

Biostratigraphic correlation in the Karoo: The case of the Middle Permian parareptile *Eunotosaurus*

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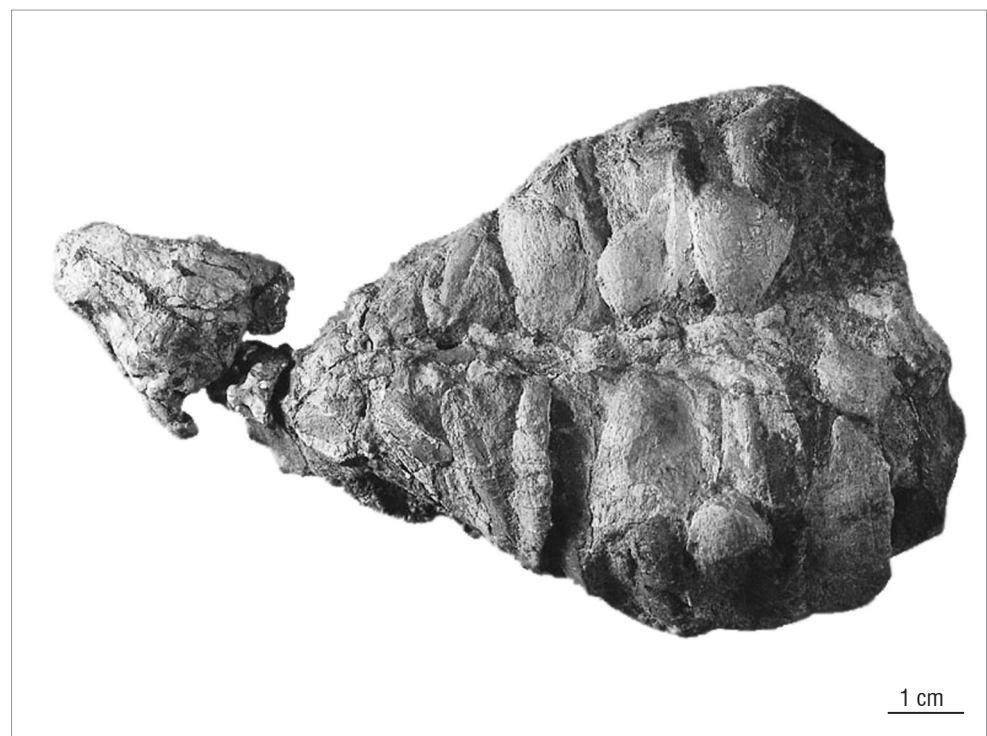
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The richness of fossil tetrapods from the Beaufort Group of South Africa has enabled biostratigraphic subdivision of this Permo-Triassic succession, with global applicability. Despite being the thickest of the seven biozones recognised, attempts at further subdivision of the Middle Permian *Tapinocephalus* Assemblage Zone (Abrahamskraal Formation) have not been successful, largely because the exact stratigraphic ranges of fossil taxa are unknown. This gap in knowledge has limited stratigraphic correlation of the Abrahamskraal Formation and hindered understanding of Middle Permian Karoo basin development. Currently, the lowermost Beaufort Group is split between an eastern and a western stratigraphic scheme and, because of poor outcrop and the relative paucity of fossils in the east, stratigraphic correlation between the two areas has been uncertain. Recent fossil discoveries of the parareptile *Eunotosaurus africanus* in the Eastern Cape and Free State provinces have extended its known geographic range in the east. An additional specimen from the lower Middleton Formation in the Eastern Cape has, for the first time, enabled the biostratigraphic correlation of this unit with the Poortjie Member of the Teekloof Formation in the west. These finds confirm the diachroneity of the boundary between the marine Ecca Group and the terrestrial Beaufort Group.

Introduction

The taxonomic affinity of the enigmatic Permian parareptile *Eunotosaurus africanus*, easily recognised in the field by its distinctive broad ribs (Figure 1), has long intrigued palaeontologists. The genus has been placed in the Parareptilia as the sole member of a sister taxon to the Millerettidae^{1,2} and, most recently, as a sister taxon to modern turtles.³ All specimens of *Eunotosaurus* come from the upper *Tapinocephalus* and *Pristerognathus* Assemblage Zones of the Permian Beaufort Group of South Africa^{4,5} and most specimens have been recovered from the western part of the Main Karoo Basin (Table 1, Figure 2) where the genus has already been used for biostratigraphic correlation.⁶



Source: Council for Geoscience, Pretoria

Figure 1: The Middle Permian parareptile *Eunotosaurus africanus*, specimen M777.

In this part of the basin the *Tapinocephalus* and *Pristerognathus* Assemblage Zones correspond approximately to the Abrahamskraal Formation and the overlying Poortjie Member of the Teekloof Formation, respectively.⁵ Correlation of these biozones with lithostratigraphic units in the east of the basin has been difficult as fossils are less abundant and the *Tapinocephalus* Assemblage Zone was only recently demonstrated to be present in there at all.⁷

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Table 1: List of *Eunosaurus* specimens included in this study.

Specimen number	Collection	Locality	District	Province	Unit	Certainty (to within)
AM5999	AM	Bucklands 108	Albany	Eastern Cape	K	Low
B46	CGS	Sterkfontein 147	Murraysburg	Western Cape	A or P	100 m
BP/1/3514	BPI	Die Bad 286	Beaufort West	Western Cape	A	150 m
BP/1/3515	BPI	Die Bad 286	Beaufort West	Western Cape	A	150 m
BP/1/5677	BPI	Kafferskraal 536	Carnarvon	Northern Cape	A	50 m
BP/1/6218	BPI	The Grant 39	Albany	Eastern Cape	K	50 m
BP/1/7024	BPI	Bullekraal 251	Beaufort West	Western Cape	A	50 m
BP/1/7027	BPI	Bullekraal 251	Beaufort West	Western Cape	A	50 m
BP/1/7121	BPI	Bullekraal 251	Beaufort West	Western Cape	A	50 m
BP/1/7198	BPI	Zwargershoek 151	De Aar	Northern Cape	?	Low
cdb3	CGS	Droogvoetsfontein 356	Fraserburg	Northern Cape	A	50 m
cm341	CGS	Kromelboog 68	Beaufort West	Western Cape	P	50 m
cm45	CGS	Esterville 57	Beaufort West	Western Cape	P or H	100 m
GM71	CGS	Bord Vol Water 313	Fraserburg	Northern Cape	A	100 m
M275	CGS	Duiker Kranse 45	Beaufort West	Western Cape	P	50 m
M775	CGS	Duiker Kranse 45	Beaufort West	Western Cape	P	50 m
M777	CGS	Drie Kop 53	Beaufort West	Western Cape	P	100 m
NM3299	NM	Philippolis Commonage	Philippolis	Free State	?	Low
NM3466	NM	Kafferskraal 536	Carnarvon	Northern Cape	A	50 m
NM3474	NM	Kareepoort 138	Philippolis	Free State	?	Low
NM3485	NM	Somersfontein 69	Philippolis	Free State	?	Low
NM3486	NM	Somersfontein 69	Philippolis	Free State	?	Low
NM3490	NM	Somersfontein 69	Philippolis	Free State	?	Low
NM3500	NM	Somersfontein 69	Philippolis	Free State	?	Low
SAM-PK-011954	SAM	De Kruis van Bloem Fontein 323	Fraserburg	Northern Cape	A	100 m
SAM-PK-K00207	SAM	Lammers Kraal 11	Prince Albert	Western Cape	A	200 m
SAM-PK-K01132	SAM	Bushmans River 312	Beaufort West	Western Cape	A	100 m
SAM-PK-K01133	SAM	Bushmans River 312	Beaufort West	Western Cape	A	100 m
SAM-PK-K01509	SAM	Bultfontein 387	Beaufort West	Western Cape	P or H	100 m
SAM-PK-K01625	SAM	Bultfontein 387	Beaufort West	Western Cape	P or H	100 m
SAM-PK-K01673	SAM	Bultfontein 387	Beaufort West	Western Cape	P or H	100 m
SAM-PK-K06732	SAM	Ryers Valley 401	Fraserburg	Northern Cape	P	100 m
SAM-PK-K07611	SAM	Bloukrans 31	Prince Albert	Western Cape	A	100 m
SAM-PK-K07670	SAM	Springfontein 305	Beaufort West	Western Cape	A	50 m
SAM-PK-K07909	SAM	Klipbanks Fontein 137	Beaufort West	Western Cape	A or P	100 m
SAM-PK-K07910	SAM	Klipbanks Fontein 137	Beaufort West	Western Cape	A or P	100 m
SAM-PK-K07911	SAM	Klipbanks Fontein 137	Beaufort West	Western Cape	A or P	100 m

AM, Albany Museum, Grahamstown; CGS, Council for Geoscience, Pretoria; BPI, Bernard Price Institute (Palaeontology), Johannesburg; NM, National Museum, Bloemfontein; SAM, Iziko South African Museum, Cape Town.

A, Abrahamskraal Formation; P, Poortjie Member; H, Hoedemaker Member; K, Koonap Formation.

Specimens in bold are at the extremes of the range.

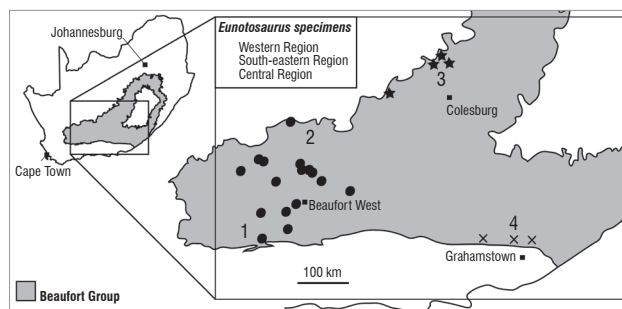


Figure 2: *Eunotosaurus* fossil localities in the Beaufort Group of South Africa, separated into regions. Numbers show the localities of the stratigraphic sections in Figure 3.

Materials and methods

The Beaufort Group fossil tetrapod geographic information system (GIS) database⁶ was used to project the localities of all specimens of *Eunotosaurus* onto Google Earth satellite imagery (both use the WGS84 coordinate system) whence their stratigraphic position was deduced from geological maps.

The quality of locality information for each specimen varies, with many earlier discovered specimens being assignable only to the area of a farm. The range of strata that outcrops in the area of a locality, or across the farm as a whole, therefore has a direct influence on the accuracy with which each specimen could be placed stratigraphically (Table 1). Extensive fieldwork allowed refinement of the stratigraphic provenance of all specimens of *Eunotosaurus* whose stratigraphic position, as calculated from the geological maps, could potentially form one of the extremes of the stratigraphic range of the genus.

For the purposes of this study, because of the heterogeneous nature of the stratigraphy, the basin was divided into four regions: the northwestern, southwestern, central and southeastern Karoo (Figure 2). Stratigraphic sections were either measured by the authors or taken from the literature⁹⁻¹² and drawn up for each region, after which each section was split into 50-m intervals. Such intervals represented the greatest provenance accuracy which could be determined for most of the fossils. The stratigraphic position of each *Eunotosaurus* specimen was then plotted on the stratigraphic section for its respective region, spread across the number of 50-m intervals each could possibly occupy. This approach compensated for the level of uncertainty accompanying all fossils, either because of the lack of precise locality data or because of the complexity of the geology or local topography. The range ultimately calculated is the minimum range for the genus based on the existing data with a maximum error of 50 m.

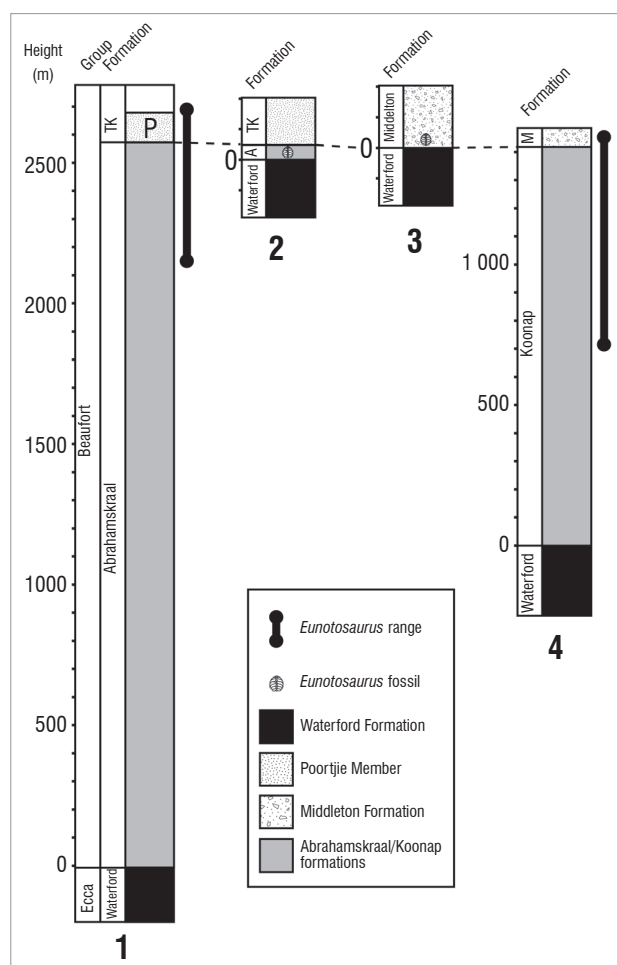
Institution abbreviations are as follows: SAM, Iziko South African Museum, Cape Town; BP, Bernard Price Institute (Palaeontology), Johannesburg; AM, Albany Museum, Grahamstown; NM, National Museum, Bloemfontein; CGS, Council for Geoscience, Pretoria.

Results

Compilation of all the locality data relating to *Eunotosaurus* indicates that the stratigraphically lowest specimens are SAM-PK-K07611 from Bloukrans 31, Prince Albert District, and BP/1/3514 and BP/1/3515 from Die Bad 286, Beaufort West District. Both localities are situated in the southwestern section of the basin. SAM-PK-K07611 occurs between 2150 m and 2200 m above the boundary between the marine Eccla Group and the terrestrial Beaufort Group as defined by Rubidge et al.¹³, while the latter two specimens are constrained to between 2200 m and 2350 m above this level. These localities are all within the upper Abrahamskraal Formation.

The stratigraphically highest specimens are CGS CM45, from Esterville 57 in the Beaufort West district, and SAM-PK-K1673, SAM-PK-K1625 and SAM-PK-K1509 from Bultfontein 387 in the Victoria West district – both localities are situated within the northwestern part of the basin. With reference to geological maps (map sheet: Republic of South Africa

3122, Victoria West, 1:250 000 Geological Series 1989), the locality data of CGS CM45 indicate that this specimen was collected from the lowermost Hoedemaker Member of the Teekloof Formation; however, as a result of the approximate determination of the coordinates, there is a slight chance that the specimen may have been found in the uppermost Poortjie Member. The SAM specimens are recorded as coming only from Bultfontein 387 – a farm which covers the upper Poortjie and lower Hoedemaker – so their actual position is not well constrained. Accordingly, CGS CM45 is the highest well-constrained occurrence and probably occurs in the lowermost part of the Hoedemaker Member. The stratigraphic range of *Eunotosaurus* in the west therefore extends from about 350 m below the top of the Abrahamskraal Formation to the lowermost Hoedemaker Member of the Teekloof Formation (Figure 3). This distribution gives it a total stratigraphic range of 450–550 m, depending on local thicknesses, and corresponds to the upper *Tapinocephalus* and the entire *Pristerognathus* assemblage zones.⁵



A, Abrahamskraal Formation; M, Middleton Formation; TK, Teekloof Formation.

Section 1 = Western Region (south); section 2 = Western Region (north); section 3 = Central Region; section 4 = Southeastern Region.

Figure 3: The stratigraphic position of *Eunotosaurus* around the Karoo Basin. The localities of each section are shown in Figure 2.

In the Eastern Cape Province, two specimens are recorded from the Koonap Formation, in the Grahamstown district. Specimen AM5999 comes from the farm Schrikwaters Poort 109 and, although its locality is not recorded precisely, it is possible to constrain its range to the upper half of the Koonap Formation. On the farm The Grant 39, specimen BP/1/6218 occurs at 730 m above the Eccla–Beaufort boundary,¹² also mid-Koonap Formation. A newly discovered specimen from the farm Wilton, 5 km west of Middleton Station in the Somerset East district

(Eastern Cape Province), occurs in the lower Middleton Formation (Figure 4).

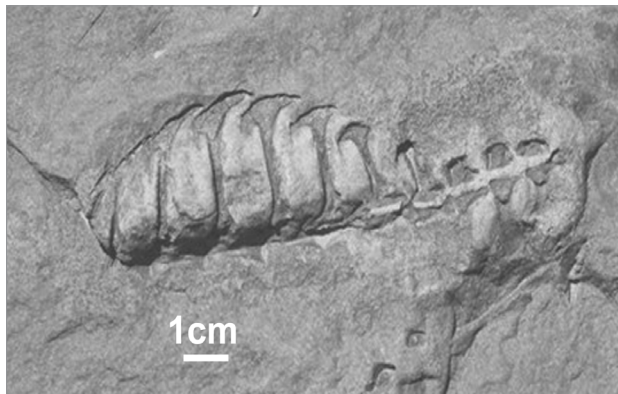


Figure 4: *Eunotosaurus* fossil impression embedded in sandstone on the farm Wilton, near Middleton, Eastern Cape Province (32°58'40.2"S, 25°45'58.5"E).

In the Free State, the specimens of *Eunotosaurus* are associated with scylacosaurid therocephalians and, as no dinocephalians have been discovered, these specimens are considered to fall within the *Pristerognathus* Assemblage Zone⁹; however, the lithostratigraphic context is uncertain here.^{9,11}

The scarcity of fossil material in the eastern part of the Basin is problematic. The difference in stratigraphic regime, confounded by the absence of the *Eodicynodon* Assemblage Zone and an unknown proportion of the *Tapinocephalus* Assemblage Zone near Grahamstown,⁷ makes subdivision of the eastern formations uncertain. Although BP/1/6218 may prove to be the lowest occurrence of *Eunotosaurus*, until collecting efforts create a larger sample size, the stratigraphic ranges of specimens from the eastern Karoo Basin have limited use unless compared to the west.

Age

Traditionally, the age of the *Tapinocephalus* and *Pristerognathus* assemblage zones has relied upon comparisons to the Russian Permian, and more specifically to the Ischeevo fauna.^{5,14} This comparison places them in the Capitanian stage, dated at 265.8–260.4 million years ago.¹⁵ From existing material, the stratigraphic range of *Eunotosaurus* corresponds to the upper third of the *Tapinocephalus* Assemblage Zone and the entirety of the *Pristerognathus* Assemblage Zone. The upper end of the *Eunotosaurus* range is therefore dated to about 260 million years ago, at the Capitanian–Wuchiapingian boundary.¹⁴ The lower extent of its range is more difficult to determine, but given the data available from biostratigraphic correlation with Russia, the first appearance of the genus would probably fall within the middle Capitanian.

Conclusion

Our study demonstrates that *Eunotosaurus* has a restricted stratigraphic range of about 450 m within the fluvial lower Beaufort Group of the Main Karoo Basin and can therefore be useful for biostratigraphic correlation. The presence of this genus in only the upper part of the Koonap Formation and lowermost Middleton Formation supports the lithostratigraphic correlation of the Poortjie Member in the western Karoo Basin to the base of the Middleton Formation in the East.¹⁶ As the distribution of *Eunotosaurus* corresponds to a fixed time period, the recognition that the genus occurs in the upper but not the lower *Tapinocephalus* Assemblage Zone in the south has further utility; the presence of *Eunotosaurus* with a *Tapinocephalus* Assemblage Zone fauna on the Ecce–Beaufort boundary in the Carnarvon district, Northern Cape,⁹ and its presence with a *Pristerognathus* Assemblage Zone fauna immediately above the Ecce–Beaufort boundary at Philippolis, southern Free State,⁹ confirm the younging of the Karoo palaeoshoreline towards the north.

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Authors' contributions

M.D. wrote the manuscript, calculated specimen stratigraphic positions and was involved in the fieldwork; B.R. was the project leader and assisted in writing the manuscript; J.A. conducted some of the fieldwork; S.J. was involved in fieldwork and assisted in stratigraphic interpretation.

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