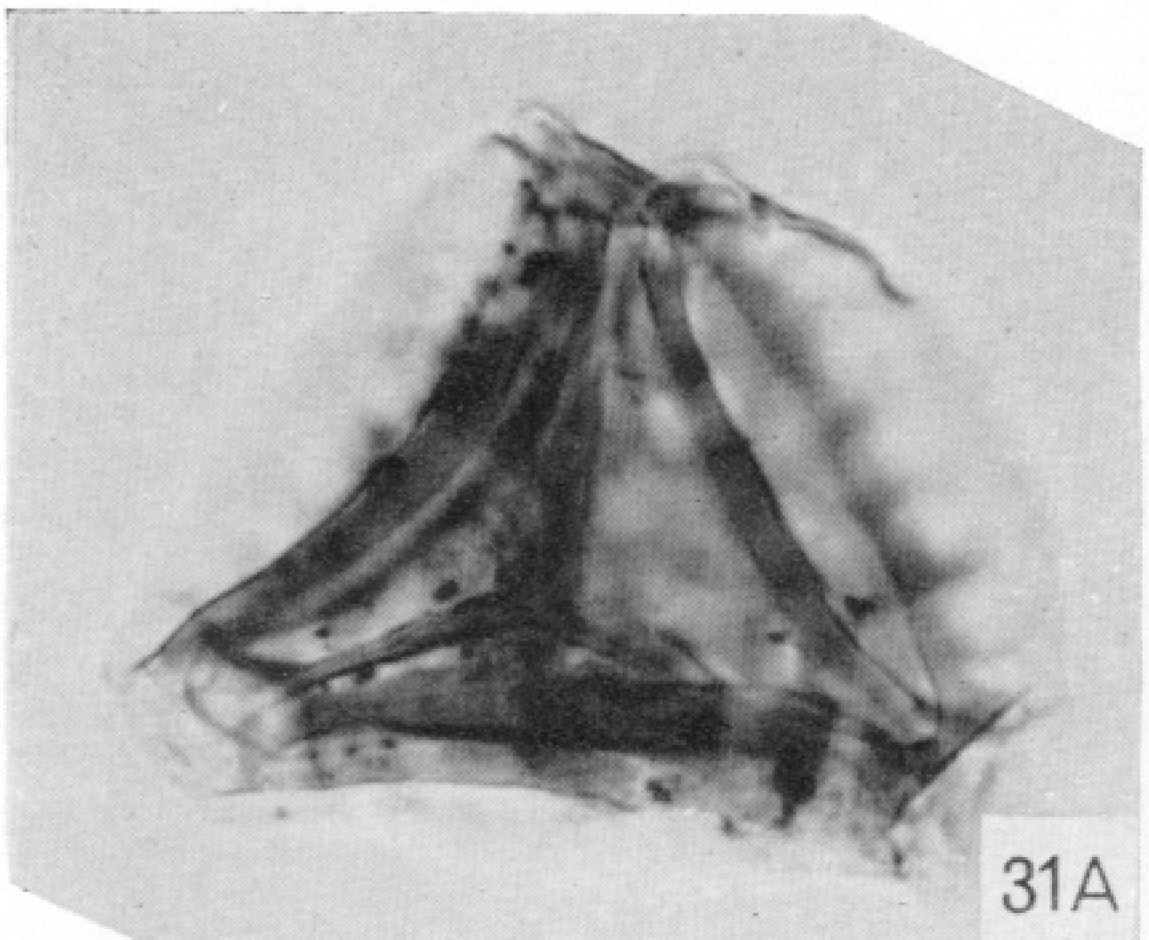

26


27

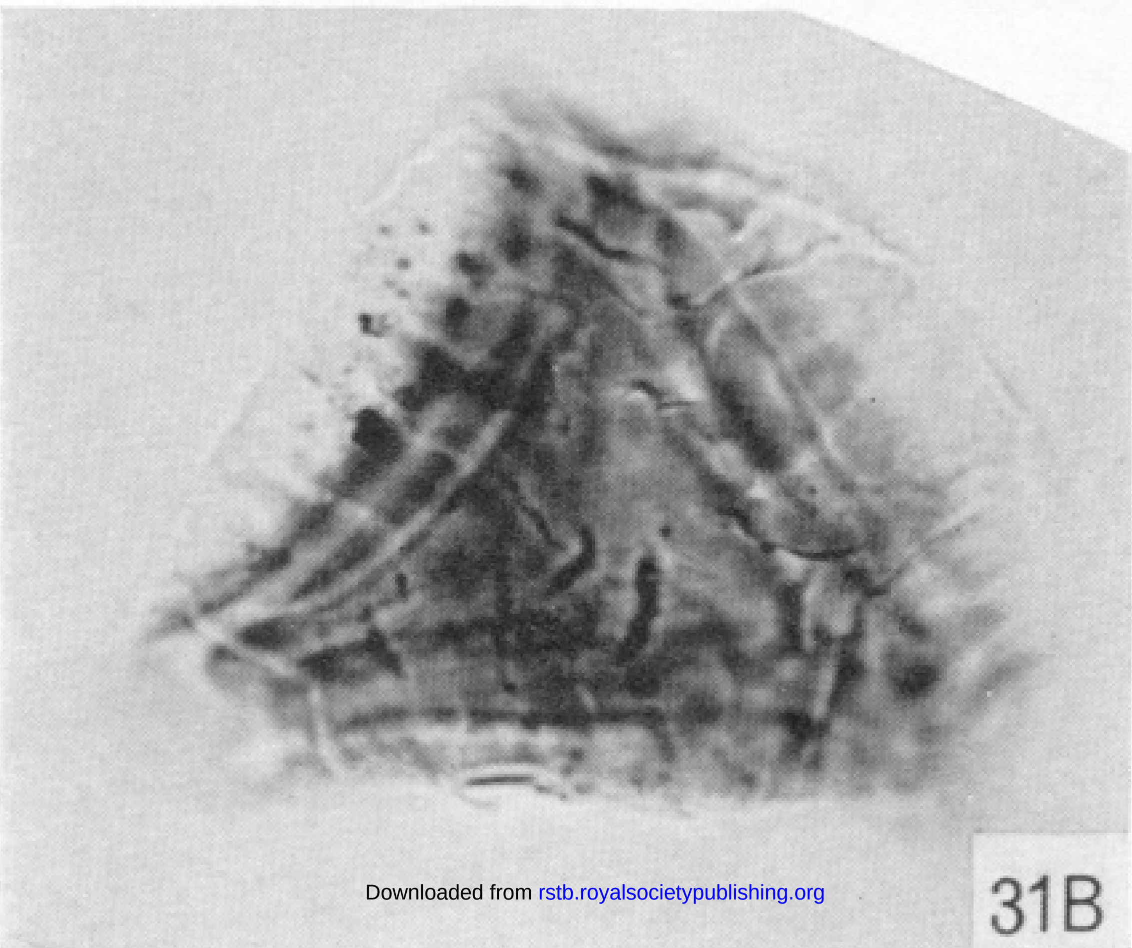

29


28

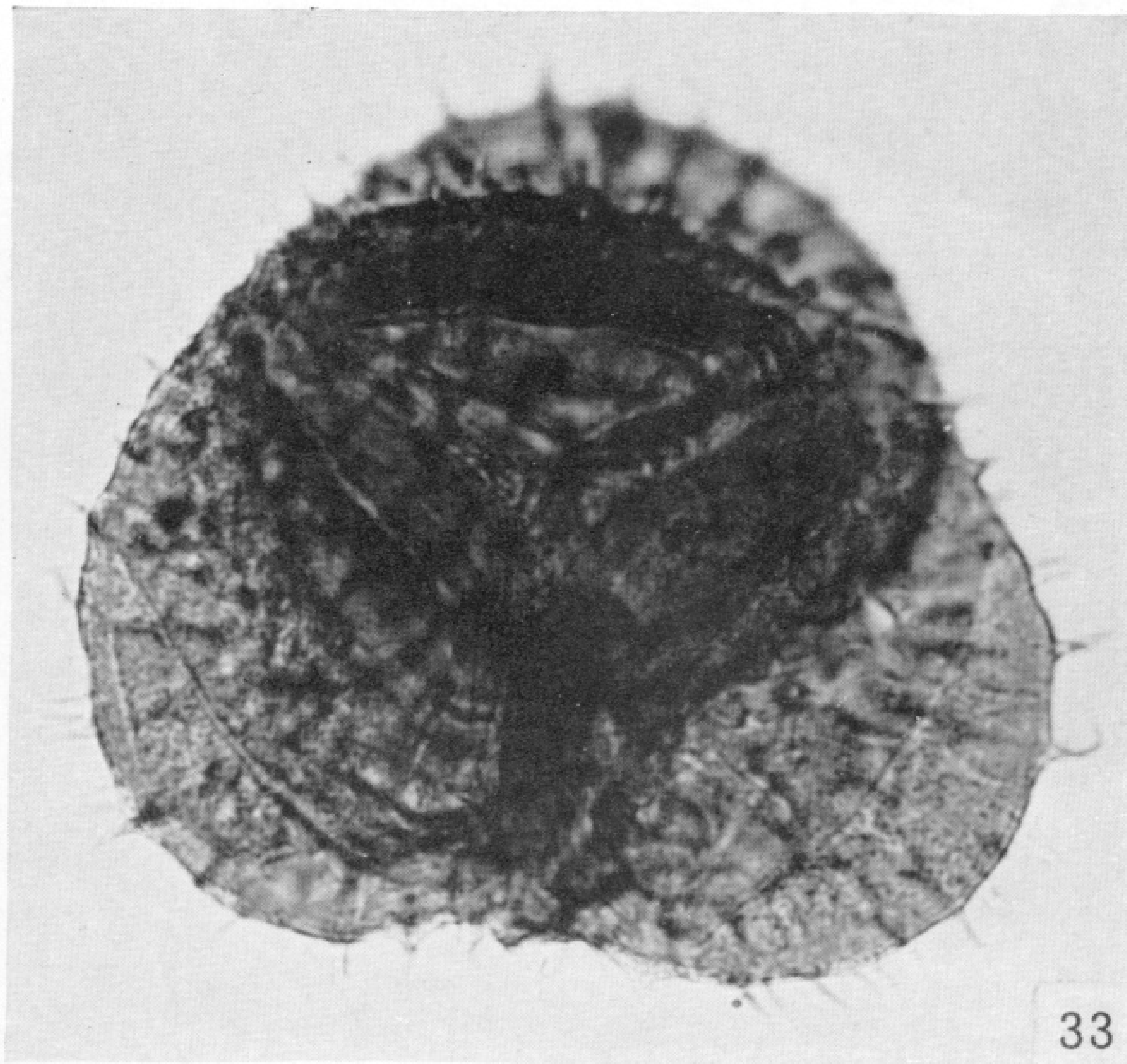

30



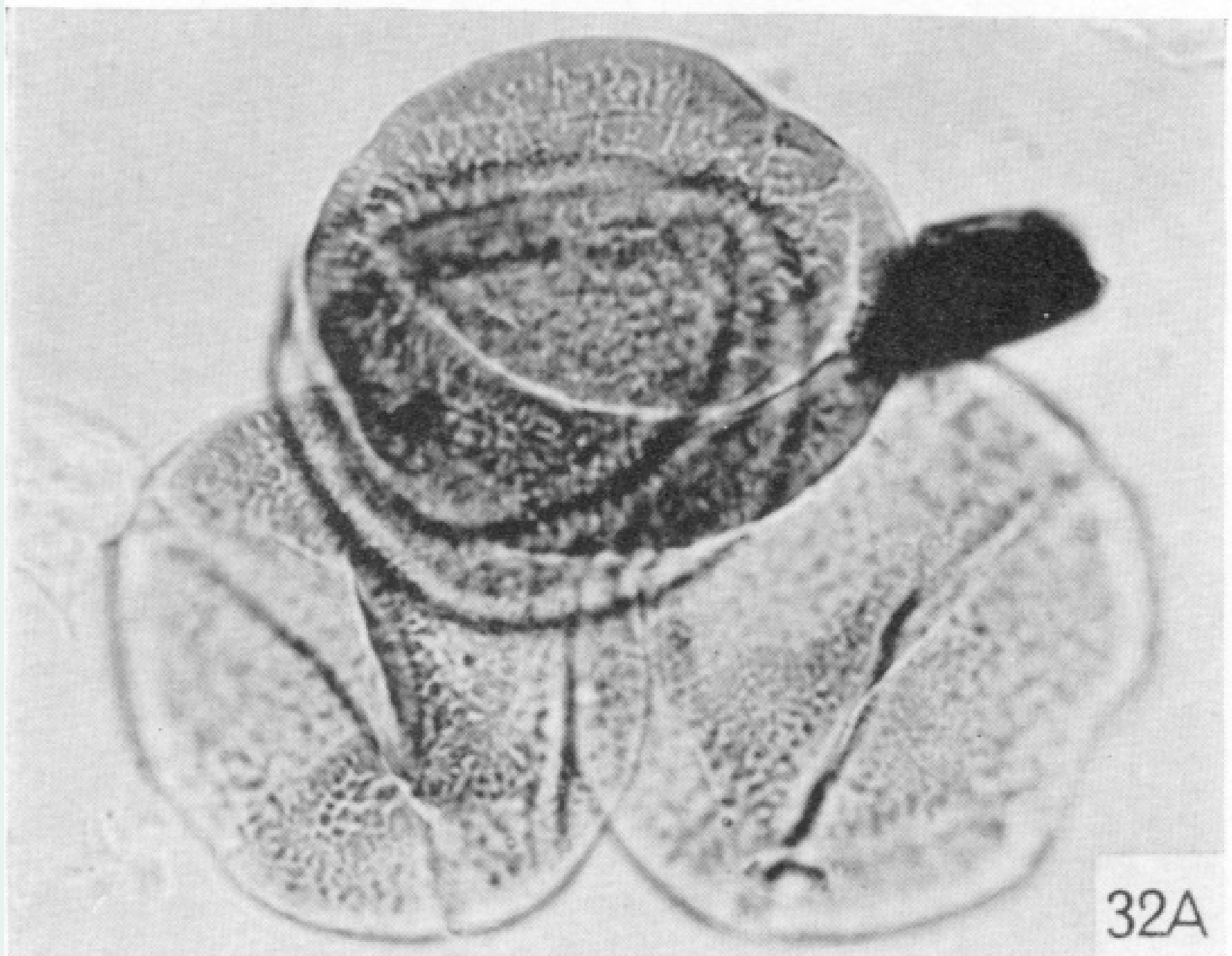
31A



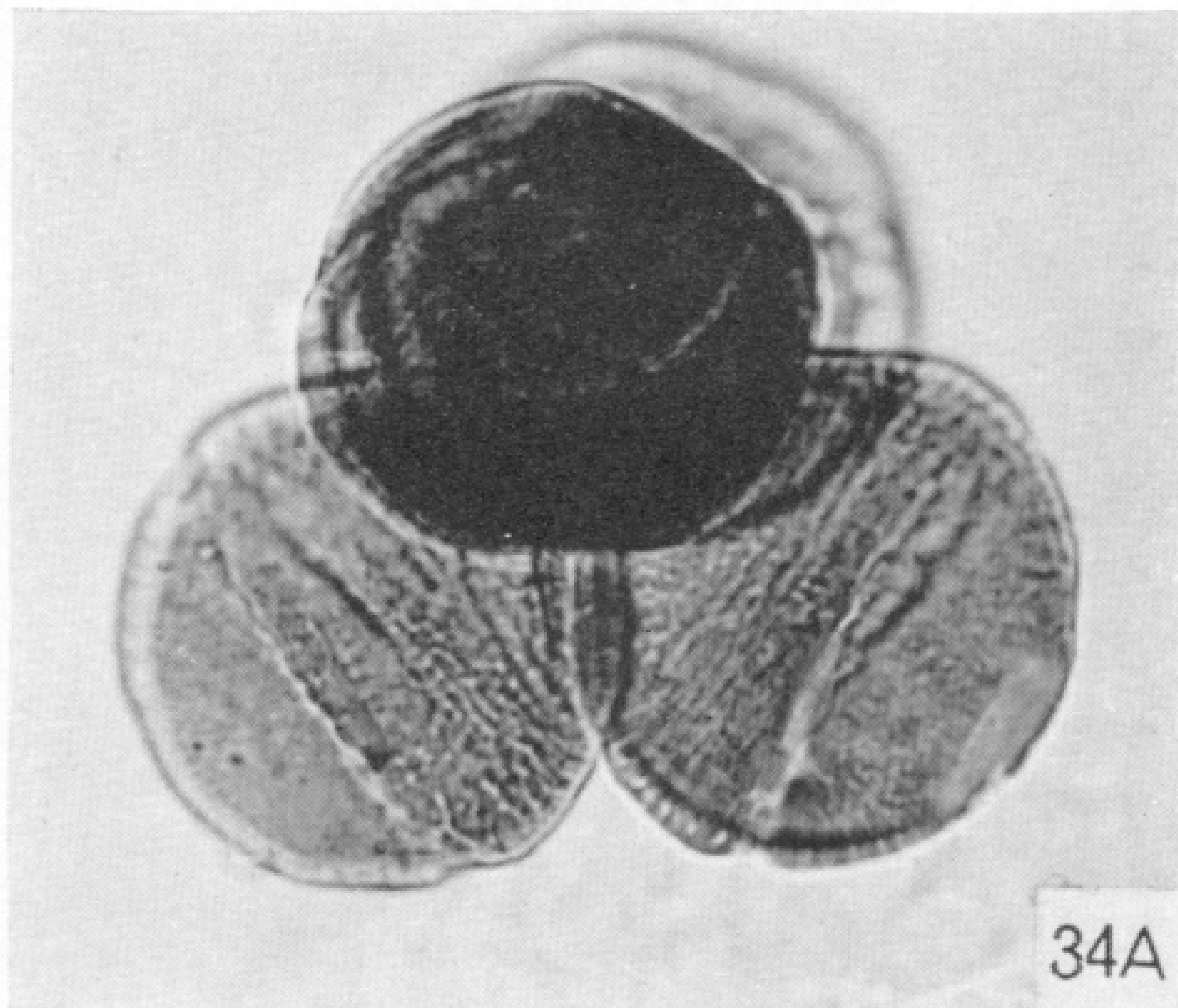
31B



33

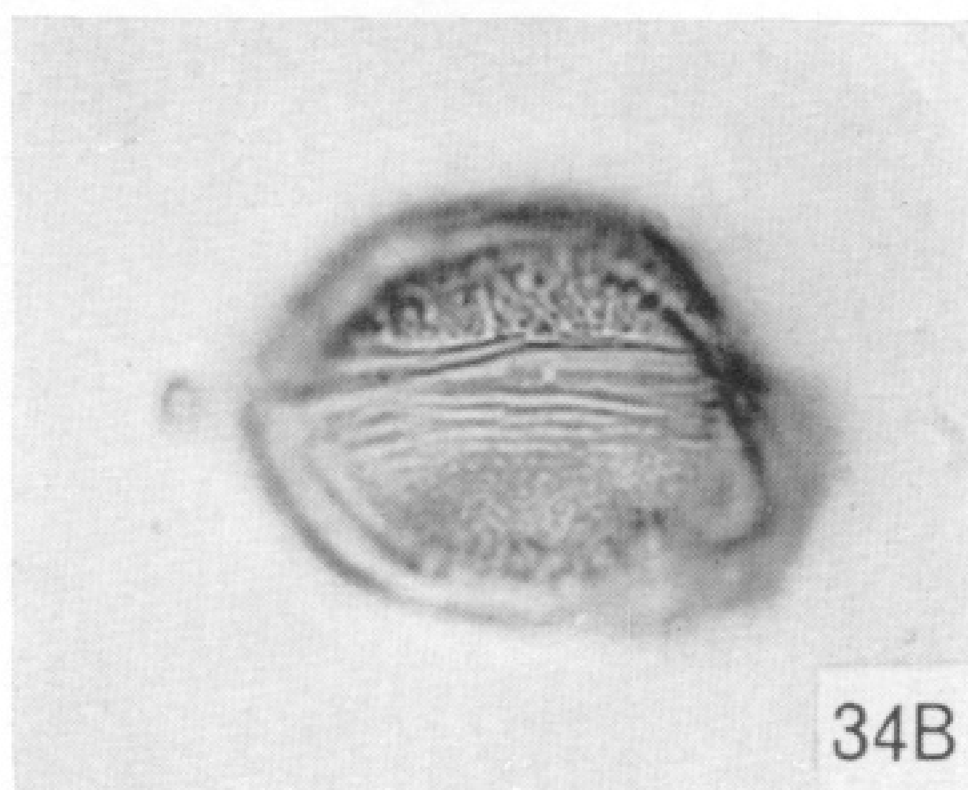


32A



34A

32B



34B