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THE DEVONIAN-CARBONIFEROUS BOUNDARY IN SOUTH AFRICA[1]

Johannes N. THERON[2]

(6 figures)

ABSTRACT. In South Africa late Palaeozoic glacial deposits (Dwyka Group) rest unconformably on a glacigene surface which is constituted of the uppermost Cape Supergroup (Witteberg Group) south of latitude 32°50'S. The duration of the hiatus between the Witteberg and Dwyka beds is uncertain and variable and fossil evidence has as yet been contradictory. The latest available data is discussed and an easily recognizable and laterally extensive Devonian-Carboniferous boundary, which is largely supported by all facts, is suggested at, or close to, the contact of the Witpoort and Kweekvlei Formations.

KEY-WORDS: Devonian-Carboniferous, southern Africa, Cape Supergroup, Dwyka-Witteberg contact, glacigene surface, plants, fish.

RESUME. La limite Dévonien-Carbonifère en Afrique du Sud. En Afrique du Sud, les dépôts glaciaires de la fin du Paléozoïque (Dwyka Group) reposent en discordance sur une surface glacigène constituée de la partie la plus supérieure du Cape Supergroup (Witteberg Group), au sud de la latitude 32°50'S. La durée de l'hiatus entre les couches de Witteberg et celles de Dwyka es incertaine et variable et les évidences des fossiles ont été jusqu'ici contradictoires. Les données disponibles les plus récentes sont discutées et une limite Dévonien-Carbonifère facilement reconnaissable et étendue latéralement, qui rends compte largement de tous les faits, est suggérée au, ou près du, contact entre les Witpoort et Kweekvlei Formations.

MOTS-CLES: Dévonien-Carbonifère, Afrique du Sud, Cape Supergroup, Contact Dwyka-Witteberg, surface glacigène, végétaux, poissons.

1. INTRODUCTION

In southern Africa, as an integral part of Gondwana, late Palaeozoic glacial deposits of the Dwyka Group are widespread. This group, which constitutes the base of the Karoo Sequence, rests unconformably on Precambrian basement and Palaeozoic Cape Supergroup rocks (fig. 1). The glacigene surface progressively transects younger rocks southwards. Eventually, south of latitude 32°50'S, the Dwyka glacial sediments overlie units of the Devonian-Carboniferous Witteberg Group (uppermost Cape Supergroup) from which a variety of vascular plants and also fish (especiallypalaeoniscoids) have been described (Theron, 1962; Gardiner, 1969). The duration of the hiatus between the uppermost Witteberg beds and the basal Dwyka glacial sediments is uncertain, although recent estimates give a figure of at least 30 Ma (Loock & Visser, 1985, Visser, 1987, 1989, 1993).

To date the fossil evidence from the Witteberg and Dwyka rocks has been insufficient to delineate the Devonian-Carboniferous boundary. There seems to be a discrepancy between the supposed ages of

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2. *Geological Survey, Postbus P.O. Box 572, Bellville, 7535, Afrique du Sud.*

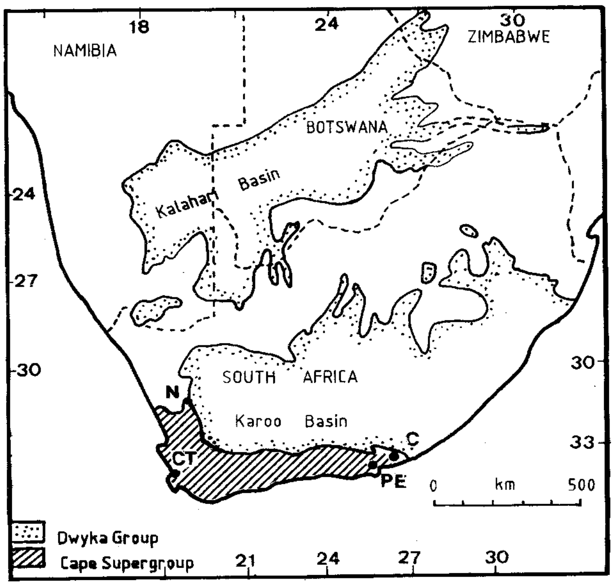

Fig. 1.- Distribution of the Dwyka and Cape rocks in southern Africa (after Visser, 1989, 1990).
CT = Cape Town, PE = Port Elizabeth, N = Nieuwoudtville.
C = Ceres

various critical units based on thediagnostic macrofloral and palynological content on the one hand, and vertebrate remains on the other hand. On the basis of the following discussion of all the latest available information an easily recognizable and laterally extensive boundary is suggested.

2. SEDIMENTOLOGICAL HISTORY

The Cape Supergroup occurs in the southern part of the Cape Province and extends from Cape Town eastwards along an 800 km belt to Port Elizabeth, and also northwards for almost 300 km to Nieuwoudtville (fig. 1). It constitutes a southward-thickening clastic wedge which is subdivided into three major lithostratigraphic units, the Table Mountain, Bokkeveld and Witteberg Groups (fig. 2). It represents almost continuous shallow-marine to deltaic deposition of sand, silt and mud from the Early Ordovician to the Early Carboniferous.

The predominantly arenitic Table Mountain Group constitutes the basal unit and has in turn been subdivided into eight formations. The only major pelitic unit, the Cedarberg Formation, has yielded a variety of microfossils as well as brachiopods and mucronaspidine trilobites which indicate an Ashgillian (Hirnantian) age (Coks & Fortey, 1986).

The overlying Bokkeveld Group is characterised by alternating sheet-like arenaceous and argillaceous units which display upward coarsening (Theron, 1972; Theron & Loock, 1988). The group varies in thickness from 1 500 m in the west to 4 000 m in the east. Its typical Malvinokaffric invertebrate fossil assemblage and trace fossils, as well as some fish (placoderm and acanthodian) and vascular plant remains, indicate shallow marine and paralic deposition during the Emsian-Givetian (Boucot, 1971; Chaloner *et al.,* 1980; Hiller & Theron, 1988).

The Witteberg Group also consists of alternating sheetlike arenaceous and argillaceous units - seven to nine formations altogether - but is distinctly more sandy than the underlying Bokkeveld Group. The Witteberg likewise varies in thickness from 1 350 m in the west to 2 200 m in the east. It is characterised by more advanced plant taxa compared to the flora of the Bokkeveld. Plant fragments consist of psilophyte and lycopod stems -among which *Haplostigma irregulare* predominates (Plumstead, 1967, Anderson & Anderson, 1985). *Spirophyton* is a prominent trace fossil in the basal Witteberg beds in which a restricted assemblage of marine bivalves and brachiopods, including the distinctive genus *Tropidoleptus,* also occurs. The last mentioned is generally indicative of a shallow-water, level-bottom environment (Boucot *et al.,* 1983).

Unfortunately, in the Western Cape no shelly fossils are known from the overlying more continuous and mature arenitic units represented by the Blinkberg and Witpoort Formations, as well as the intervening more pelitic Swartruggens Formation, although plant and trace fossils do occur. The sandy units indicate shallower water and more extensive reworking of the deltaic sediments as barrier and shore sands, seaward of tidal flats which are represented by the bioturbated silty to sandy rhythmites, mudrocks and fine-grained sandstone horizons of the Swartruggens Formation. In the Eastern Cape the equivalent lower half of the Witteberg Group can no longer be subdivided, due to the eastward thinning of the Blinkberg Formation, and is accordingly inclusively known as the Weltevrede Formation. Only the Weltevrede and Witpoort Formations are therefore recognizable here.

In the Western Cape the Witpoort Formation, which constitutes the most prominent arenitic unit of the Witteberg Group, attains a maximum thickness of between 310 and 380 m, thinning west and southwards. In the Eastern Cape it thickens to more than 800 m. The medium- to thick-bedded, fine- to medium-grained grey sandstone displays tabular cross-bedding, wavy and flaser bedding, micro cross-lamination and small-scale upward-coarsening cycles. Rarely thin mudstone lenses are present. The Witpoort Formation reflects deposition along a linear coastline where the sand was extensively reworked in the surf zone and in tidal channels, and then distributed by longshore drift along the edge of a wide, shallow, sandy bay.

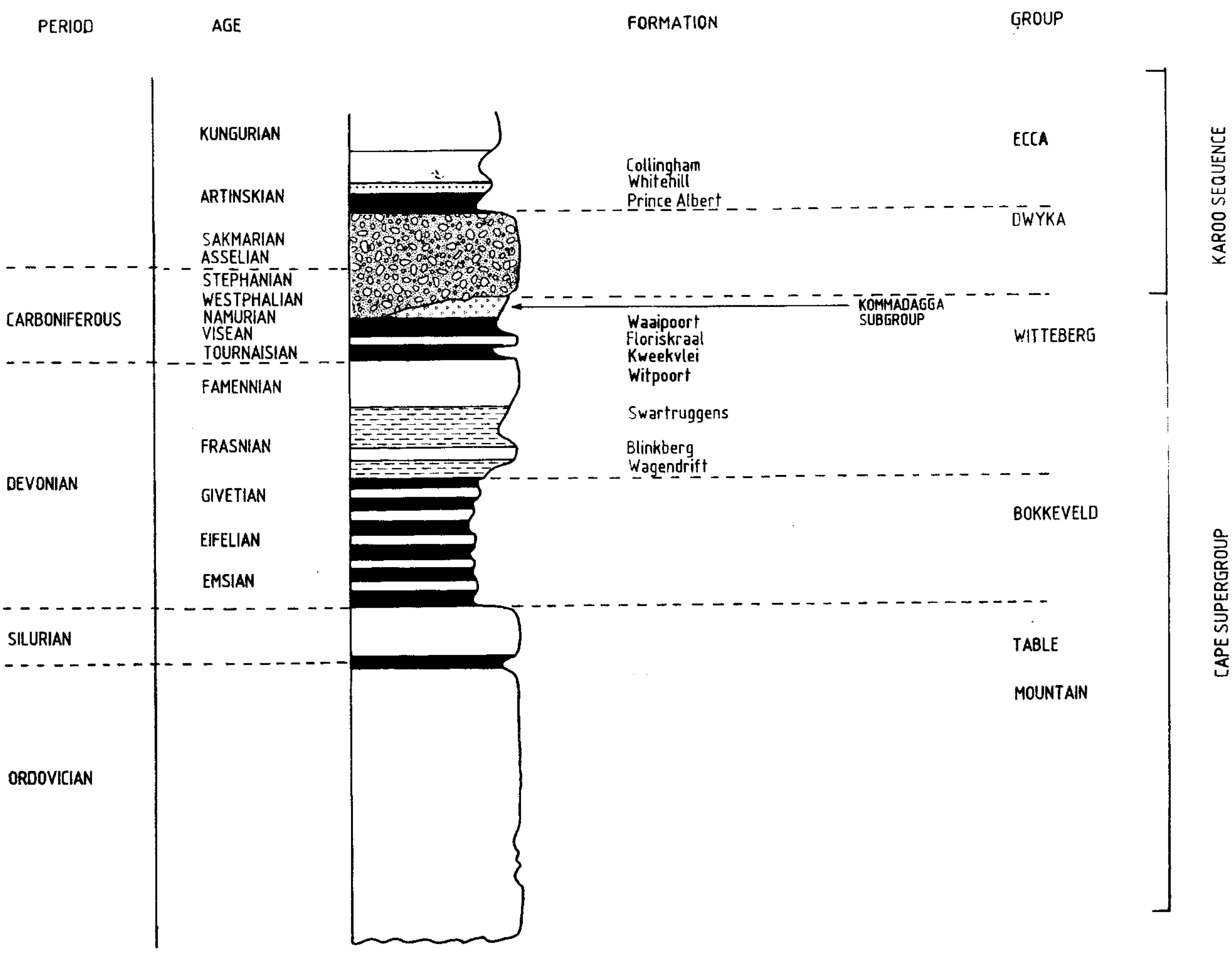

Fig. 2.- Generalized stratigraphical column of the Cape Supergroup and the lower Karoo Sequence in the Cape-Karoo basin.

Approximately in the middle of the Witpoort Formation, near Grahamstown, an intercalated (2-6 m) black shale lens, evidently representing back-barrier lagoonal mud, has yielded numerous fragmentary plant remains as well as a number of fish fossils (Hiller & Taylor, 1992). Included in the flora are the species *Dutoitia alfreda, Praeramunculus capensis* and *Leptophloeum australe,* well known from other Witteberg exposures in the Eastern Cape, as well as a species of the Late Devonian genus *Archaeopteris* and several new, as yet undescribed, forms (Taylor & Hiller, 1992). The fish remains include a holocephalian chondrichthyan, an acanthodian, a lung-fish, and three placoderms consisting of the antiarch *Bothriolepis* and two arthrodires - a groenlandaspid and a phyllolepid (Anderson & Hiller, 1992).

A sudden, rapid, basin-wide subsidence terminated this sandy depositional phase, to be followed by fine muddy sediments of the Kweekvlei Formation. The ripple-marked and bioturbated Kweekvlei sediments gradually become more silty upwards and have as yet only yielded plant fragments. As the basin gradually shallowed, deltafront, mouth-bar, barrier-bar and shoreline sands of the Floriskraal Formation encroached upon the Kweekvlei mud and silt. The palaeo-drainage pattern in the Western Cape indicates major south- and eastward-directed transport (Loock, 1967), reflecting a marked easterly longshore drift and probable reactivation of a western source area, as well as a significant contribution from a major western delta system (Theron & Thamm, 1990).

The overlying Waaipoort mud- and siltstone represent a lagoonal to mud-flat environment behind and adjoining the prograding Floriskraal shoreline sands. Extensive bioturbation and thin carbon-bearing fossiliferous lenses occur (fig. 3). From the last mentioned an assemblage of palynomorphs, lycopods (*Protolepidodendron eximium*) and rare sphenopsids (*Calamophyton* sp.) has been described (Plumstead,

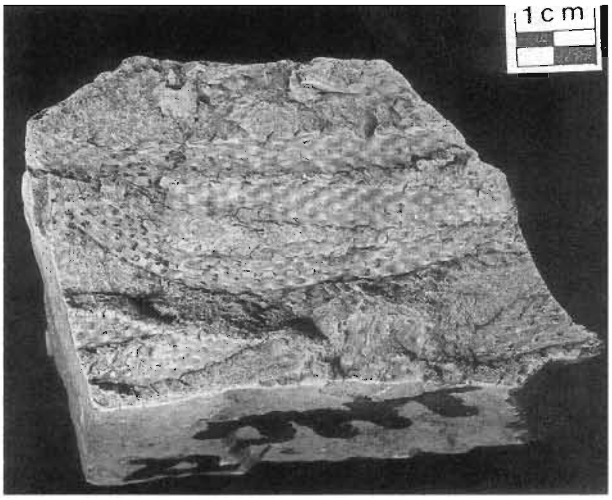

Fig. 3.- Carbon-bearing fossiliferous lens, with lycopod stem fragments, Waaipoort Formation.
Photo by J.E. Almond

1967; Stapleton, 1977). More significant, however, is the peculiarly restricted fish fauna present (figs. 4, 5), consisting almost entirely of Palaeonisciformes (Jubb, 1965; Gardiner, 1969). Of the eight palaeoniscid families represented two are unique to South Africa, i.e. the Willomorichthyidae and the Dwykiidae. The other six families are well known from the Cementstone Group of Scotland. Preservation of many of the fish with their mouths open could indicate either asphyxiation following entrapment in shallow, stagnant, anaerobic pools, or rapid salinity fluctuations. The restricted nature of the fossilized fauna - dominated by palaeoniscoids - may indeed reflect an inherent failure of this group to tolerate wide salinity variations. The advent of glacial conditions, as indicated by the overlying Miller diamictites (Kommadagga Subgroup), could very well have led to variable influx or restriction of water masses entering the basin.

Dwyka tillite follows directly on the Waaipoort beds in the Western Cape and evidence points to partial erosion of the underlying sediments (fig. 6) in some areas (Visser & Loock, 1982). East of longitude 23°E the Kommadagga Subgroup (Miller, Swartwaters-poort, Soutkloof and Dirkskraal Formations) interposes between the Waaipoort and the basal Dwyka beds. Plate subduction along the proto-Pacific margin of Gondwanaland which had started towards the end of the Devonian gave rise to basin inversion and the creation of alpine-type mountains with north- and northwesterly-directed drainage (Bigarella, 1970; Martin, 1981a; Visser, 1987). The Miller diamictite, which occurs intermittently, has a sharp paraconformable basal contact with the Waaipoort Formation and evidently records the earliest glacigenic episodes. The intertongued Swartwaterspoort sands, which possibly represent wave reworking of glacial sands in a beach/foreshore setting, were clearly deformed by drag or density loading due to ice from an overriding glacier during a pulsating glacial episode. The fine rhythmic ("varve-like") layers of the lower Soutkloof sequence accordingly may reflect accumulation of fine glacial outwash in a lacustrine to shallow pro-glacial marine setting. The upward- coarsening succession of Soutkloof silts and overlying Dirkskraal sands probably represents the subsequent regressive cycle and deposition in a near-shore to deltaic environment (Johnson, 1976). Alternatively, a shelf to pro-delta setting may have existed during the Soutkloof and Dirkskraal sedimentation (Loock & Visser, 1985).

Periodic climatic cooling was probably influenced most markedly by the rising southern highlands and, as indicated by the basal Dwyka glacigenic sediments along the southern perimeter of the Karoo Basin, the earliest ice streams radiated northwards into the basin. The northern provenance gradually became more prominent (Visser & Loock, 1982; Visser, 1989). In the continental interior, towards the north, a valley and inner platform association which was deposited on a dissected regional plateau has been recognised. Extensive glacial erosion of the Precambrian floor is evident here (Visser, 1983). Southwards, where an outer platform facies of the Dwyka can be identified, the uppermost sediments of the Cape Supergroup display bedrock, boulder and soft-sediment pavements, or locally deformed beds. In places a gradational contact seems to be apparent between the two units, with dropstones occurring in the uppermost beds of the Witteberg Group (Visser, 1983, 1989).

During Dwyka glaciation a huge continuous ice sheet covered the northern interior plateau. This was fringed to the south by a grounded ice sheet resting on a continental platform. Glaciers from a southern source eventually joined those from the north and the Karoo Basin began to close in the southeast. The palaeo-iceflow directions indicate convergence of ice sheets westwards towards an open body of marine water; some erosion of upper Witteberg rocks in the west occurred (Visser & Loock, 1982). Initial lodgement deposits changing to debris-rain-out and debris-flows and eventually, suspension settling of sediments as the ice sheets disintegrated, are recognized (Visser, 1989). Water depths may have exceeded 250 m and were probably even greater as amelioration of climate led to the final stages of ice-sheet disintegration. At least two major interglacial periods occurred in the southern Karoo Basin (Visser, 1983, 1989). During the maximum of the last intergalcial only small ice caps remained on the higher mountains. The retreat of the ice-grounding line was accelerated by a rapid rise in sea level so that muds of the Prince Albert and Whitehill Formations were

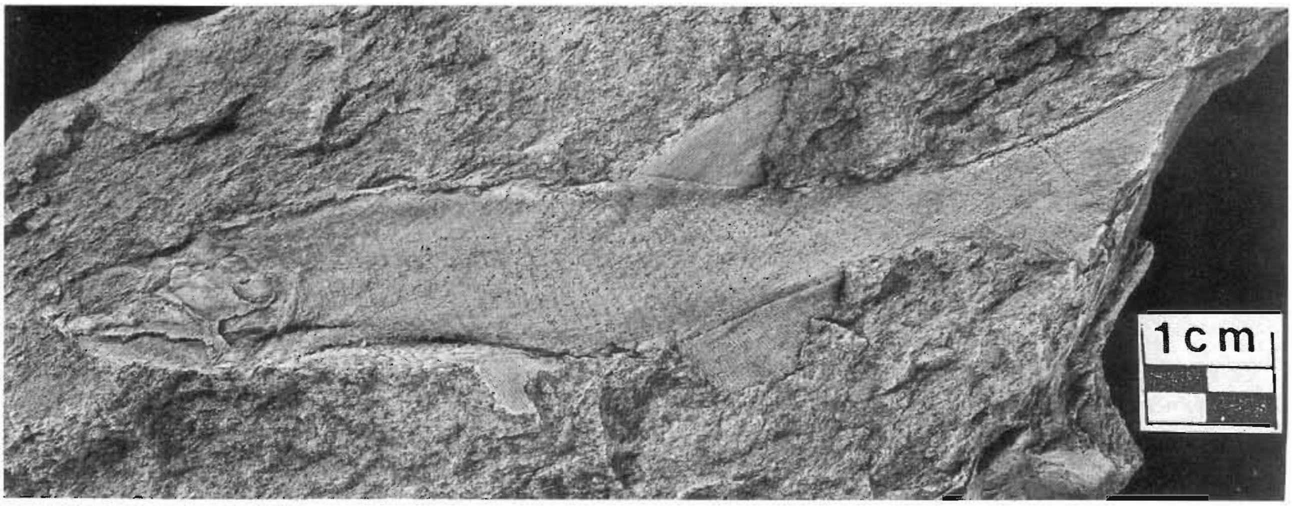

Fig. 4. Palaeoniscoid fish *Mentzichthys* from the WaaiportFormation (K 1170). Sample K 1170 was borrowed from the South African Museum in Cape Town. Photo by J.E. Almond.

successively laid down on top of the glacial beds. The black organic-rich shales of the latter are ascribed to suspension settling of mud under reducing conditions.

3. AGE OF THE GLACIGENIC SEDIMENTS

It is very difficult to quantify the amount of erosion of Cape rocks during the hiatus separating the Witteberg and Dwyka Groups. Local soft-sediment deformation structures in the uppermost Witteberg Group seem to be the effect of overriding by the glaciers relatively shortly after deposition (Bell, 1981).

Stratigraphic studies by Theron and Blignault (1975) and Visser (1986) clearly indicate northward pinch-out of the lower diamictite units against a palaeo-basement escarpment. Furthermore, progressively younger glacial sediments generally occur in glaciated basins up the depositional slope. The lower part of the valley facies is therefore clearly the lateral equivalent of upper diamictite units of the shelf facies, both having had a northern provenance. Visser (1990) amply proves further diachronous sedimentation eastwards, as well as a variation in the total depositional period of the Dwyka Group from west to east.

Miospore analyses of basal Dwyka samples from the northern valley facies reveal a late Carboniferous (Stephanian) to early Permian (Artinskian) age (Anderson, 1977; MacRae, 1987). Various fossils (*Peruvispira, Eurydesma, Orthoceras,* crinoid stems and foraminifera) described by Martin (1981b) from the Dwyka Group in the Kalahari Basin in Namibia were dated as early Sakmarian (Dickens, 1961, 1984; Veevers & Powell, 1987). These apparent discrepancies are caused by the diachronous sedimentation of the Dwyka rocks.

A late Sakmarian to early Artinskian age is suggested for the upper part of the Prince Albert and the overlying Whitehill Formations (Anderson, 1977; MacRae, 1987). The latter is recognized in the western parts of both the Karoo and Kalahari Basins (fig. 1) and is a reliable synchronous marker unit (Oelofsen, 1981). The remains of the aquatic reptiles (*Mesosaurus tenuidens, Stereosternum tumidum*) and fish (*Palaeoniscus capensis*) confirm this uppermost Sakmarian age (Oelofsen & Araujo, 1987).

Veevers and Powell (1987) relate transgressive-regressive depositional sequences in Europe and America to synchronous sea-level fluctuations controlled by the Gondwana glaciations. They conclude that the only dominant glacial episode which affected Gondwana as a whole lasted from the early Namurian to the Sakmarian-Artinskian boundary.

An excellent review of the wide and often conflicting range of published ages for the Dwyka Group is given by Visser (1990).

Although minor variations exist, the general consensus is that the onset of glaciation in southwestern Gondwana, then in a near-polar position, occurred in the Namurian. The partially disconformable relationship between the Witteberg Group and the Dwyka glacial deposits in the Western Cape indicates a period of non-deposition and erosion over southern Africa. Since the major mid-Carboniferous regression started towards the mid-Namurian (Saunders and Ramsbottom, 1986) the onset of glaciation in southwestern Gondwana may also tentatively be considered as mid-Namurian (Visser, 1989, 1990). Evidence of glacial activity in the Paraná and Tasmania Basins up to the Kungurian (Rocha-Campos and Dos Santos, 1981; Banks, 1981), led Visser to propose that the Dwyka glacial episode lasted from the mid-Namurian (c. 324 Ma) to the early Kungurian (c. 260 Ma).

4. POSITION OF THE DEVONIAN-CARBONIFEROUS BOUNDARY

The extent of the hiatus between the lowermost glacigene deposits and the Witteberg units varies from west to east as amply discussed by Visser and Loock (1982).
Consideration of all the evidence, i.e. dropstones in uppermost Witteberg beds as well as soft sediment deformation, sporadic variable erosional features from different localities, limited amounts of debris of Cape Supergroup derivation in the basal tillite even in the Western Cape, etc., indicates that glacial erosion of the Cape Supergroup in the southern part of the basin was on a small scale and localised (fig. 6).

An indisputable Devonian age for the Bokkeveld Group and major portion of the Witteberg Group is evident from their fossil content.

Data regarding the stratigraphical range of the brachiopod genus *Tropidoleptus* elsewhere in the Malvinokaffric Realm, especially in Bolivia (Isaacson and Parry, 1977) just prior to later Devonian or early Carboniferous non-marine sedimentation, indicates a late Givetian-Frasnian age for the lower part of the Witteberg Group, i.e. the Wagen Drift Formation (Boucot *et al.,* 1983).

According to Plumstead (1967) *Leptophloeum australe,* mainly from the Witpoort Formation, and in particular *Protolepidodendron eximium* from the Waaipoort Formation support an Upper Devonian age for these units. She does concede, however, that the stratigraphical extent of the latter plants may reflect a longer time range for the species in West Gondwana.

The presence of specimens of the typical Late Devonian plant genus *Archaeopteris* from the upper part of the Witpoort Formation as well as a fish fauna from the same beds containing amongst others *Groenlandaspis* and the typical Upper Devonian genus *Bothriolepis,* strongly suggests a typical latest Devonian (Famennian) association (Taylor and Hiller, 1992; Anderson and Hiller, 1992). This fauna is comparable to the well known Devonian fish faunas of Australia and Antarctica.

Miospore studies by Stapleton (1977a) ascribed a Givetian-Frasnian age to the Waaipoort Formation. This was however based on the analysis of a single sample containing highly carbonised spores. The delicate nature of the specimens prevented any extensive treatment and SEM identification was based only on the overall shape of the spores and the structures and ornament of the upper visible face. Furthermore, these carbonised spores proved to be markedly smaller than is usual for Devonian spores, making correct taxonomic assignment very difficult. Very few of the characteristic large spinose Devonian forms occurred. Mixed megaspores and miospores of widely different sizes, as featured by Stapleton, are furthermore generally more indicative of rocks of Famennian or younger age. Fifteen species were recognized, of which eleven could be identified. In a later, more detailed investigation (Stapleton, 1977b) three samples were analysed, two of which were obtained from basal units of the Dwyka tillite and one from the Miller diamictite. Although he admitted that the palynomorph microfossils had been very badly damaged by heat and tectonism, some too severely to permit identification even to generic level, he assigned an early Permian age to all these units. Therefore, according to Stapleton (1977b), no Carboniferous rocks occur in South Africa, implying a major unconformity between the Waaipoort and the Miller Formations.

However, there is no field evidence to support this conjecture. Furthermore, recent analyses of samples of similar fossiliferous nodules from the Waaipoort Formation make these conclusions even more contentious since the thermal maturity proved to be so high that it was impossible to identify the palynomorphs, even when they were present. The spore evidence presented by Stapleton for the age of the Waaipoort Formation is therefore regarded as inconclusive.

Research by MacRae (1991) has also since proved the existence of Carboniferous palynomorphs in the basal channel fill of the palaeo valleys of the northern Dwyka deposits. This is in turn overlain by beds with typical Lower Permian pollen. All detailed field analyses of the basal Dwyka deposits in the Western and Southern Cape (Theron and Blignault, 1975; Visser and Loock, 1982) prove a gradual northward pinch out of the older, lower diamictite units against a palaeo-basement escarpment with preservation of progressively younger glacial sediments towards the north (fig. 6). The presence of undoubted Carboniferous palynomorphs in the northern beds therefore makes Stapleton's major contention regarding the absence of any Carboniferous deposits in South Africa untenable.

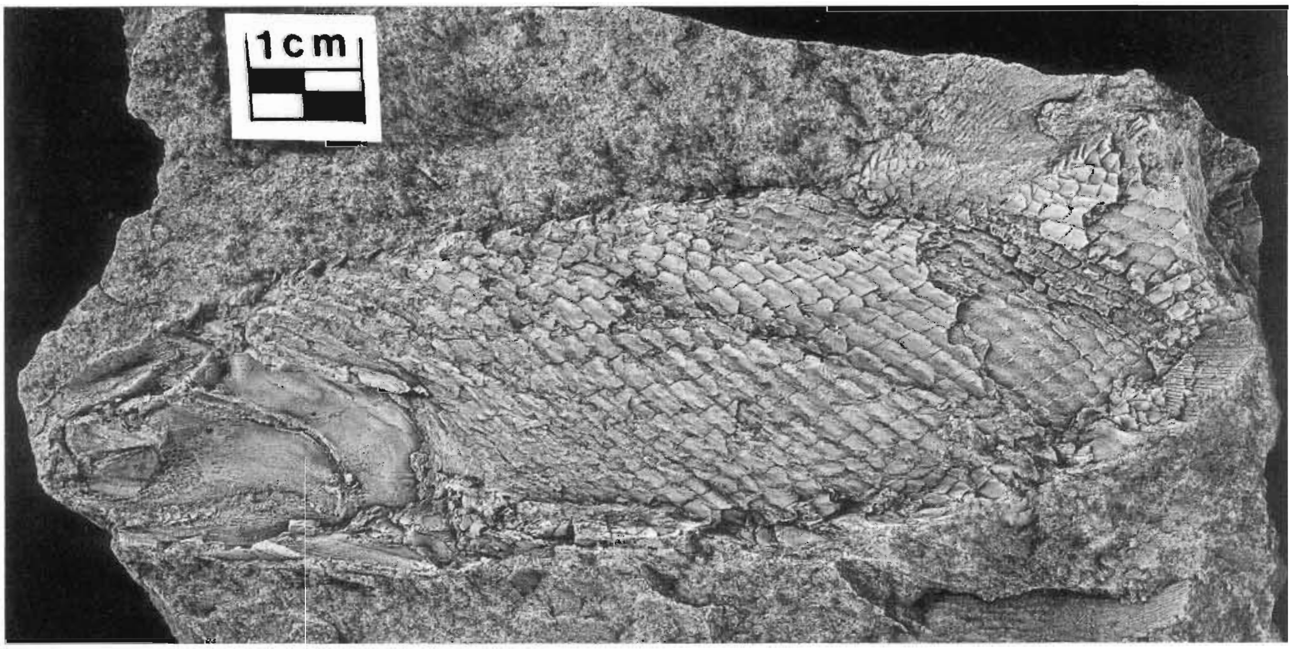

Fig. 5 A and B.- Palaeoniscoid fish from the Waaipoort Formation (B: K1169). Sample K 1169 was borrowed from the South African Museum in Cape Town. Photo by J.E. Almond.

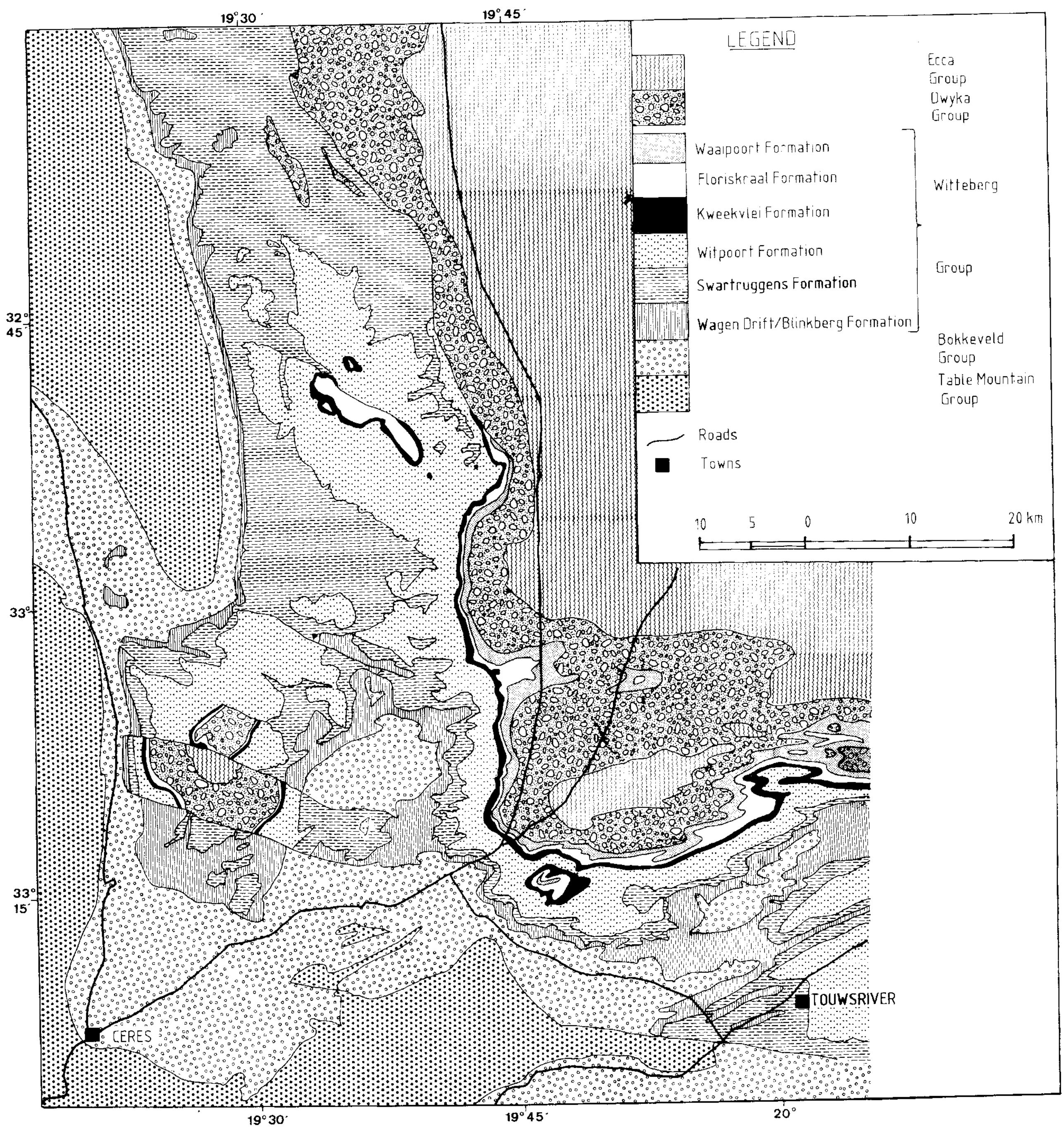

Fig. 6.- Geological map depicting the erosive nature of the Dwyka Group with respect to the uppermost Witteberg unitys

The fish fauna (figs. 4, 5) from the Waaipoort Formation has been compared to the Lower Carboniferous (Viséan) palaeoniscoid fauna from the Cementstone Series of Scotland by Gardiner (1969). Although no common taxon occurs in the two sequences, no less than six of the eight families present in South Africa also occur in Scotland.

The Canobiidae, a short-ranging family confined to the Viséan, is represented by the genus *Sundayichthys* in the Waaipoort Formation. The family Rhadinichthyidae, represented in the Witteberg by the genus *Mentzichthys* and in Scotland by *Rhadinichthys* and *Cycloptychius,* is likewise well known from Lower to Upper Carboniferous sequences elsewhere. The families Holuridea, Amphicentridae and Platysomidea, represented by various genera in both sequences, similarly range from Lower Carboniferous to the Permian-Triassic. The family Atherstoniidae, represented in the Witteberg by the genus *Aestuarichthys,* is only known from the Upper Permian to Upper Triassic in Europe. None of the fauna therefore correlates with any known Devonian taxa. Indeed, only *Willomorichthys,* the single member of the family Willomorichthyidae from the Witteberg, seems to be earlier than Viséan in age. It closely resembles Scottish members of this family i.e. *Strepheoschema* and *Aetheretmon* which are confined to beds regarded as Tournaisian in age. The only other member of the family, *Benedenius,* is likewise only known from the Tournaisian of Belgium (Gardiner, 1969).

Although the correspondence between the South African fish fauna and that of Scotland is only at the familial level, the degree of correspondence is nevertheless remarkable since a southern Gondwanan fauna is being compared with a northern hemisphere fauna. The Lower Carboniferous age assigned to the Waaipoort Formation is therefore not unreasonable, especially in view of the age relationships of the overlying earliest Dwyka glacial deposits as discussed earlier.

The marked lithological change between the white-weathering quartzitic sandstone beds of the Witpoort Formation and the overlying black to dark-grey pelites of the Kweekvlei Formation makes this contact a very conspicuous marker in the field which can be recognized for more than 700 km throughout the outcrop area of the Witteberg Group. It obviously represents a major transgressive event in the history of the basin.

Indeed Cooper (1986), applying event stratigraphy to the Devonian of South Africa, related this extensive quartz-shoal sedimentation of the Witpoort Formation to the prominent Famennian regression (Hercynian structural event) of the northern hemisphere. The Kweekvlei shale event would then reflect the following Tournaisian transgressive cycle (i.e. the *crenulata* Zone transgression).

Extensive investigation of the Kweekvlei Formation over the last few years has unfortunately not as yet yielded any identifiable spores owing to the high thermal maturity of samples (pers. com. M. Streel, K.C. Allen).

The seemingly contradictory ages for the Waaipoort Formation could therefore merely reflect a much longer time range for plants with a Devonian affinity in West Gondwana.

Consideration of all the evidence presently available therefore suggests that the Devonian-Carboniferous boundary in South Africa was close to, or at, the Witpoort-Kweekvlei contact. This conclusion therefore supports the earlier tentative proposal by Loock and Visser (1985) and simultaneously endorse the opinion expressed by Cooper (1986).

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