Plant fossils from Gross Brukkaros (Namibia) and their biostratigraphical significance

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A small collection of newly discovered plant macrofossils from lacustrine sediments at Gross Brukkaros (Namibia) is examined in order to attempt a biostratigraphical age bracketing. Two shoots of the conifer *Brachyphyllum* sp. indicate a Permian or, more likely, a post-Permian age, while the presence in the assemblage of a likely dicotyledonous leaflet, a probable angiospermous flower, and numerous carpofossils that are very similar to those of angiosperms suggest a Cretaceous or post-Cretaceous age.

Introduction

This paper presents a description of newly discovered plant fossils from the Brukkaros mountain (southern Namibia). The extreme rarity of Mesozoic fossil sites in Namibia renders this find of great importance with regard to the development of flora, climate and palaeogeography in this region. The samples were collected in October 1991 during a joint field trip of a German/South African research group studying the Gibeon/Gross Brukkaros volcanic field. Unfortunately, only a few samples could be taken during this reconnaissance trip. The identified and classified fossils in these samples, as well as the discovery itself, nevertheless justify this preliminary publication.

Despite its paucity and incompleteness, the material provides sufficient evidence for a first attempt at a biostratigraphical age evaluation. The purpose of this paper is: 1) to identify and illustrate the material; 2) to comment on its biostratigraphical significance; and 3) to compare the material with published data on the flora of lake beds from maar-diatreme volcanoes in southern Africa.

Figure 1: Location of Gross Brukkaros alongside the main road between Windhoek—Keetmanshoop—Upington (from Stachel *et al.*, 1993)

Geological setting

Gross Brukkaros is situated in southern Namibia, between Mariental and Keetmanshoop (Fig. 1). It forms a prominent landmark within the Nama plain, rising up to 1600 m above sea level. A large dome-like structure with a central depression of about 3 km in diameter can be observed (Fig. 2). The morphological features and the occurrence of volcanic and subvolcanic rocks in the vicinity led Janse (1969) to the interpretation that Brukkaros represented a volcanic crater. Later studies, e.g. Nicholayson and Ferguson (1990) supported a volcanic origin and postulated a cryptovolcanic event.

The main part of the dome consists of quartzites and shales of the Fish River Subgroup (Nama Group) with a late Precambrian to Cambrian age. These sediments are intruded by several dykes and diatremes of the Gibeon Province with carbonatitic and kimberlitic compositions.

The Nama sediments are unconformably overlain by a sequence of gravelly sandstones and mudstones of fluviatile and mass-flow origin (Brukkaros sediments). The whole pile has an exposed thickness of almost 300 m and dips towards the centre of the depression. Lenses of lake beds are intercalated within the sediments in the upper level of the Brukkaros sequence. These lake beds were first described by Miller and Reimold (1987) and form isolated bodies 100-500 m in diameter. In the central parts of these bodies a laminated fine-grained facies is interbedded with sandy, turbiditic deposits. At the edge, the lake beds are intercalated with fluviatile and mass-flow deposits. Fossil plant remains were found within sand- and mudstones in the central parts of the former lake bodies.

Age relationship between the Brukkaros sediments and the Mesozoic volcanic activity

Detailed geological mapping (Stachel *et al.*, 1993) showed that the above-mentioned dykes are generally cut by the Brukkaros sediments. At one location, however, several thin carbonatite dykes intrude the lowermost part of the Brukkaros sediments and are cut off within this sequence. This clearly proves that the magmatic activity took place, at least in part, penecontemporaneously with the deposition of the Brukkaros sediments. Evidence to support
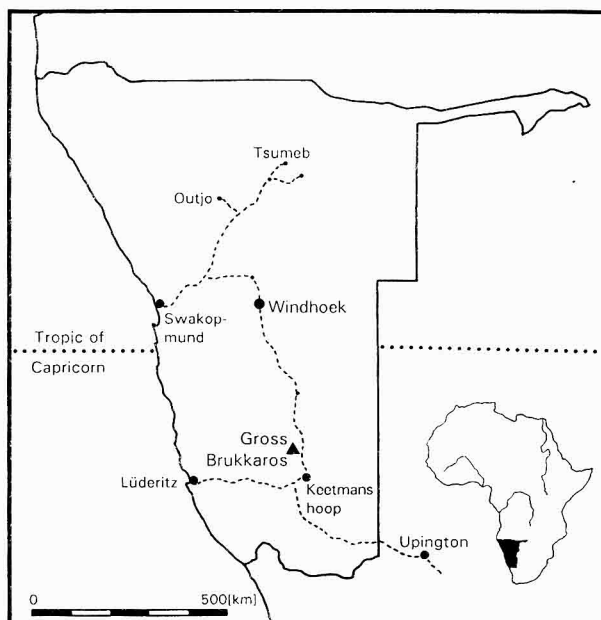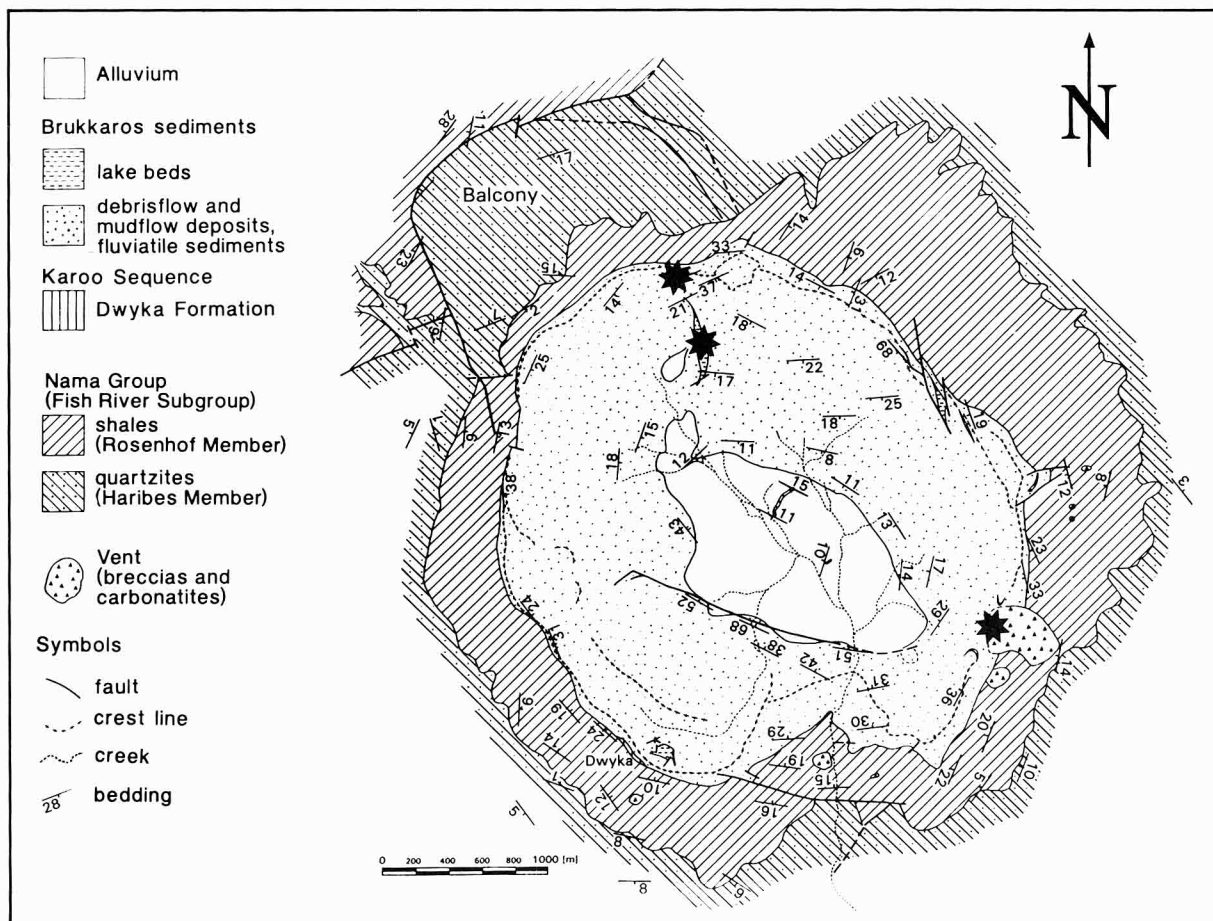
Figure 2: Geological map of Gross Brukkaros (modified from Stachel *et al.*, 1993). Stars indicate sample locations

this includes the occurrence of small vents at the edge of the Brukkaros mountain mainly filled with originally unconsolidated Brukkaros material. Therefore, the Rb-Sr ages reported by Davies *et al.* (1991) and Smith (pers.comm), suggesting an upper-Cretaceous age for the surrounding volcanic rocks, may be transferred to the age of the Brukkaros sediments.

Preservation of material and methods of investigation

Thin sections of fossiliferous lake beds reveal a well-sorted, fine-grained sandstone, in which grain size varies between 60 and 200 m. Sedimentary layering is well defined by alternating quartz- and clay mineral-rich beds. The grains of the sediment are poorly rounded and, in the case of feldspar, always angular. Besides quartz, clay minerals, and flaky carbonate grains, plagioclase and subordinate microcline are observed. The feldspar content often exceeds 25% which classifies these rocks, in part, as arkoses. Accessories are opaque minerals, apatite, mica and tourmaline. Intergranular spaces are mainly filled with quartz and clay minerals, whereas carbonate is scarce.

The majority of the finds are either fragmented plant litter mostly of unverifiable origin which is more or less sorted in a unified size class (Fig. 3g-k) or they are indeterminable axes and fragments of axes, partly subparallel in orientation (Fig. 3f, Fig. 4a). The plant fossils are preserved as impressions with no remaining carbonaceous film or cuticle. Some wood pieces, however, and all carpofossils, were originally in a state of massive ore preservation, now being dissolved by weathering and oxidation with no preservation of internal biological structures. Carpofossils remained as "negative" inconspicuous pits (see little arrows in Fig. 3f, and Fig. 4a). Lamination planes have been stained by iron oxide/hydroxide. Impressions of fossils are often covered with tiny quartz and calcite crystals.

Because of both the poor contrast between matrix and specimens as well as the three-dimensional architecture of the carpofossils, it was necessary to produce latex casts. Black-coloured liquid rubber latex was poured onto the surface or filled pits to make a "positive" copy of the rock as a replica. The replica surfaces were coated with magnesium-oxide in order to attain a better photographical contrast. Grinds and thin sections were made in order to examine fossil diagenesis and to search for possibly preserved phytoanatomical structures. At present all specimens are stored in the collection of the Institute of Geology, University of Würzburg, Germany and will be housed permanently with the Geological Survey of Namibia.

Description of material and systematic palaeobotany

undetermined twig

Figure 3f

Impression of an undetermined twig showing a lateral branch or a bud on the right side on top (see large arrow).
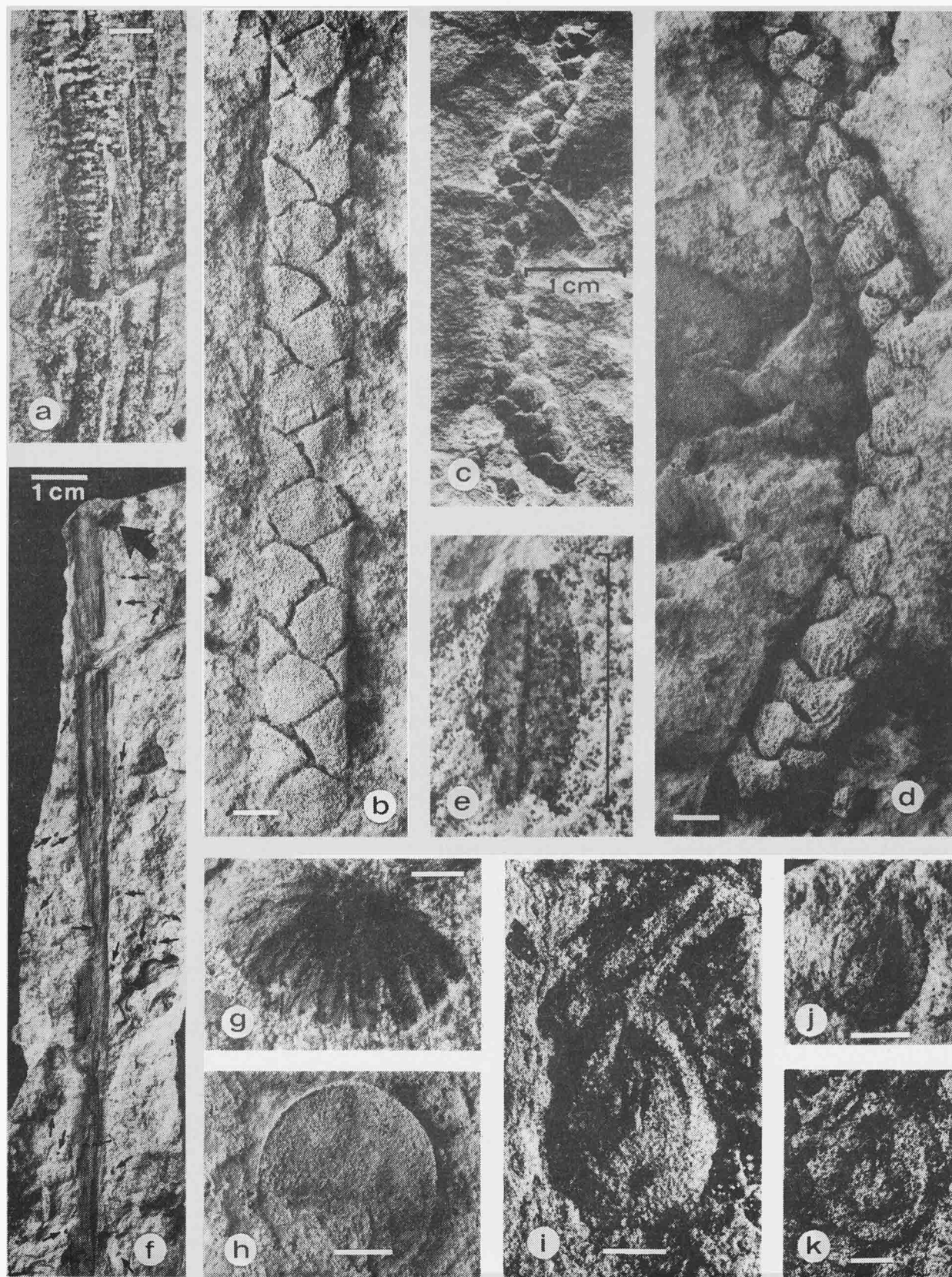
Figure 3: Plant macrofossils from the Gross Brukkaros lake beds, Namibia. Unless otherwise stated scale bars are 3 mm.
a) Wood fragment, GB 91 7e;   b) *Brachyphyllum* sp., latex cast, GB 91 G1;

c, d) *Brachyphyllum* sp, GB 91 8b;   c = impression,   d = latex cast;   e) ?dicotyledonous leaf, GB 91 S3;

f) Undetermined twig, GB 91 S2. Large arrow points to a branch or a bud, little arrows indicate tiny impressions of carpofossils;

g) ?fractured transverse face of an inflorescence, GB 91 7c;   h) *Equisetites* sp., GB 91 8b;

i) Isolated leaf scar of a fern trunk, GB 91 S1;

j) Isolated leaf scar of a fern trunk, GB 91 8d;

k) Isolated leaf scar of a fern trunk, GB 91 8d

?fractured transverse face of an inflorescence

Figure 3g

This fragment of a transverse fracture which presumably originated from a microstrobilus (male cone) is exemplary for some other poorly preserved and indeterminable strobili. They also occur longitudinally split. Segments in the figured example that might have been microsporophylls are cyclically arranged, with truncated abaxial tips.

Wood fragments

Figure 3a

Wood pieces occur in massive goethite preservation or as impressions and moulds of flattened fragments showing extensive shrinkage cracks. The longitudinal elements are intersected by thin and isolated fractures which run parallel to each other and which are transversely oriented to the stem axis. Impression surfaces and shrinkage fractures are mostly wallpapered by calcite and quartz crystal lawns.

Division PTERIDOPHYTA
Class SPHENOPSIDA
Order EQUISETALES
Family EQUISETACEAE
Equisetites sp.

Figure 3h

The latex cast of an isolated nodal diaphragm is 10 mm in diameter, consisting of a central circle with smooth surface. Vascular bundles on the edges are not recognisable due to the poor state of preservation.

The internal structures of horsetails are characterised by nodal diaphragmae separating successive internodal zones and providing considerable rigidity of the hollow shoot. The phytotaphonomical process of diaphragm removal from the stem was easily possible using a mechanism like zipper unfastening, as could be shown on Mesozoic horsetails (Mader, 1990: 1146).

Division PTERIDOPHYTA
Class FILICOPSIDA
Leaf scars of ferns

Figure 3i-k

Several impressions of fractured and isolated trunk fragments show singular leaf scars about 6-10 mm wide and 7-13 mm high, with elongated U-shaped bundle traces. All specimens are very uniform in shape and size although ornamentation apparently was slightly deformed by sedimentary compression. Leaf scars on stems are distinguishing marks in fern families like Marattiaceae and Osmundaceae.

Division CONIFEROPHYTA
Class CONIFEROPSIDA
***Brachyphyllum* sp.**

Figure 3b-d

Description of material - Two impressions of leafy coniferous twigs 17.5 cm and 4.5 cm long are developed. Latex casts reveal spirally disposed, appressed leaves with a triangular or hexagonal form. The specimen in Figure 3b appeares to be flattish due to compression. Leaves in specimen Figure 3g-d seem to be composed of a basal cushion tapering into a small free part. The abaxial surface of the leaf is distinctly convex, rounded throughout and slightly coined by longitudinal ridges. All leaves are wider than they are long.

Discussion - The two specimens are poorly preserved and lacked cuticles and epidermal features. Therefore, they can only be assigned in an artificial system of form genera based primarily on external morphology of twigs and their leaves (Harris,1979; Meyen 1987; Stewart 1983).

Harris (1979) pointed out that certain specimens of *Brachyphyllum* with unusally long leaves overlap the boundary of *Pagiophyllum*. On the other hand occasional twigs of *Pagiophyllum* have leaves short enough to fit *Brachyphyllum*. Besides these determination problems, De Laubenfels (1953) has demonstrated on present-day conifers that several leaf types may occur on the same plant during different periods of its ontogeny. In some taxa the transition from juvenile to adult foliage is extended over several years. This observation is an additional reason to use the clearly defined organ genus *Brachyphyllum*.

To avoid any nomenclatural confusion and to clarify the phytostratigraphical implications a brief outline of *Brachyphyllum*-type and probably *Brachyphyllum*-like conifer shoots is given, with respect to occurrences in space and time in the southern continents.

Form genus Brachyphyllum

Twigs of *Brachyphyllum* are characterised by small helically-arranged leaves. Each leaf consists of a basal cushion, tapering into a free part. The total length of the free part is less than the width of the cushion. The genus *Brachyphyllum* has been reported in Tertiary sediments as Araucaria or Araucarites (Townrow, 1967).

Assignation to natural families: Araucariaceae, Hirmerellaceae (Cheirolepidiaceae), Podocarpaceae (Harris, 1979; Stockey, 1990; Watson, 1988).

Fossil occurrences on the southern land masses:

Cretaceous: Antarctica, Australia, India, South America, South Africa (McLachlan and McMillan, 1976; Vakhrameev, 1991).

Jurassic: Antarctica, Australia, India, North Africa (Libya, Negev desert, Saudi Arabia), South America (Vakhrameev, 1991).

Triassic: India (Bose *et al.*, 1990), South Africa: *Voltziopsis angusta (Brachyphyllum angustum)* (Anderson and

Anderson, 1989).

Form genus Pagiophyllum

Pagiophyllum-shoots have spirally-arranged leaves that contract gradually from a basal cushion. The width of the leaf is comparable to that of the cushion. The free part of the leaf is longer than the width of its cushion.

Assignation to natural families: Hirmerellaceae (Cheirolepidiaceae), Taxodiaceae (Harris, 1979; Watson, 1988).

Fossil occurrences on the southern land masses:

Cretaceous: Antarctica, India (Vakhrameev, 1991).

Jurassic: Antarctica, Australia, India, Northern Island of New Zealand, North Africa (Libya), South America (Bose *et al.*, 1990; Vakhrameev, 1991).

Triassic: India, Livingston Island, South Shetland Islands (Anderson, 1990; Bose *et al.*, 1990).

Araucarites

The shoots are covered with leaves of one sort which are helically arranged, closely set and imbricated. These leaves arise from a rhomboidal cushion (Townrow 1967). Especially the seed scales of fossil Araucariaceae were described under the name *Araucarites*, whereas leafy twigs were mostly assigned to the form genera *Brachyphyllum* and *Pagiophyllum* or directly to the genus *Araucaria* (Meyen, 1987).

Assignation to natural family: Araucariaceae.

Fossil occurrences on the southern land masses:

Tertiary: Antarctica, Australia, King George Island, Seymour Island, South Shetland Islands (Townrow, 1967; Stockey, 1990).

Cretaceous: Alexander Island, Antarctica, South Africa, South America (McLachlan and McMillan, 1976; Vakhrameev, 1991).

Jurassic: Antarctica, Australia, India, Northern Island of New Zealand, South America (Vakhrameev, 1991).

Athrotaxis

Shoots show closely appressed, spirally-arranged leaves, which are more or less triangular, scale-like with rounded apex and not keeled.

Assignation to natural family: Taxodiaceae (Townrow, 1967).

Fossil occurrences on the southern land masses:

Tertiary: Australia (Townrow, 1967).

Cretaceous: South America (Stockey, 1990).

Allocladus

Shoots have helically-arranged leaves, which arise from a decurrant base and which overlap with the next leaf above. The free part of the leaf has a length/width ratio greater than 1 (Townrow, 1967).

Assignation to natural family: Incertae sedis.

Fossil occurrences on the southern land masses:

Jurassic: Australia, India (Gould, 1975; Stockey, 1990).

Walkomiella

Twigs covered with helically-arranged, overlapping squamiform leaves. In contrast to other Buriadia species the Walkomiella leaves are not forked. Some of the described remains may be in doubt (Pant, 1982) or synonymous with *Brachyphyllum,* e.g. *Walkomiella australis* Florin = *Brachyphyllum australe* O. Feistm. (Stockey, 1990).

Assignation to natural families: Buriadiaceae, (?)Lebachiaceae (Meyen, 1987).

Fossil occurrences on the southern land masses:

Permian: Australia, India, South Africa (Stockey, 1990).

Rhombic structures on sterile shoots certainly occur on plants from the Devonian and Early Carboniferous, e.g. *Archaeosigillaria caespitosa* and *Leptophloeum australe* from Argentina, Australia and South Africa (Archangelsky, 1990; Gould, 1975; Plumstead, 1967). The salient feature of these fossils are hexagonal scars after leaf abscission and decortication. Thus confusion with *Brachyphyllum* shoots from Gross Brukkaros described in this paper can be excluded.

?dicotyledonous leaf

Figure 3e

Description of material - An impression of a tiny, narrow, elliptical leaflet 3 mm long and 1.4 mm wide, with smooth entire margin, which is revolute or has a marginal bulge as can be seen on the right edge. The leaf apex is obtuse or rounded in shape, with midvein moderate and straight. Venation of higher order is not preserved.

Discussion - This specimen is propably a simple dicot leaf, but unfortunately there is no evidence of leaf base or petiole. Leaves which are comparable to that described here, although commonly somewhat larger in size, have been observed in deposits of early Cretaceous age (see Vakhrameev, 1991: 151), and more often in beds from the early Cenomanian (Upchurch and Wolfe, 1987: 82).

?angiospermous flower

Figure 4h

Description of material - Top view of the latex cast of a scarcely recognisable impression revealing an almost complete carolla composed of 5 petals in a whorled arrangement displaying a diameter of 12 mm. The petals are free with obovate outline. The centre zone of the supposed position of the non-preseved carpels (female parts) and/or stamens (male parts), also has a conspicious pentagonal shape.

Discussion - This cyclic, actinomorphic, pentamerous flower seems to have the showy petals of an insect-pollinated, angiospermous flower which occurs from the Cenomanian onwards (Friis and Crepet, 1987). Delicate structures of flowers preserved in their organic configuration are rare in the fossil record. An exceptional occurrence is known from Cretaceous lake beds overlaying the diamon-
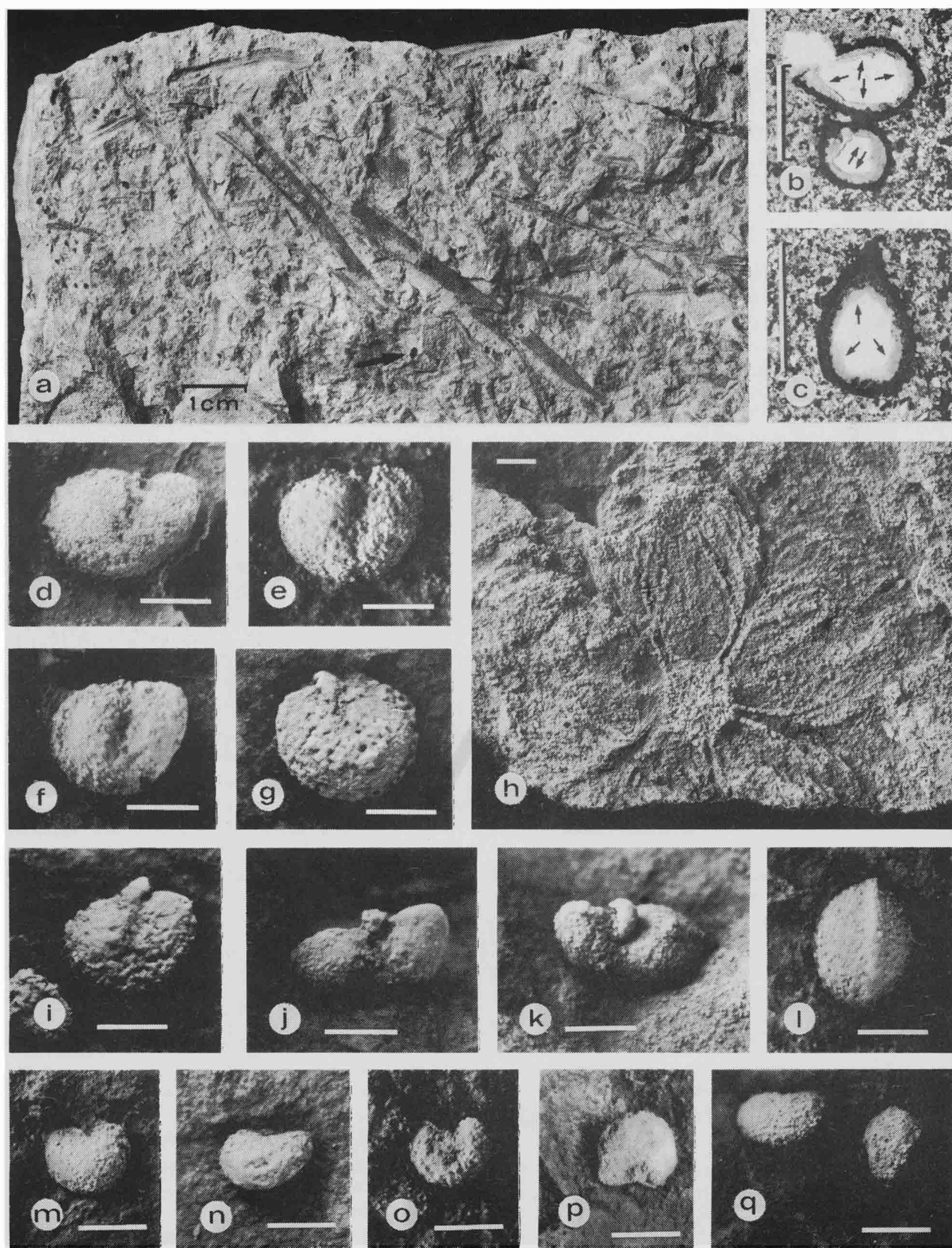
Figure 4: Plant macrofossils from the Gross Brukkaros lake beds, Namibia. Unless otherwise stated scale bars are 1 mm.
a) Assemblage of plant litter with fragments of axes in subparallel preferred orientation and pits caused by former carpofossils, GB 91 7a. Arrow indicates carpofossil impression that is shown as replica in j; b-c) Photomicrographs of thin sections showing transverse sections of *Carpolithus* B. Black = oxidised goethite, little arrows indicate boundary of calcite wallpaper; b = GB 91 7d, c = GB 91 7a; d) *Carpolithus* A, latex cast, GB 91 S2a; e) *Carpolithus* A, latex cast, GB 91 S1b; f) *Carpolithus* A, latex cast, GB 91 7a4II; g) *Carpolithus* A, latex cast, GB 91 7a3III; h) ?angiospermous flower, latex cast, GB 91 S1; i) *Carpolithus* A, latex cast, GB 91 7aIII; j) *Carpolithus* A, latex cast, GB 91 7a1; k) *Carpolithus* A, latex cast, GB 91 S1a; l) *Carpolithus* B, latex cast, GB 91 7fa; m) *Carpolithus* C, latex cast, GB 91.S2b; n) *Carpolithus* C, latex cast, GB 91 7aIII; o) *Carpolithus* C, latex cast, GB 91 Sib; p) *Carpolithus* C, latex cast, GB 91 S2a; q) *Carpolithus* C, latex cast, GB 91 7fb
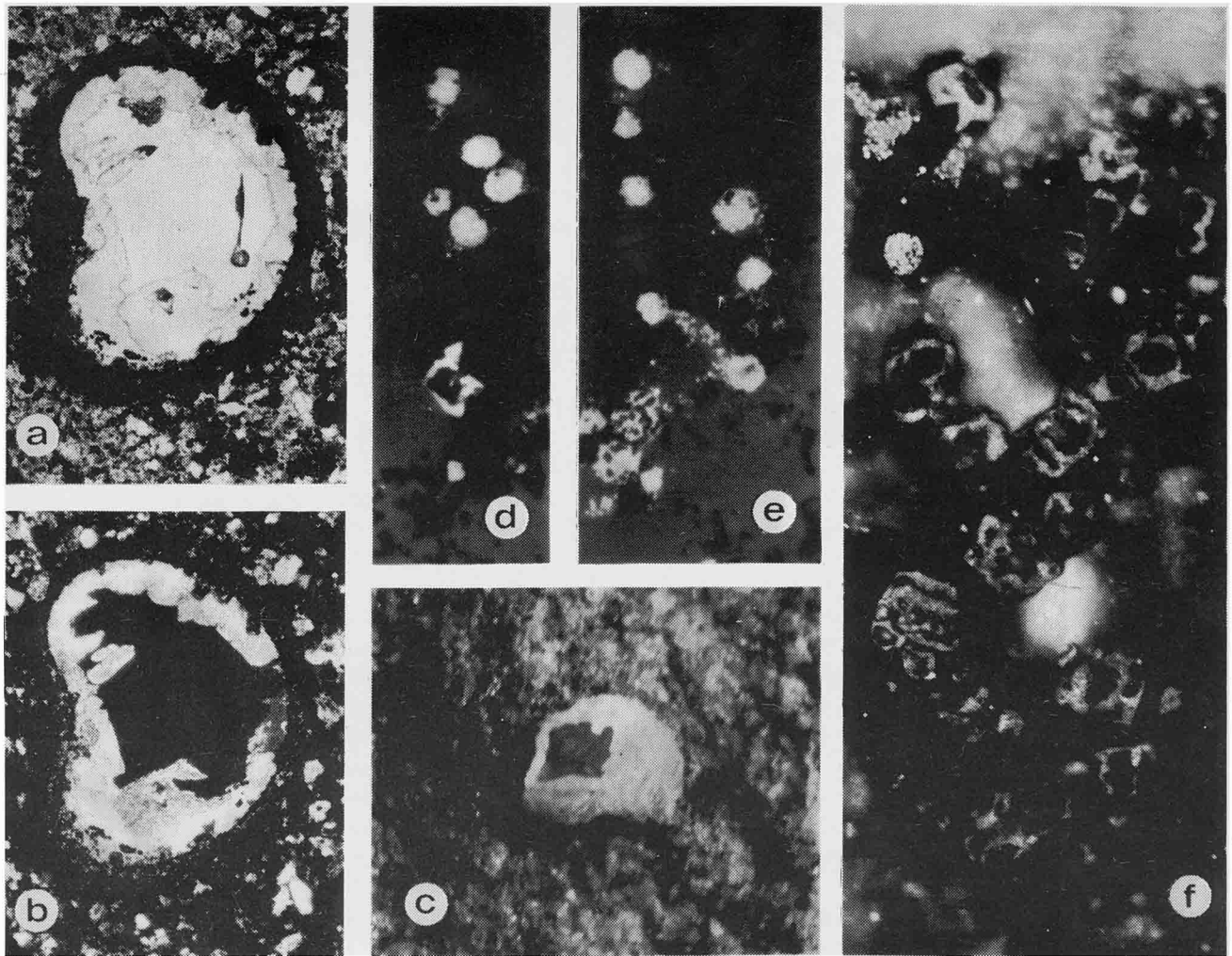
Figure 5: Plant macrofossils and polished thin sections from the Gross Brukkaros lake beds, Namibia.
a-b) *Carpolithus* C, GB 91 7a. Photomicrographs of a slightly transverse view in transmitted light, X 41; a = II pol, b = X pol;
c) *Carpolithus* C, GB 91 8d. Three-dimensional calcite coating of the locule or seed with a hole, X 25; d-f) Pseudomorphs of pyrite framboids and pyrite cubes in reflected light. GB 91 7a, X 280

diferous kimberlite at Orapa, Botswana, where angiosperm flowers attain the extreme ratio of 14% of the macroflora (Rayner *et al.*, 1991).

Carpolithus A

Figure 4d-g, i-k

Faithful copies of the original carpofossils were obtained by making casts of the impressions in latex rubber. The seeds or endocarps are globose, heart-shaped to reniform, and all in the same size class of 2 mm breadth and 1.7 mm height. The funiculus, the stalk of the ovule that attaches it to the placenta, can be observed in Figure 4d, g, i-k.

Carpolithus B

Figure 4b-c, l

Thin sections and a latex replica from an ovoid seed or endocarp. A prominent longitudinal ridge runs around the periphery and bisects the carpo-type into two segments.

Carpolithus C

Figure 4m-q; Figure 4a-c

Description - The specimens are latex casts of external moulds and yielded no internal structure. The tiny seeds are bisymmetrical kidney-shaped and are uniformly in a size class of 1.2 mm breadth and 0.8 mm height.

Discussion - Despite the insufficient assignments of all carpofossils due to the lack of significant diagnostic features they bear a strong resemblance to angiospermous seeds or fruits. In Carpolithus A the funiculus is attached near the equator of the ovule body, showing a campylotropus architecture (see Corner, 1976). One of the earliest comparable carpo-types in the fossil record seems to be *Curvospermum marketense* from the Cretaceous (Knobloch and Mai, 1986). The reniform *Carpolithus* C shows a strong affinity to morphologic types arising in mid-Cretaceous and Tertiary times, e.g. the genus *Toddalia* (Gregor, 1989).

Palaeoecological and phytotaphonomical remarks

As with any other fossil plant assemblage, the flora from Gross Brukkaros is the result of a combination of taphonomic factors: e.g. transport by water, degradation, fragmentation, sorting and size classification as well as the ecological pattern such as the composition of the plant community and climatic conditions (Spicer, 1991).

Using criteria developed during studies on sociological and ecological characteristics of present-day vegetation, it is possible to distinguish two different plant communities at Brukkaros. Mesophilous conifers represented by *Brachyphyllum* sp. grew in drier habitats at a greater distance from the waterside, in contrast to hygrophilous horsetails and ferns. These preferred the vicinity of a water body or a more groundwater-saturated soil.

The taphoflora from Gross Brukkaros is an accumulation of plant organs of different resistance, because the degree of preservation depends on the distance, time and mode of transportation and the influence of biological and mechanical degradation (Rich, 1989). The observation of a delicate flower structure among plant parts of higher durability, which nevertheless fit into almost the same size class, especially highlights the degree of multiple taphonomic case histories.

Flower heads have a low fossilisation potential. They are ephemeral, fragile and lack durable tissues. Their time availability for fossilisation burial may last approximately one or two weeks in the year (Hughes, 1976: 22). Following Rayner and Waters (1991: 280) we suggest a growth close to the lake side and a nearly instantaneous burial after abscission.

The mix-up of a high ratio of fragile flower heads and insects in whole-body preservation among more resistant megafloral remains seems to be a distinguishing pattern of some post-volcanic crater lakes and probably categorises an exceptional type of fossil Konservat-Lagerstätten (*sensu* Seilacher *et al.*, 1985). A good example for this type of fossil site is the Miocene Randeck maar in Germany (Gregor, 1986).

Another interesting phytotaphonomical aspect is the fact that carpofossils are the only impression-fossils which preserve their original three-dimensional shape. The multiple stages of this fossil diagenesis could be deciphered by microscopical research.

Description - Polished thin sections and grinds of the unweathered carpofossil-bearing sediment show dispersed cubic and rounded aggregates of goethite (Figs 5d-f) which are interpreted as pseudomorphs of former pyrite crystals and pyrite framboids (Canfield and Raiswell, 1991). The transverse faces of carpofossils do not display a massive mineralised locule cast or seed cast but, rather surprisingly, a permineralised testa or endocarp with uniform wall thickness and goethite preservation. The testa or the inside of the endocarp is mostly wallpapered by calcite (see Fig. 5c, and little arrows in Figs 4b,-c). Calcite crystals are also sprouted up into the locule or seed cavity (Figs 5a-b).

Discussion - Carpofossils entered a water body under anoxic conditions or were slightly embedded in a sediment with iron-dominated pore water. Sulphate reduction then generated H_2S, which would be fixed in the testa or endocarp and contemporaneously dispersed in its surrounding area. Mineralisation with respect to pyrite took place either in a pre-burial stage or at least prior to sediment compaction, because the rigidity of the permineralised carpo-hardparts withstood sediment pressure. Thus pyritisation is responsible for the undistorted three-dimensional preservation.

Subsequently all organic matter was dissolved away. Simultaneously calcite precipitated in the seed cavity and supplementarily stableised the testa or endocarp.

Biostratigraphical evaluation

A first reliable indication of biostratigraphical (phytostratigraphical) age-bracketing is given by the leafy coniferous shoots that are generally assigned to the form genus *Brachyphyllum*. However, similar morphotypes are sometimes classified in the literature as *Pagiophyllum, Araucaria, Araucerites, Athrotaxis, Allocladus* and *Walkomiella*. Based on cuticular evidence most of these genera belong to the Araucariaceae, Hirmerellaceae (Cheirolepidiaceae), Podocarpaceae and Taxodiaceae, which appeared at the Triassic—Jurassic boundary and which still exist up to the present (Dettmann, 1989: 96; Miller, 1982: 102) with the exception of the Hirmerellaceae (Cheirolepidiaceae).

Only the genus *Walkomiella* that belongs to the Palaeozoic family Buriadiaceae appeared in Permian sediments. East of our locality lies one of the earliest occurrences of *Walkomiella transvaalensis (Brachyphyllum ? australe)* from the Permian Middle Ecca Beds of Vereeniging, Transvaal (Le Roux, 1964). Within the context of the biostratigraphical range of sterile *Brachyphyllum*-type foliage mentioned above, it can be inferred that the Gross Brukkaros lake bed sequence is of Permian or more likely of post-Permian age.

A more complete taxonomic determination should be the basis of any further consideration. Unfortunately some of the plant fossils could not be properly identified because they are too rare or because indifferent preservation prevented them from being studied in sufficient detail. Further careful collecting may resolve this problem and it is likely that additional material would ensure a more faithful taxonomic identification of the few specimens figured here.

However, the presence of a probable dicotyledonous leaflet, a feature thought most likely to be an entomophilous flower head, and angiosperm-like carpofossils, is significant in terms of biostratigraphy, since angiosperms appear in the fossil record only from the Lower Cretaceous onwards. On the basis of these preliminary results we suggest a Cretaceous or post-Cretaceous age for the Gross Brukkaros taphoflora. As indicated above, the available radiometric age determinations (Davies *et al.*, 1991) support these results.

Comparison

Because of the paucity of terrestrial and lacustrine sediments in southern Africa (Tyson, 1986), few macrofloras of Cretaceous and Tertiary age have been described (see Drinnan and Crane, 1990:194; Hughes, 1976:40-43; Vakhrameev, 1991). The same applies to palynofloras

(Axelrod and Raven, 1978; Coetzee, 1986; Van Zinderen Bakker, 1986; Van Zinderen Bakker and Mercer, 1986; Scott, 1986). The late Cretaceous was largely a period of erosion in this area, therefore two other floras preserved in the craters of kimberlite pipes deserve special attention.

Based on palynomorphs, the age of Arnot Pipe sediments, at Banke, Namaqualand, is regarded as close to the Cretaceous—Tertiary boundary (Scholtz, 1985). Beside ferns (Polypodiaceae, Schizaceae) and conifers (Podocarpaceae, Araucariaceae), fourteen families of angiosperms are abundantly represented in the palynological assemblage. A single fern frond remain, small pieces of wood and an unidentifiable fruit were also described together with a small collection of at least twelve different types of dicotyledonous leaf fragments (Rennie, 1931), predominantly those of *Myrica-* or *Engelhardia*-like shape. According to Scholtz (1985) the subtropical forest community at Arnot represented climatic conditions drier than those which existed in the Late Cretaceous. This is thought to indicate the beginning of the trend towards the cooler and drier climates of the later Tertiary.

A taphoflora together with a large number of beautifully preserved whole-bodied fossil insects is known from the mid-Cretaceous crater lake sediments of Orapa, Botswana. Regarding palaeobotany, little information has been published so far in detail although in a preliminary review (Rayner *et al.*, 1991) a palaeoenvironmental reconstruction is given. Among 2640 plant remains, there are 237 pteridophytes, 1188 angiospermous leaves, 396 seeds and 369 angiospermous flowers. Accounts of only 3 fern remains, 3 seeds or fruits, 3 angiospermous leaves and 5 angiospermous flowers have been published (McKay and Rayner, 1986; Rayner and McKay, 1986; Rayner and Waters, 1991; Rayner *et al.*, 1991). None of these is taxonomically identified, with the exception of the fern genus *Asplenium*.

The Orapa flora is thought to contain up to 23 angiospermous leaf types belonging to families, orders and subclasses such as Lauraceae, Cunoniaceae, Hamamelidaceae, Dilleniidae and Saxifragales (unpublished thesis in Rayner *et al.*, 1991). Conifers are obviously absent, but wood occurs, among other things, in a small amount of charcoal. The area surrounding the crater lake would have been forested but no forest occurred within the crater. Rayner *et al.* (1991) suggested a seasonal temperate climate with cool winters and substantial rainfall. Previous opposing interpretations ranging from arid climate to a subtropical rainforest were reviewed in McKay and Rayner (1986).

Based on preliminary evidence from Gross Brukkaros, as described here, the similarities of the three taphofloras are the occurrences of wood, ferns, (?)dicots and seeds or fruits. Flowers, however, have not yet been found at Arnot. The macrofossils of *Brachyphyllum*-type conifer shoots from Gross Brukkaros of presumably Cretaceous or post-Cretaceous age, together with the pollen record of Arnot reinforce the scenario of a Podocarp—Araucarian coniferous forest during the Cretaceous—Palaeogene (Coetzee, 1983; Dettmann, 1989:92).

The fossil plant assemblages from Arnot, Orapa and Gross Brukkaros are isolated in time and space. Thus a subsequent thorough collection of samples and a detailed systematic palaeobotanical study of the Gross Brukkaros sediments is necessary to provide more biostratigraphical evidence for a stable dating framework and to expand our scant knowledge of the vegetation and climatic history well history in these time ranges in southern Africa.

Acknowledgements

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