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Upper Cretaceous Dinosaur-bearing Sediments in Majunga Region, Northwestern Madagascar*

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Introduction

In 1973 and 1975 the National Science Museum, Tokyo, carried out a reconnaissance survey of the paleontology of Madagascar (ASAMA, 1977). OBATA participated in the work in 1975, and KANIE in 1973 and 1975. As one of the main subjects in Madagascar, the party excavated dinosaur remains near Majunga, in the northwestern part of the island on both visits. In order to clarify the stratigraphy and geologic structure of the Cretaceous dinosaur-bearing beds, in 1975 the authors surveyed the area around the excavated sites at Berivotra, about 50 km southeast of Majunga. The present paper reports the results of the stratigraphic investigations of the Upper Cretaceous formations exposed in the southeastern part of Berivotra.

The authors wish to record here their gratitude to the following persons, of the National Science Museum, who helped this study in various ways: Dr. Kazuo ASAMA and Mr. Satoshi MATSUBARA kindly offered the topographic map made by themselves; Dr. Yoshikazu HASEGAWA assisted the authors in the field work; Dr. Hiroshi UJIIÉ critically read through the manuscript; Dr. Keisaku TANAKA of the Geological Survey of Japan identified the echinoids: Dr. Itaru HAYAMI of the University of Tokyo identified the pelecypods. Mr. S. MATSUBARA identified the barite and gave the authors some comments on the condition of crystal growth in the natural environment. The sincere thanks extend also to Dr. J. M. HANCOCK of King's College, London, who kindly checked the English.

The 1975 National Science Museum Party, having been granted permission by the Malagasy Government, carried out field work, in cooperation with the Service Géologique, Direction des Mines et de l'Energie, Repoblika Malagasy. The authors are deeply indebted to Mr. RASOAMAHENINA-ANDRIAMAZOTO, Chief of the Service Géologique, who kindly made arrangements for the field work, and allowed the authors

* Contribution to the Paleontology of Madagascar, IV.

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Geologic Notes

Study of the Cretaceous sequence and fossils of the Majunga region goes back about eighty years. The first discovery of dinosaur bones from this region was reported in 1896 from Maevarano, about 40 km southeast of Majunga. They were *Titanosaurus madagascariensis* DEPÉRET, based upon part of a humerus and two caudal vertebrae, and *Megalosaurus crenatissimus* DEPÉRET, based upon several teeth. The former species was later assigned to *Laplatosaurus* and reported from the Cenomanian to Turonian deposits of India (HUENE, 1927; HUENE and MATLEY, 1933). The latter species was later assigned to *Majungasaurus* by LAVOCAT (1955), who established the genus on the basis of an imperfect right mandibular ramus with numerous associated teeth which are identical with those from the same locality described by DEPÉRET (1896) as *Megalosaurus crenatissimus*. THEVENIN (1907) pointed out that the dinosaur-bearing beds are overlain by deposits containing mollusks such as *Gryphaea vesicularis* and *Alectryonia ungulata*.

From excavation for the main road in 1926 *Laplatosaurus madagascariensis* (DEPÉRET), *Majungasaurus crenatissimus* (DEPÉRET), land cheolonians and crocodilians were discovered at Berivotra (PIVETEAU, 1926; BESAIRIE, 1972). On that occasion PIVETEAU (1928) described as *Stegosaurus madagascariensis* PIVETEAU two teeth from Berivotra, but since *Stegosaurus* is essentially a North American Upper Jurassic genus this determination must be regarded as highly improbable (STEEL, 1969). HOFFSTETTER (1961) described *Madtsonia madagascariensis*, a Cretaceous ophidian. Quite recently RUSSEL *et al.* (1976) have added to our knowledge of the vertebrate fossils from the Majunga region, listing one species of selachian, pycnodontid, ophidian, lacertilian, and pleurodir turtle, beside of three species of crocodiles and dinosaurs which are one sauropod, one theropod and one ankylosaur (probably a nodosaurid).

On the Majunga-Ambalakida sheet of the 1: 100,000 geological map published by the Service Géologique de Madagascar, the stratigraphic sequence of the area is summarized in ascending order as follows.

C^{6-8}:–Turonian to Campanian; continental deposit. C^{9}:–Maastrichtian; marine, marl. C^{10}:–Danian; marine, marl or limestone.

Thus the dinosaur-localities are included in C^{6-8}.

BESAIRIE (1972) called C^{6-7} the Marovoay Series, regarding it as Coniacian to Santonian, and C^{8} the Maevarano Series as Campanian. He divided C^{8} into two parts, a lower and an upper. According to him, the lower part of the Maevarano Series is 270 m thick, and the upper part is 100 m thick at Maevarano. The dinosaur-localities are contained in the upper part. Generally speaking the sediments, *i.e.* C^{8},

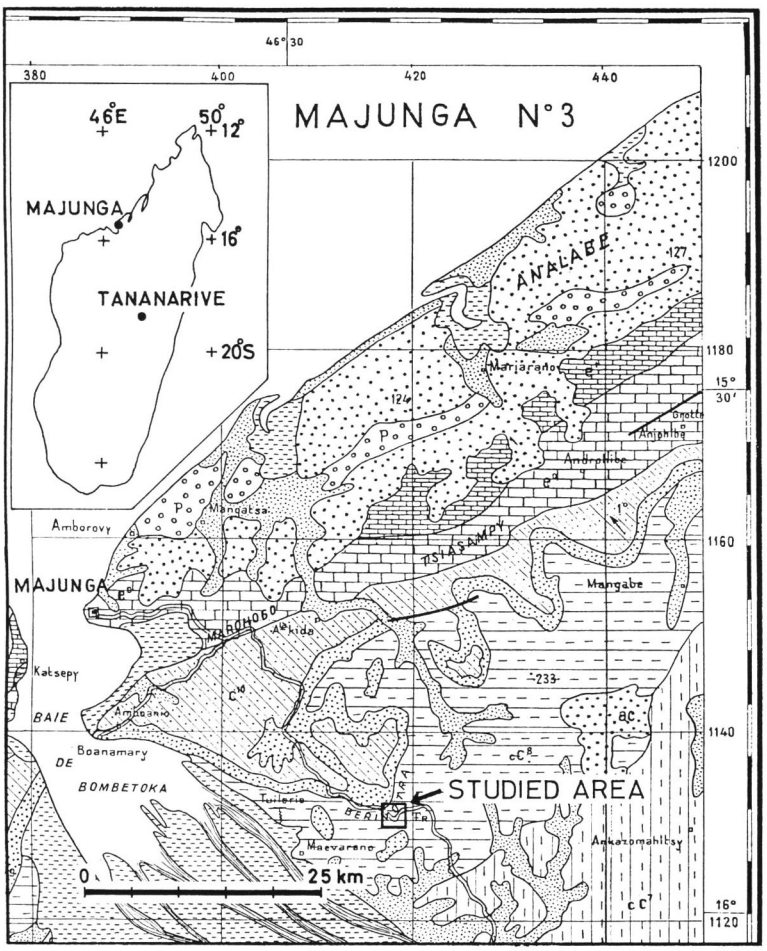

Fig. 1. Geological setting of the studied area in the geological map "Majunga" (1/500,000). Adapted from the Service Géologique de Madagascar (1969). Legends: $_cC^7$ Santonian, C^8 Campanian, C^9 Maastrichtian, C^{10} Danian, e^0 Paleocene, e^1 Ypresian, p Pliocene

C^9 and C^{10}, of the Berivotra area dip gently to the northwest (Fig. 1). C^8 is a continental formation and consists mainly of alternating sandstone and siltstone. The detailed stratigraphy is described in the next chapter. Topographically the deposits of C^8 have been much eroded, but the remaining portion forms hills here and there that extend NNW-SSE or NW-SE. Erosion has frequently formed flat surfaces along bedding planes.

The marine formation C^9 unconformably overlies the non-marine sediments of C^8. C^9 is composed of marl, and is 40 m in thickness. Ostreid species, such as *Picnodonte vesicularis* (LAMARCK), were found to be abundant in the marl, the basal part of which yielded several species of mollusks. C^9 is overlain conformably by C^{10},

which is formed of 60 m of chalky dolomite. From C^{10} came numerous specimens of echinoids such as *Hemiaster* (*Bolbaster*) *hawkinsi* LAMBERT and *Linthia* (*Linthia*)

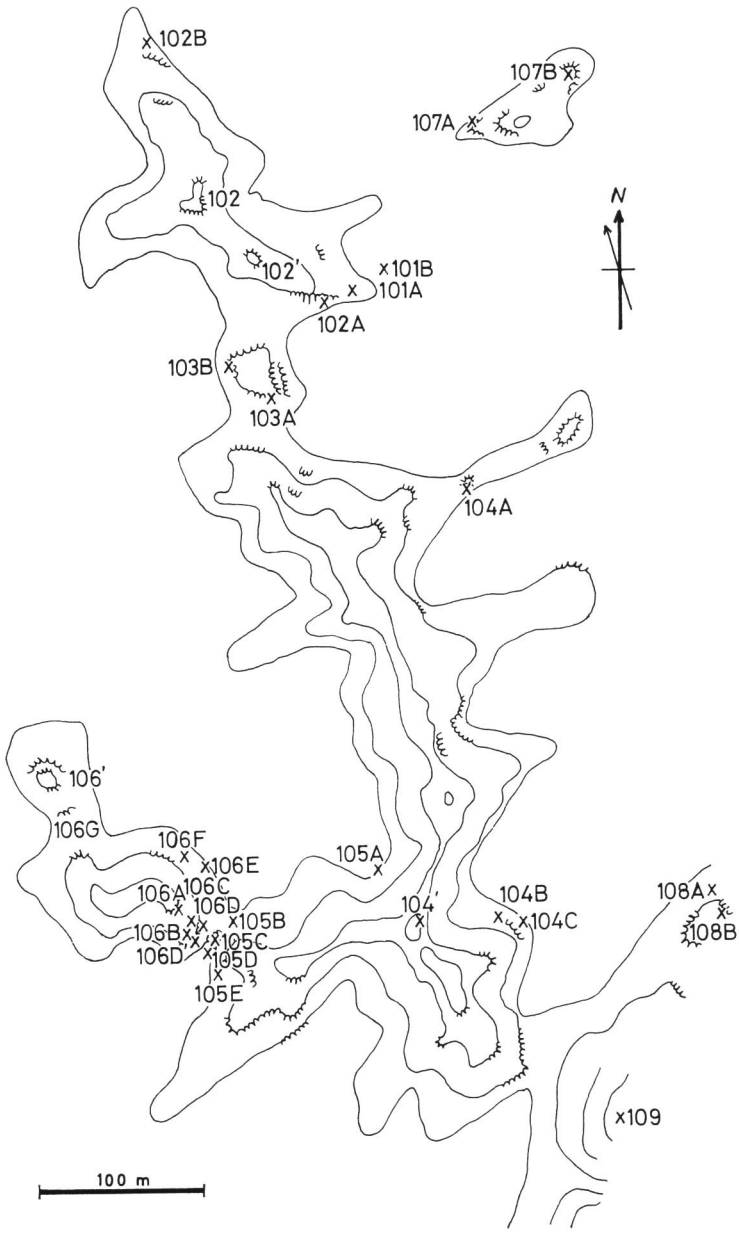

Fig. 2. Topographic sketch map of the south of Berivotra Village, originally drawn by ASAMA and MATSUBARA. Locality numbers beginning with prefix "Mj"

inconstans (LAMBERT), and several species of pelecypods such as *Modyolus* sp. As C^{10} is more resistant to weathering than the underlying C^{9} and C^{8}, the eastern and

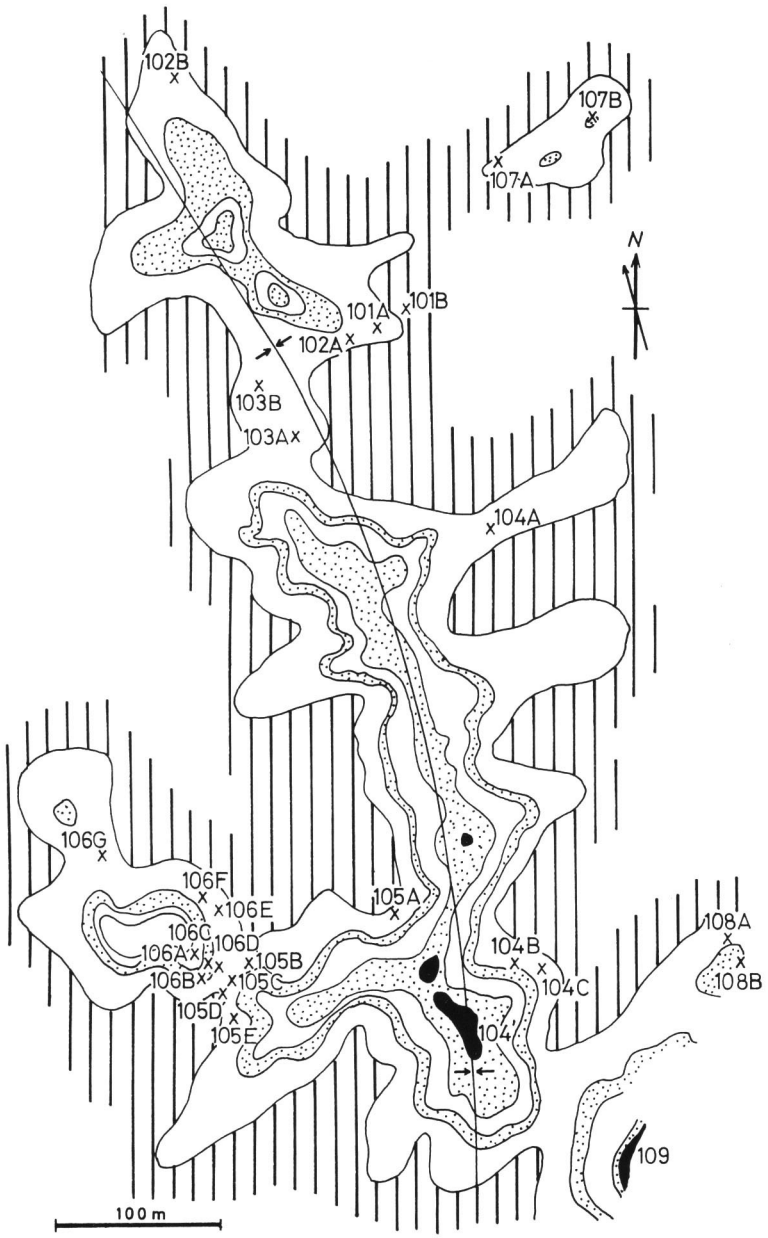

Fig. 3. Geological map of the south of Berivotra Village. Legends are shown in Fig. 5. Locality numbers beginning with prefix "Mj"

southern boundaries of C^{10} are often characterized by steep cliffs.

The fossil localities Mj 101 to 109, south of Berivotra, are indicated on a topographic sketch map (Fig. 2). As shown on the map, four topographic surfaces due to differential erosion are distinguished there. In some places on the highest surface in this limited area, there are residual hillocks of marl, *e.g.* locs. Mj 104′, 109.

Stratigraphy of the Continental Sediments

In naming formations and members, the recommendations of the International Subcommission on Stratigraphic Classification of IUGS Commission on Stratigraphy (HEDBERG, 1976) should be followed. However, the area studied was too small to decide the scope of formations and members, so the authors have generally used the divisions of BESAIRIE (1972). The essential stratigraphic facts, including both lithofacies and fossil occurrences, are outlined below. For convenience, the exposures along Route No. 4 between Berivotra and Amboanemba, and the area south of Berivotra, will be considered separately.

A. South of Berivotra

$_{c}C^{8}$ is widely distributed in the area surveyed. It is about 24 m thick, and is composed of sandstone and siltstone. The authors give a topographic map (Fig. 2), a geologic map (Fig. 3), columnar sections (Fig. 4) and a geologic cross section (Fig. 5) of the area. The formation is divided into two members, lower and upper, in the area surveyed.

a) Lower member

Distribution: This member is widely exposed in depressions amongst the hills. As shown in Figure 5, it lies below 173 m altitude in the northern part of the area, 165 m in the south, 177 to 172 m in the east, and below 168 m in the west. Thickness: 7 m+.

The lower member consists mainly of spotted greenish and reddish sandstone or siltstone, and white sandstone. The sandstone is fine- to medium-grained, and is occasionally cross-laminated. Parts of the lower member are composed of red sediments, which are suggestive of a fossil soil (*e.g.* loc. Mj 101; see Pl. 1, fig. 4).

b) Upper member

Distribution: This member forms much of the hilly country that runs NNW-SSE and NW-SE. Thickness: ca 17 m±. There is a minor break between the lower and upper members.

Sometimes a local surface of erosion can be seen between the two members and small angular slabs of the lower member are enclosed in the basal part of the upper. The upper member, composed of greenish siltstone or sandstone, cross-bedded white quartzose sandstone, and massive white sandstone, represents several incomplete semi-cycles of sedimentation (Fig. 4).

The basal part, covering the lower member, consists of greenish fine-grained sandstone or siltstone and white cross-bedded medium-grained sandstone.

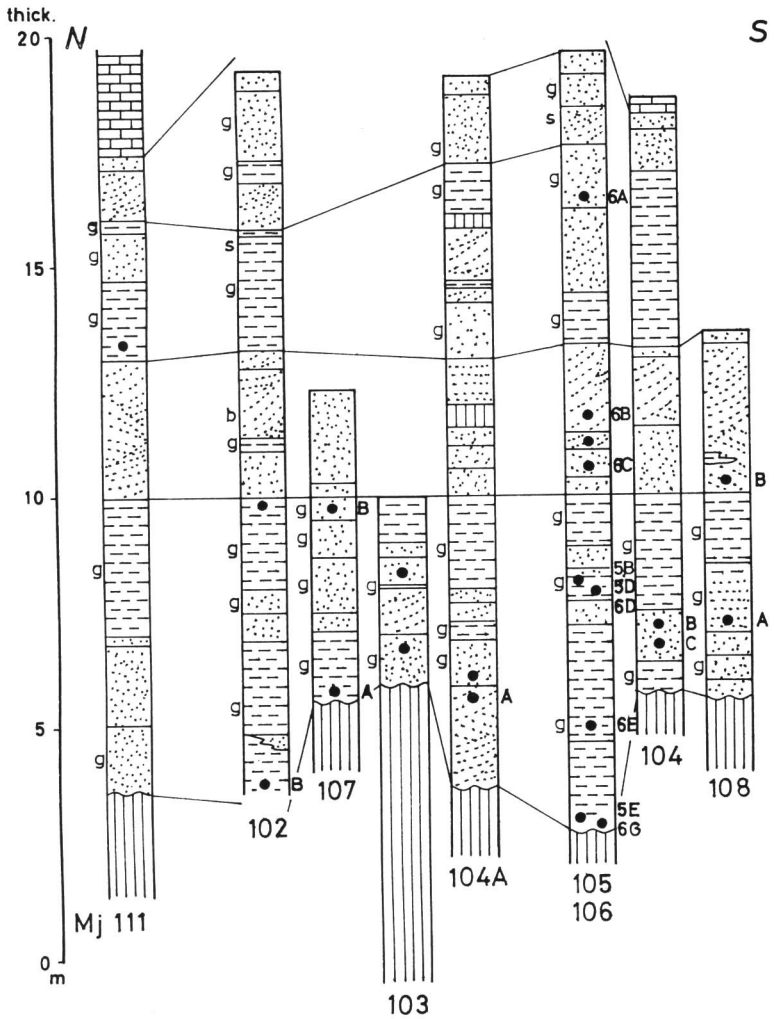

Fig. 4. Columnar sections of the south of Berivotra Village. Legends are shown in Fig. 7, except for S (Sandpipe)

In the lower part greenish siltstone predominates, but in places grades laterally into fine-grained sandstone. White cross-bedded sandstone is intercalated.

The middle part is marked by white, medium-grained, cross-bedded quartzose sandstone. Very rarely reddish and greenish siltstones are lenticularly intercalated. In one of the sandstone horizons numerous idiomorphic crystals of barite, several centimeters across, were discovered.

The upper part is again marked by greenish rocks, which are partly siltstone and partly fine-grained sandstone. Rarely reddish siltstone is intercalated. Numerous

sandpipes were seen locally.

The uppermost part is marked by white, cross-bedded, medium-grained sandstone. Sometimes greenish siltstone or fine-grained sandstone is intercalated and some sandpipes were seen.

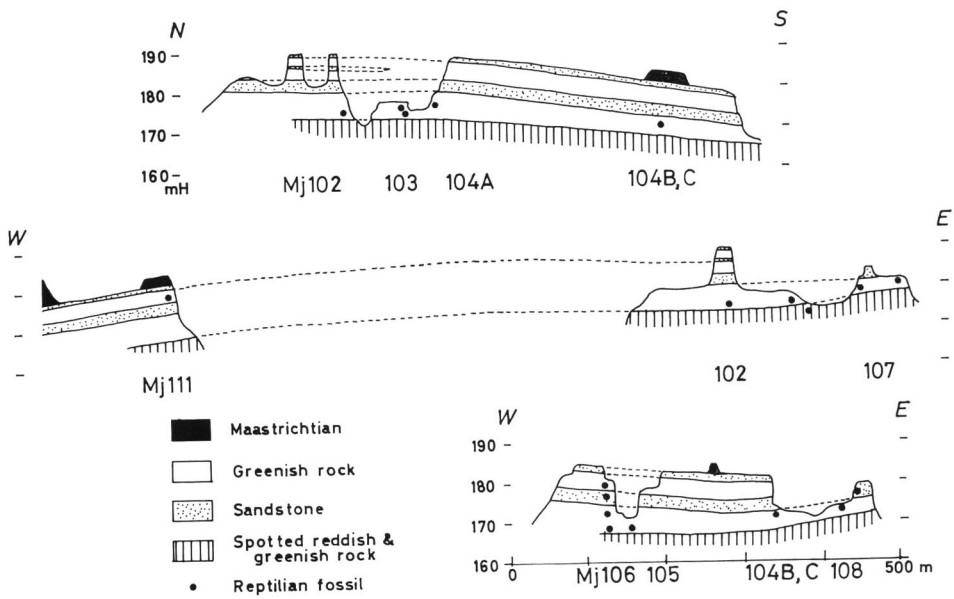

Fig. 5. Geological profiles in the south of Berivotra Village. mH: meters above sea-level

In the columnar and geologic sections (Figs. 4 and 5) the horizons of reptilian fossils are indicated. These reptilian fossils are commonly found in the greenish sediments of the basal and lower parts of the upper member (Pl. 1, fig. 2), occasionally in the cross-laminated sandstone of the middle part (Pl. 1, fig. 3), and rarely in the greenish sediments of the upper part. The bones are usually preserved still articulated in the greenish sediments, whilst isolated bones are found sporadically in the cross-laminated sandstone.

The marl of formation C^9 rests disconformably on the older non-marine formation ${}_cC^8$ (Figs. 3–5). The authors obtained *Arctostrea ungulata* (SCHLOTHEIM), *Neithea* (?) sp., *Limatula* (?) sp., *Baculites* (?) sp. and an ornate ammonite from loc. Mj 104′; *Neithea* (?) sp. from loc. Mj 109. This is a new discovery; the marl containing fossils has not previously been reported from the area surveyed (Service Géologique de Madagascar, 1960). The marl, 1 m or so in thickness, is distributed on the tops of hills at a few localities in the southeastern part of the area.

Thus the Cretaceous strata have a gently undulating dip as illustrated in the geologic sections (Fig. 5).

B. Berivotra to Amboanemba along Route No. 4

The authors surveyed the non-marine deposits along Route No. 4. The route map (Fig. 6) and the columnar section (Fig. 7) are presented, in which the occurrence of the reptilian fossils is indicated.

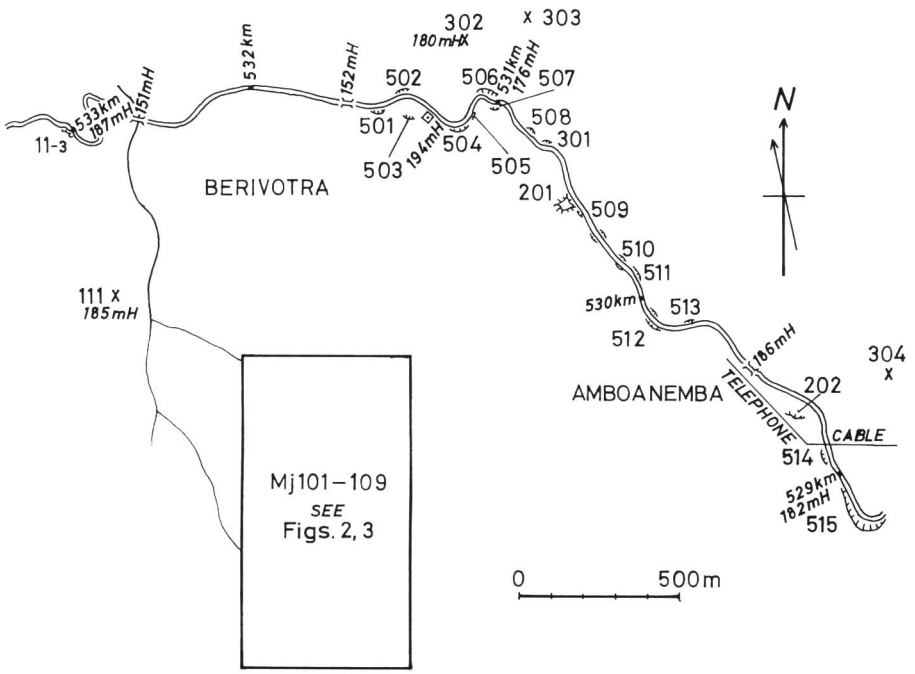

Fig. 6. Locality map along the Route No. 4 at Berivotra-Amboanemba. mH: meters above sea-level, km: km-stone from Tananarive. Locality numbers beginning with prefix "Mj"

a) Lower member

Distribution: As shown in Fig. 7, the lower member lies below an altitude of 166 m at loc. Mj 503, Berivotra, below 174 m at loc. Mj 507 to the east, below 188 m at locs. Mj 201 and Mj 512 in the south-east, and 191 m at loc. Mj 202. Thus the lower member is higher at Amboanemba than at Berivotra and south of Berivotra. Thickness: 10 m+.

The litho-facies of the lower member along this route is similar to that south of Berivotra. Isolated bones are occasionally found in the spotted greenish and reddish sediments.

b) Upper member

Distribution: This member is widely exposed along Route No. 4, as shown in Fig. 7. Thickness: 10 m±.

The stratigraphic sequence in this area is similar to that of south of Berivotra,

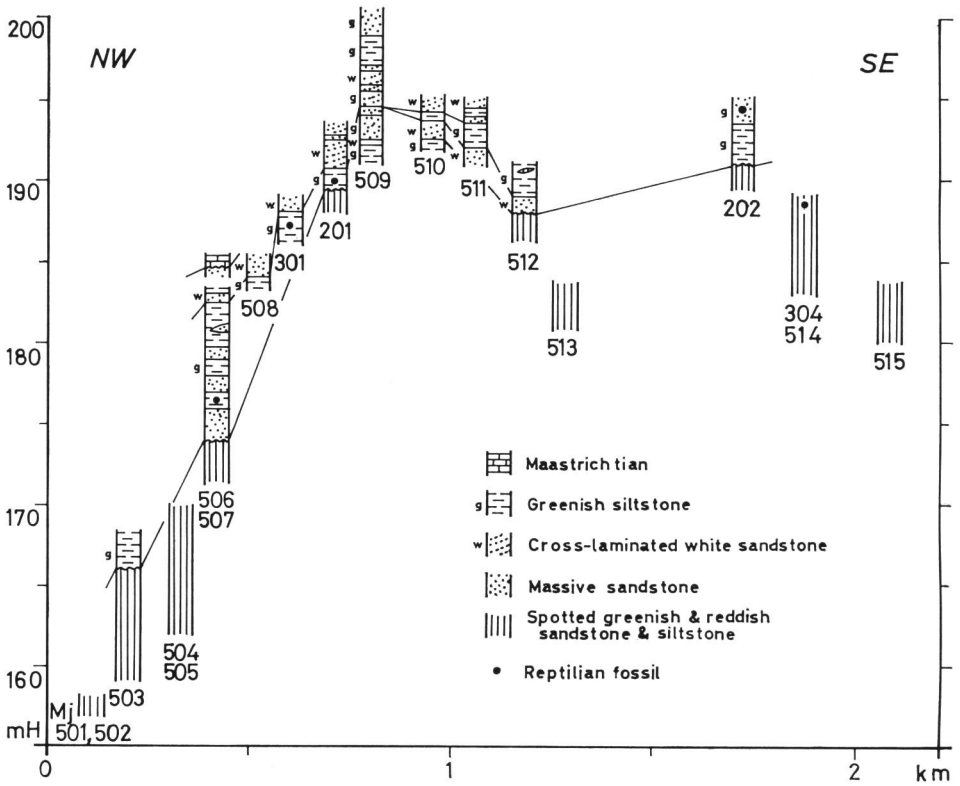

Fig. 7. Columnar sections along the Route No. 4 at Berivotra-Amboanemba. mH: meters above sea-level

though its thickness is much less. There are considerable lateral changes in the sandstones and silts. For example, white, cross-bedded sandstone of the middle part is 3 to 4 m thick south of Berivotra, but is only 2.5 m at loc. Mj 506 and 1.5 m at loc. Mj 201. Numerous reptilian bones are frequently found in an articulated state in the greenish silts. In some cases the inner portion of the dinosaur bones is replaced by idiomorphic crystals of barite, several centimeters across.

It is possible that the Cretaceous strata dip gently northwestwards, with very slight up-warping along an axis through Amboanemba (Fig. 7).

Concluding Remarks

The localities surveyed at Berivotra in 1975 are shown in three figures (Figs. 1, 2 and 6). The geologic map (Fig. 3), the columnar sections (Figs. 4 and 7) and the geological profile (Fig. 5) are presented, with the fossil localities indicated. Generally the Cretaceous strata dip gently northwestwards, although there are minor undulations

in the area surveyed. The litho-facies of the continental sediments varies rapidly laterally.

The dinosaur-bearing formation is divided into two members. Reptilian bones are abundant in the basal and lower parts of the upper member. They are preserved in an articulated state at several horizons in the greenish siltstone or sandstone, whereas in the cross-bedded quartzose sandstone the bones are sporadic and isolated.

As already reported by previous authors the association of a sauropod dinosaur such as *Laplatosaurus*, with a theropod such as *Majungasaurus*, an ophidian such as *Madtsonia*, and chelonian, crocodilian and fish-remains suggests a marshy environment. Existence of sandpipes and cross-lamination, as well as idiomorphic crystals of barite, strongly suggest a lacustrine environment. It would seem that the dinosaurs lived in a calm lake where barium sulfate was precipitated in fresh-water.

The continental formation is overlain disconformably by the marl, which is probably correlated with the Maastrichtian from the marine mollusks. In short, the dinosaur-bearing deposits may be regarded as Campanian in age. The non-marine deposits of the surveyed area are correlated with the highest part of the Maevarano Series in Maevarano, 10 km SW of Berivotra. However, the thickness of the continental deposits seems to be very different in the two areas. It is not known whether the sedimentary accumulation in the Berivotra area was much slower and hence thinner than that in the southwestern Maevarano area during the Campanian, or whether the deposits near Berivotra were largely removed by erosion before the deposition of the Maastrichtian marl.

In any case further detailed stratigraphic study will be necessary to decide the precise correlation between the two areas. For these areas are important, because it is from them that the dinosaur-bones are mainly known, in spite of the vast development of contemporaneous deposits in Madagascar. A reliable paleogeographic reconstruction is needed.

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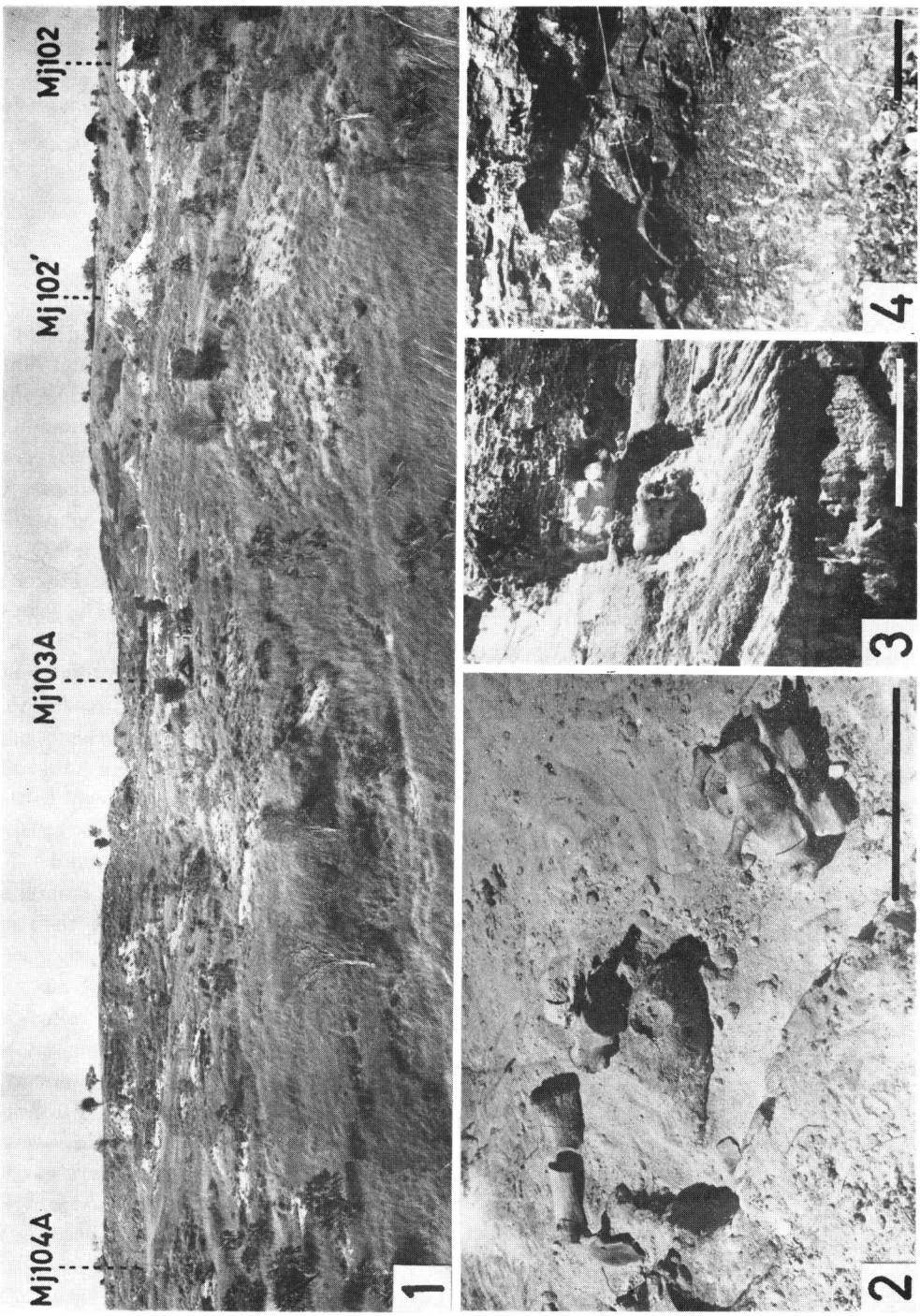
Explanation of Plate 1

Fig. 1. Scenery south of Berivotra Village, Majunga region, northwestern Madagascar, viewed from Loc. Mj 107.

Fig. 2. Articulated dinosaurian vertebrates at Loc. Mj 103A (scale: 50 cm).

Fig. 3. Scattered dinosaurian bones in the cross-laminated sandstone at Loc. Mj 106C (scale: 50 cm).

Fig. 4. An exposure of spotted reddish and greenish-colored sediment in the lower member of ${}_{c}C^{s}$ at Loc. Mj 101 (scale: 50 cm).


Mj102
Mj102'
Mj103A
Mj104A
1
2
3
4