Chapter 2.1
The Tolagnaro (Fort Dauphin) Region: A Brief Overview of the Geology, Hydrology, and Climatology

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Abstract

The Tolagnaro littoral region is dominated by the Vohimena Mountains and a rolling coastal plain that extends for several kilometers to the Indian Ocean. This plain is mostly composed of littoral sands that were deposited during Pleistocene marine transgression. These sands, which are notably mineralized, have formed a series of low-amplitude beach crests, which terminate at the shoreline in a series of coastal lagoons. Coastal hydrology between Petriky in the south and Sainte Luce in the north shows that drainage catchments extend from inland mountainous regions to coastal alluvial plains. Rivers are clearly defined in the highlands, while within the coastal plains, the interaction between rainfall infiltration and river flow leads to considerable seasonal variation. Annual temperatures range from 23.3 to 24.2°C with an average of 23.7°C. Annual precipitation shows a steep gradient from Petriky to Sainte Luce. Mandena, located between these two sites, has an average annual rainfall of about 1600 mm.

Résumé

Brève revue de la géologie, de l'hydrologie et de la climatologie de la région de Tolagnaro (Fort Dauphin). La région littorale de Tolagnaro est dominée par les montagnes de Vohimena dont les zones ondulées de basse altitude se prolongent en une plaine côtière qui s'étend sur plusieurs kilomètres vers l'océan Indien. Cette plaine est surtout composée de sables littoraux déposés au cours des transgressions marines du Pléistocène. Ces sables qui sont remarquablement minéralisés, ont formé une série de plages en crête de faible amplitude qui se termine le long du rivage par un ensemble de lagunes côtières. L'hydrologie côtière entre Petriky dans le sud et Sainte Luce dans le nord montre que les zones de captage des systèmes s'étendent depuis les régions montagneuses de l'intérieur vers les plaines alluviales côtières. Les fleuves sont bien définis dans les hauts mais dans les plaines côtières, l'interaction entre infiltration des eaux de pluies et écoulement du fleuve est source d'une considérable variation saisonnière. Les températures annuelles varient de 23,3 à 24,2°C avec une moyenne de 23,7°C. La pluviométrie annuelle est marquée par un gradient abrupt de Petriky à Sainte Luce. Mandena, situé entre ces deux stations, reçoit une pluviométrie moyenne annuelle de l'ordre de 1600 mm.

Introduction

This chapter presents information on the geology, hydrology, and climatology of southeastern Madagascar, particularly the region in close proximity to Tolagnaro (Fort Dauphin). Information on these parameters, particularly associated with the ilmenite-mining zone, provides the physical context for the biological communities. We have used data presented in a number of different works (Australian Groundwater Consultants 1988, CDN Water Management 2001, Mackie, Martin and Associates 1992, QMM 2001, Rio Tinto Iron and Titanium 2005).

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Geology

The eastern coastline of Madagascar, facing the Indian Ocean, is characterized by its narrow band of low amplitude dunes, flanking the more interior crystalline Precambrian Massif. In most cases, this system is enclosed by a lagoon and a coastal barrier dune. In the extreme southeastern portion of the island, near Tolagnaro, the coastal region is characterized by complex geology and geomorphology, giving a unique characteristic to the local surroundings, the natural environment, and the climate. The landscape of the Tolagnaro region is dominated by the Vohimena Mountains, which terminates at its southern end at Pic Saint Louis (529 m). At the base of the mountain, a rolling coastal plain extends for several kilometers before reaching the Indian Ocean (Fig. 1). This plain is mostly composed of littoral sands that were deposited in association with marine transgression. The mineralized sand surrounding the Precambrian rock has formed a series of low-amplitude beach crests that end at the shoreline in a series of coastal lagoons. In many cases, a frontal dune system closes off the sea entrance to the lagoon complex.

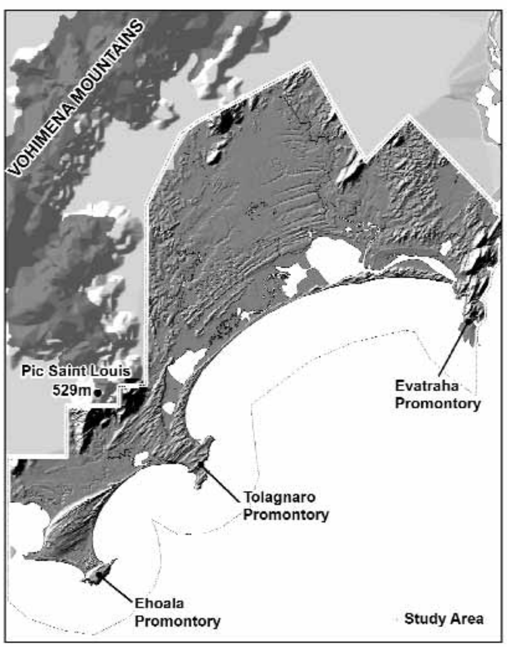

Figure 1. Relief map of the study area surrounding Mandena and the Tolagnaro region.

The bedrock of the more inland and highland zones is composed of granite. Near Mandena, the bedrock is cordierite gneiss, and this reappears near Pointe Evatraha. On satellite images, these massive blocks of granite have widely spaced orthogonal lineaments. Generally, the metamorphic gneiss has a lower topographic profile along a northeast axis. Some of the major lineaments passing through the granite have extensions into the metamorphic rocks (Fig. 2).

The sedimentary model

The period of the mineralized sand deposition is thought to date from the middle to late Pleistocene sea transgression/regression cycles, which occurred specifically during the Riss-Würm interglacial era, 150,000 to 80,000 years B.P. The initial stage of Pleistocene sea transgression laid-down marine clay to a depth of about 8 m below present sea level. This was succeeded by deposition of fluvio-deltaic sands filling the bays, which were subsequently reworked during a marine transgression-regression cycle of the pre-Flandrian (35,000-10,000 years B.P. or even Karimbolian (35,000 years B.P.). This reworking of the littoral sands favored the formation of heavy mineral concentrations. At a subsequent stage, development of an offshore bar permitted the building of a fore-dune/beach system. Remnants of this offshore bar can still be seen today on the Tolagnaro and Ehoala Promontories. The embayments, protected by headlands and under conditions of static sea level, contributed to a constant supply of sediments. The external barrier dune complex, which originated since the end of the Flandrian transgression (6,000 years B.P.), extends along the entire east coast of Madagascar. At the foot of the Vohimena Mountains, transgressional lag deposits, rich in heavy minerals (ilmenite, zircon, rutile, and monazite), were preserved. These are found above sea level in the northernmost areas of Mandena, including much of the Sainte Luce sands. The combined actions of the waves on the littoral zone and the wind on the backshore created the beach crests that characterize the mineralized sands of the Tolagnaro region. Aerial photographs show up to 15 beach crests, the most recent and better preserved is located next to the coastal lagoon in the Mandena Bay. Along the south littoral, beyond the Petriky zone, the dry climate has favored the consolidation of sands of Karimbolian age, and thus of the same type as those in Mandena. Residual deposits, formed by the transgression and now rich in heavy minerals, are still present at the base of the mountain range. They can be observed at a depth of 5 m below sea level, in the northernmost reaches of the Mandena region, while in the Sainte Luce zone, these deposits constitute the majority of the residual sands. Generally low in minerals, these residual sands extend the entire length of Madagascar's eastern coast, reaching heights of over 50 m in some areas. An even older system of dunes, still present in the south as well as inland, on the outskirts of Sainte Luce, can be traced back to the Early Pleistocene (Tatsimian), which might demonstrate the existence of an older marine transgression prior to the Middle Pleistocene cycles (Fig. 2).

The Mandena sector covers about 30 km^2 along an E-W axis of 6 km and N-S axis of 4.5 km (Fig. 3). The relief is fairly flat, featuring low amplitude dunes at elevations varying from 9 to 11 m above sea level. Erosion of these dunes has filled interdunal areas to the extent that elevation differences between crests and swales are less than 3 m. Swamps and intermittent streams have formed along the axis of the interdunal areas, creating an interdigital drainage pattern. The dunes immediately adjacent to the lagoon have been less affected by erosion, reaching heights of 12 to 20 m and having deeper interdunal valleys. These dunes terminate along the edge of the coastal lagoon, which is enclosed by a frontal dune anchored between the Tolagnaro and Evatraha Promontories. Transversal dunes, found in coastal lagoons, are formed by the infilling of lakes and subsequent receding shorelines. The types of sands found at these sites are similar to the older fore-dune/beach system and contain significant heavy mineral concentrations.

The frontal dune reaches an elevation of more than 50 m. The exposed foot of the deposit is relatively steep-sided with a base along the landward edge following the seal level contour and deepening towards the east. At this level, the mineralized sand along the northern perimeter of the deposit rests directly on laterite or bedrock. Mineralized sand vanishes where bedrock rises above the 10 m contour essentially forming the northern limits of the deposit. Along both the eastern and western perimeters, the mineralized sands are cut by alluvial sediments of the Mandromondromotra and Lanirano Rivers. In the NE corner of the region, the sands thin out to a shallow blanket of poorly mineralized deposits covering both bedrock and alluvial sands.

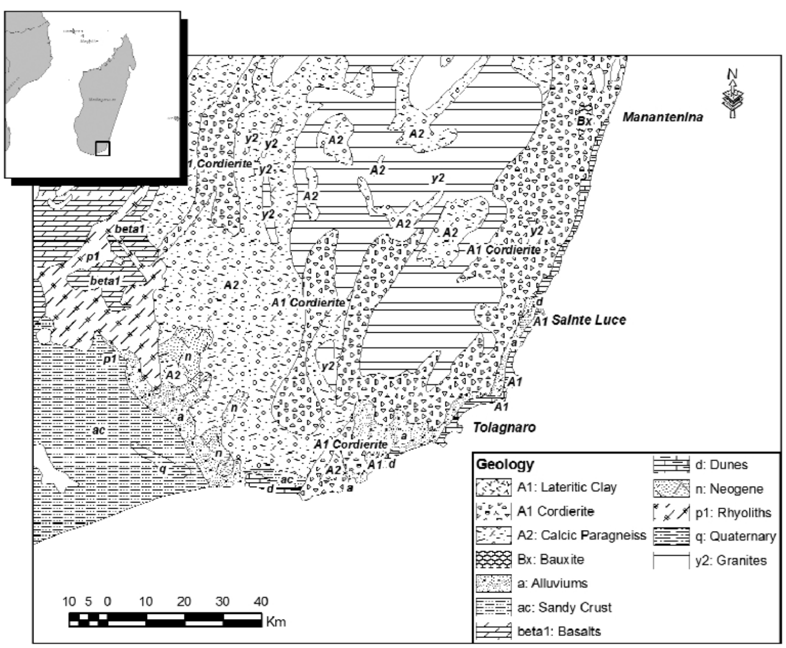

Figure 2. Regional geology of southeastern Madagascar (Besairie 1964).

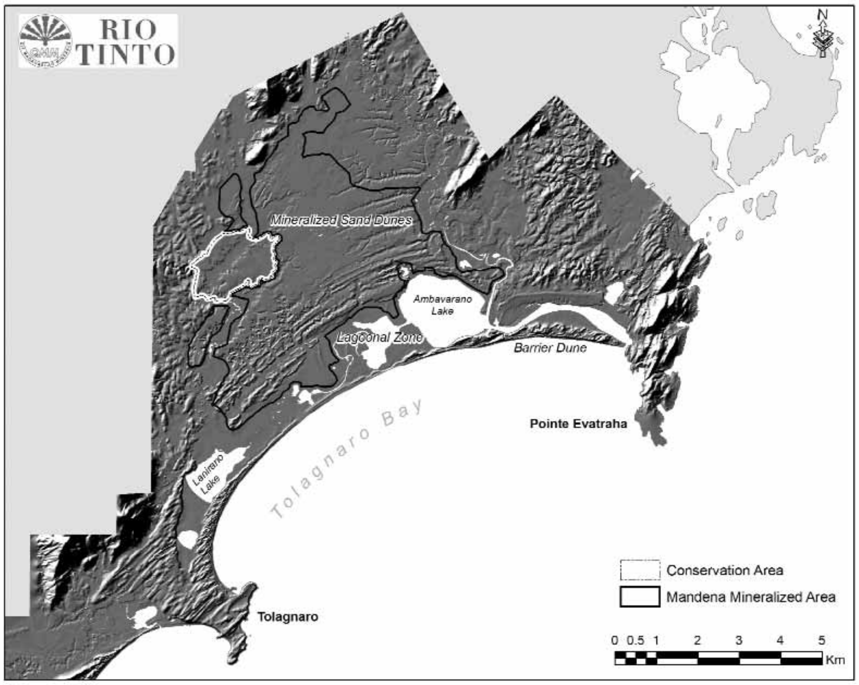

Figure 3. The Mandena Bay and surrounding features of the landscape.

Mandena's mineralized sand stratum, whose average thickness is 18 m, rests on a thick layer of marine clay and/or a laterite substratum. Given the inclination of the underlying layer of clay, there is a marked increase in the thickness of the mineralized sand stratum closer to the ocean. This rocky substratum often crops up at the periphery of the basin and forms a pan, sloping towards the ocean. The outcroppings are made of high-grade metamorphic rock consisting primarily of quartz-feldspar-garnet gneiss. Across a 2 m section, the upper portion of the rocky substratum outcropping has a lateritic horizon. Laterite is also present in the peripheral zones where the stratum is thin, as well as in the deeper reaches of the basin underneath the deep-water clay. The clay layer has covered the rocky crests and filled in the depressions, thus leveling out the surface on which the mineralized sands are deposited. A few rocky crests cut deeply across the deposit following the structure of the Vohimena Mountains, and, in a few places, pierce through the clay cover.

The southern extremity of Petriky is situated some 30 km^2 southwest of Mandena. The morphology of Petriky is quite similar to Mandena. Sands are contained in an embayment, which penetrates the zone in an inland direction. A well-developed network of lagoons borders the dune system and is enclosed by a coastal barrier dune. As in Mandena, the same stratigraphic units are recognized in Petriky's main sand body.

The Sainte Luce mineralized area stretches 12 to 45 km north of Mandena, and forms a series of long sinuous dunes along the coastal zone. Mineralized sands are encased in a strip between coastal lagoons and inland ridges of bedrock, which extend parallel to the coastline. Landward dunes exhibit a similar style of mineralization and sand deposition to the deposits of Mandena. The Sainte Luce coastline is much more exposed to wave action than the larger Mandena Bay.

Hydrology

Southeastern Madagascar can be sub-divided into three main hydrologic drainage units: mountain zone, bedrock plain, and coastal sands. Mountain ranges comprise more than 30% of the total catchment area draining the region. Satellite imagery shows mountainous areas with steep slopes that will ensure rapid concentration and high runoff of rainfall. Stream courses are principally controlled by bedrock structure (jointing) with dominant southeast and northeast axes.

Bedrock plains are typified by low relief, rolling hills, and valleys with dendritic drainages incised in high-grade metamorphosed basement (quartz-feldspar-garnet gneiss). Superficial weathering is evident on the hillcrests, where thin veneers of sand have developed. Deeper weathering of feldspars and development of kaolinitic and lateritic clays are notable along some drainages. A number of large rivers traverse the bedrock plain.

Coastal sands are deposited within several clearly defined bays. Their extent is variable from less than a few square kilometers to more than 20 square kilometers (e.g., the Mandena region). Most deposits are dissected by a number of rivers with complex meandering systems. Ribbon lakes commonly develop behind coastal dune systems, their waters being discharged via subsurface seepage to the ocean beneath the fore dunes, or via river channels passing through dune swales. Coastal river mouths typically comprise a sand bar offering a barrier to river discharge during periods of low runoff, and being broken during periods of high rainfall with subsequent flushing of saline waters.

Coastal hydrology between Petriky in the south and Sainte Luce in the north shows that drainage catchments extend from inland mountainous regions, where stream and river channels are controlled by structural deformation of underlying geology, to coastal alluvial plains comprised of quartz sands. Rivers are clearly defined in the highlands while, in the coastal plains, the interaction between rainfall infiltration and river flow produces considerable seasonal variation. Waters in the highland areas are generally potable while, in coastal rivers systems water is influenced by tidal movement at low elevation and saline dispersion and diffusion. During periods of high rainfall, flushing of the lower portions of these systems occurs.

The area of the Mandena mine site is located in a coastal environment with relatively close mountain ranges, rising abruptly from a narrow coastal plain. The area is composed by a number of watersheds. The main hydrological components are the Anandrano and Mandromondromotra Rivers, the Lanirano and Ambavarano Lakes, and the Lanirano River, which connects the two lakes across a swampy area of about 4 km. The lakes and interconnecting river form an estuary system. The system is connected to the ocean via the Anony River.

Several catchments can be defined from satellite imagery and from 1:100,000 topographical maps, which are presented in Table 1 and illustrated in Figure 4.

Vatomena River catchment

The source of the Vatomena River is the mountainous area approximately 12 km from the coast. The river discharges to the ocean across a sand/rock bar, which may become blocked during certain weather conditions. At other times, sand may be fully removed by storm action thereby allowing full tidal entry into the lower portion of the river system. In recent years, the sand bar has been open. To the north of the bar and extending to the northernmost part of the sub-region are three lakes enclosed behind the coastal dune system. Only the most southerly of these is connected to the river system and salinities in this lake were found to decrease in a northerly direction. These lakes act as

Catchment	Rivers	Catchment area (km^2)	Zone
Vatomena	Vatomena	177	Sainte Luce
Vatomirindry	Vatomirindry	185	Sainte Luce
Bakika	Bakika Ankarefobe	300	Sainte Luce
Antorendrika	Antorendrika Ampamokonambe	111	Sainte Luce
Mandromondromotra	Mandromondromotra	66	Mandena
Lanirano	Lanirano Anandrano	94	Mandena
Andriambe	Andriambe Manambaro	795	Petriky

Table 1. Major river catchments in the study area of extreme southeastern Madagascar.

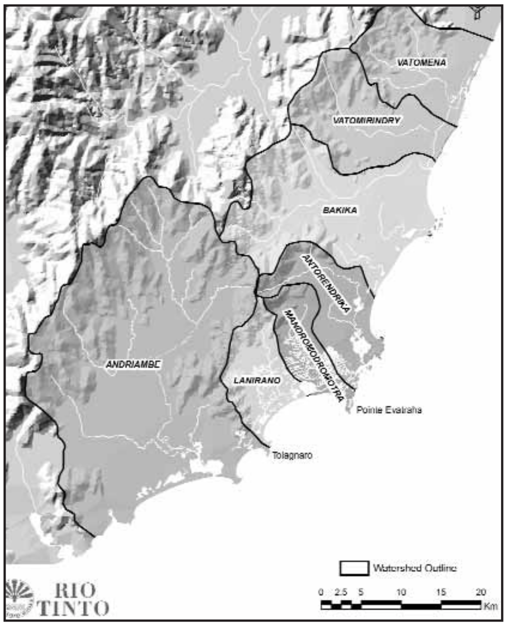

Figure 4. The major water catchment zones of the study area in southeastern Madagascar.

"windows" in the groundwater table and discharge into the ocean through the coastal dunes. Sand deposits in this area are generally less than 1 km in width.

Vatomirindry River catchment

The Vatomirindry River starts approximately 18 km from the sea in steep mountainous country joining the Vatomena River approximately 3 km from the ocean. It is also linked by a series of channels to the Bakika River 4 km to the south. These channels enclose an area of sand dunes, which are discontinuous seaward with bedrock outcrops visible on aerial photos. Conductivity measurements made in the lower reaches of the river indicate that tidal influence extends a considerable distance up river.

Bakika River catchment

The Bakika River is the largest water catchment zone in the Sainte Luce area, flowing in a northeasterly direction for about 25 km from its sources in the mountains to the ocean. Where this river traverses the bedrock plain, narrow strips of overbank deposits have been formed. Agricultural cultivation of these soils is practiced widely. Cap Sainte Luce headland lies within this catchment 6 km to the south of the Bakika River mouth. South of Sainte Luce, a long sweep of coastal dune (14 km) encloses a complex chain of lakes and braided streams. Broad sand bodies up to 1 km in width occur inland of these lakes. A small river, the Andohafasy, reaches the sea at Sainte Luce at the northern end of this lake chain.

Antorendrika River catchment

This river has a relatively short length of 7 km between the inland mountains and coast, and corresponds to a small catchment area. Extensive erosion in the upper reaches is suggested from satellite coverage. The river discharges to the ocean via a large lake and channel system bounded by bedrock over most of its perimeter. A delta is developed where the river enters the first of these lakes.

Mandromondromotra River catchment

This river marks the northeast boundary of the Mandena region. It discharges into Lake Ambavarano and then into the sea at Pointe Evatraha via the short Anony River. Along this drainage, the tidal effects are evident at least 5 km from the ocean with comparatively high salinities. The Mandena aquifer is hydraulically connected to the river permitting seepage to or from the mineral deposit depending upon the river relative to groundwater table heights.

Lanirano River catchment

Three rivers, Antinosoro, Anandrano, and Lanirano, lie within this catchment and discharge into Lake Lanirano via a complex web of braided channels. Major groundwater rises are evident during periods of high rainfall. Lake Lanirano is connected to Lake Ambavarano via narrow channels. Flow is generally from Lanirano to the ocean, but sampling by Australian Groundwater Consultants (1988) after a period of drought showed significant salinity levels in the lake, suggesting that tidal effects may extend high into the system during such periods.

Andriambe River catchment

The Andriambe River is the largest entering the sub-region and the only major one in the Petriky area. Overbank deposits are evident along much of its course and extensive cultivation is practiced on these soils. A wide flood plain is developed in the lower reaches of the river and the Petriky sand unit abuts this on its northern boundary. Elevation of the dune top is some 3 m above the flood plain. The river discharges to the ocean via Lake Andriambe, which is the most northerly of a string of wide lakes enclosed by the narrow coastal dune. Turbidity plumes were clearly visible on aerial photos of this section of the coastline taken in early 1989 during a period of high rainfall. These plumes may indicate soil erosion, perhaps due to the extensive cultivation practiced on the richer soil types, and higher sediment loads in the Andriambe River relative to other systems of the sub-region. A hydrometric network has been installed since 2000 to monitor water fluctuations along the Anandrano, Mandromondromotra, and Anony rivers, and Lanirano and Ambavarano lakes. The results of the different measurements for two of these rivers are presented in Table 2.

Climatology

The regional climate is dominated by a warm coastal monsoon with occasional cyclonic activity. The eastern part of the island receives considerable precipitation by northeast trade winds, all in the form of rainfall. Mean annual precipitation at some locations exceeds 6,000 mm. Much of Madagascar is exposed to cyclonic activity producing severe storms, particularly along the eastern coast. From meteorological data registered since 1850, the annual frequency of cyclones seems to have increased over time. Since 1980, the Indian Ocean zone has registered 10 to 15 cyclones per year. The central part of the island is more vulnerable to cyclonic activity than the Tolagnaro region. The worst cyclone ever registered in Tolagnaro was “Deborah” in January 1975 that caused considerable damage and human casualties.

The Tolagnaro area is subject to prevailing northeasterly winds, which carry moisture on shore and produce high rainfall particularly during the warmer months. Due to orographic effects, the inland portion of the study area experiences higher precipitation than the lower coastal areas. The precipitation data obtained from Tolagnaro airport (1967 - 2005) was combined with annual rain data available since 1925 (Ratsivalaka-Randriamanga 1985). The mean annual precipitation between 1925 and 2005 ranges from 966 mm (1962) to 2,899 mm (1972), with an average of 1,589 mm. The wet season extends from November to May and accounts for 70% of the annual precipitation. There is no well-defined dry season near Tolagnaro, as a certain amount of precipitation falls each month. On average, January is the wettest month and September the driest. The highest monthly rainfall on record between 1967 and 2005 is 747.1 mm (March 2005) and the lowest is 0.6 mm (June 1997). The monthly rain data for the last six years (2000 - 2005) were calculated from data collected at the Tolagnaro airport (Table 3). There is considerable variation in the quantity of rain between months of a given year, as well as between different years. Precipitation data were collected at the sites of Sainte Luce, Mandena, and Petriky over three years and the results are presented in Figure 5. Based on these data, there is a notable decrease in rainfall from the north to the south.

Despite a warm and humid climate, the temperatures in Tolagnaro are generally cooler than in other areas of similar conditions, with an annual average temperature of 23.7°C. Monthly temperature data were obtained from Tolagnaro airport covering the period 1979 -1998 (Table 4). On average, the warmest month is January with a mean temperature of 26.9°C, and the coldest month is July with a mean temperature of 20.3°C. For the last six years, from 2000 to 2005, these average temperatures have increased by 0.4°C and

Table 2. Flow rates of the Anandrano and Mandromondromotra Rivers measured in m^3/sec.

Rivers	Flow m^3/s	2000	2001	2002	2003	2004 *
Anandrano	Minimal	0.33	0.42	0.30	0.34	-
	Maximum	29.9	18.8	39.6	34.5	57.4
	Average	2.58	1.69	2.38	2.33	-
Mandromondromotra	Minimal	0.17	0.19	0.18	0.32	-
	Maximum	28.8	21.9	39.7	34.5	-
	Average	1.91	1.19	1.82	2.06	-

* When cyclones Elita and Gafilo hit the region in February and March 2004, all the water level recorders in the rivers and lakes were submerged and damaged.

Table 3. Monthly precipitation in mm at the Tolagnaro airport from 2000 - 2005.

	MONTH												
	Jan	Feb	Mar	Apr	May	June	July	Aug	Sep	Oct	Nov	Dec	**Total**
2000	252.2	160.0	13.9	118.3	29.3	74.3	409.7	81.6	14.9	62.2	69.4	139.4	**1425.2**
2001	84.7	71.8	96.8	147.8	134.0	91.0	107.0	113.2	27.4	44.4	55.2	392.4	**1365.7**
2002	230.9	110.3	162.8	205.3	194.9	34.5	76.0	100.2	40.2	35.7	262.8	377.8	**1831.4**
2003	83.9	134.4	200.8	161.4	225.2	155.8	100.9	107.4	56.6	48.1	34.8	109.4	**1418.7**
2004	119.0	306.0	482.1	85.2	113.8	156.4	156.2	26.7	44.9	90.5	7.3	106.0	**1694.1**
2005	510.5	146.0	747.1	377.3	26.1	63.1	95.1	10.3	10.9	27.8	76.0	232.6	**2322.8**

Table 4. Climatology at the Tolagnaro Airport for a 20 year period (1979 - 1998).

	UNIT	YEAR	J	F	M	A	M	J	J	A	S	O	N	D
Temperature	°C	79-88	26.8	26.7	26.1	24.6	22.6	20.7	20.2	20.7	21.7	22.9	24.4	27.8
		89-98	26.9	26.5	26.1	24.8	22.2	20.3	19.6	20.9	-1	23.6	24.7	25.9
Precipitation	mm	79-88	202	162	143	170	125	108	136	64	101	82	146	138
		89-98	244	193	127	129	164	103	123	75	44	88	95	129
Rel. Humidity	%	79-88	80	81	82	83	81	80	81	78	79	80	82	81
		89-98	83	83	81	81	80	79	79	78	79	79	79	82
Insolation	h/mo	79-88	266	219	231	209	232	205	218	239	227	229	239	247
		89-98	239	208	238	208	218	223	219	251	245	251	250	247
Wind speed	km/hr	79-88	23	22	23	22	19	17	16	18	21	26	24	23
		89-98	21	21	19	19	16	16	18	21	25	26	24	20
Evaporation	mm	79-88	168	136	143	121	128	111	116	147	154	158	143	155
		89-98	138	122	140	119	102	116	125	144	158	178	159	165

0.2°C, respectively. The highest temperature on record is 32.6°C (January 1981), and the lowest is 14.1°C (July 1992). The relatively narrow range of temperatures is typical of coastal areas and is associated with the proximity of the ocean.

Monthly wind data were obtained from Tolagnaro airport covering the period 1979 -1998 (Table 4). The average wind speed ranges, by month, from 18.6 to 23.8 km/h with an annual average of 20.7 km/h. The months of September and October are windier than the rest of the year with average winds above 24 km/hr. The highest average monthly wind speed on record is 36 km/hr and occurred in November 1986.

The climatology data collected from 1979 to 1998 was compiled in 10-year periods (1979 - 1988 and 1989 - 1998) to detect regional climatic trends over two decades (Table 4). The data presented are monthly averages, calculated for each 10-year period.

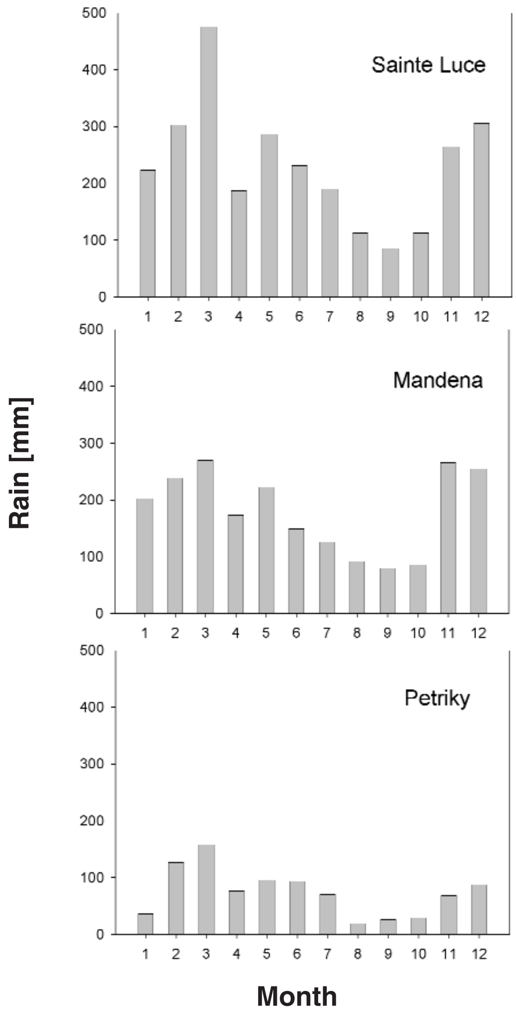

Figure 5. Average rainfall data from January 2002 - October 2004 from Sainte Luce, Mandena, and Petriky.

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Chapter 2.2
The Archeological Evidence of the Anosy Region

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Abstract

The Anosy region of southeastern Madagascar possesses an historical record almost unprecedented in the world of pre-state societies. There is a complete archeological sequence, based on surveys, test excavations, and absolute radiocarbon dates. The accounts of would-be colonizers of the XVIIth and XVIIIth centuries, particularly the detailed account of Etienne Flacourt (1661), provide a detailed view of people just coming into contact with the emerging world of European commerce and militarism. We also have detailed studies of existing Tanosy communities and their traditions. While archeological constructions based on settlement traces and potsherds left by local people, historical constructions based on the written accounts of outside visitors (albeit visitors with close social relations and some understanding of the language), and ethno-historical constructions based on geographical and anthropological inquiries must not be uncritically combined, careful comparisons provide an extraordinarily rich record. Our preliminary studies in the Anosy region show that the area has great potential for future research documenting processes of ecological and cultural change.

Résumé

L'évidence archéologique de la Région de l'Anosy. La région de l'Anosy dans le sud-est de Madagascar montre une information historique presque sans précédent dans le monde des sociétés pré-étatiques. Il y existe une séquence archéologique complète mise en évidence grâce aux inventaires, aux fouilles-test et aux dates absolues du radiocarbone. Les rapports des premiers explorateurs, prétendus colonisateurs des XVIIe et XVIIIe siècles, et plus particulièrement les écrits détaillés d'Étienne Flacourt (1661) permettent d'imaginer précisément les peuples malgaches qui venaient juste d'entrer en contact avec le nouveau monde du commerce et du militarisme européen. Nous disposons également d'études détaillées sur les communautés Tanosy existantes et leurs traditions. Si les constructions archéologiques, basées sur des traces d'installations ou type d'élevage laissés par les gens de la région, les constructions historiques, basées sur des données écrites par des visiteurs étrangers (même s'il s'agit de visiteurs ayant entretenu des relations sociales étroites, certains montrant même une compréhension de la langue) et les constructions ethnohistoriques, basées sur les enquêtes géographiques et anthropologiques, ne doivent pas être combinées aveuglément, il n'en reste pas moins que leur comparaison minutieuse constitue un trésor inégalable. Nos premières études dans la région de l'Anosy montrent qu'il s'agit d'une région de prédilection pour de futures recherches à mener dans le cadre de la documentation des processus inhérents aux changements écologiques et culturels.

The Archeological Evidence: A Summary

The Anosy has been the object of an intensive, long-term study by Rakotoarisoa (1994, 1998) and the team of the Musée d'Art et d'Archéologie de l'Université de Madagascar. The archeological sequence is well defined, although it is possible that some settlements have not yet been recorded (Wright *et al.* 1993). In the Efaho Valley, archeological research has shown that there was a lengthy occupation divisible into five cultural units.

What may be evidence of relatively early human

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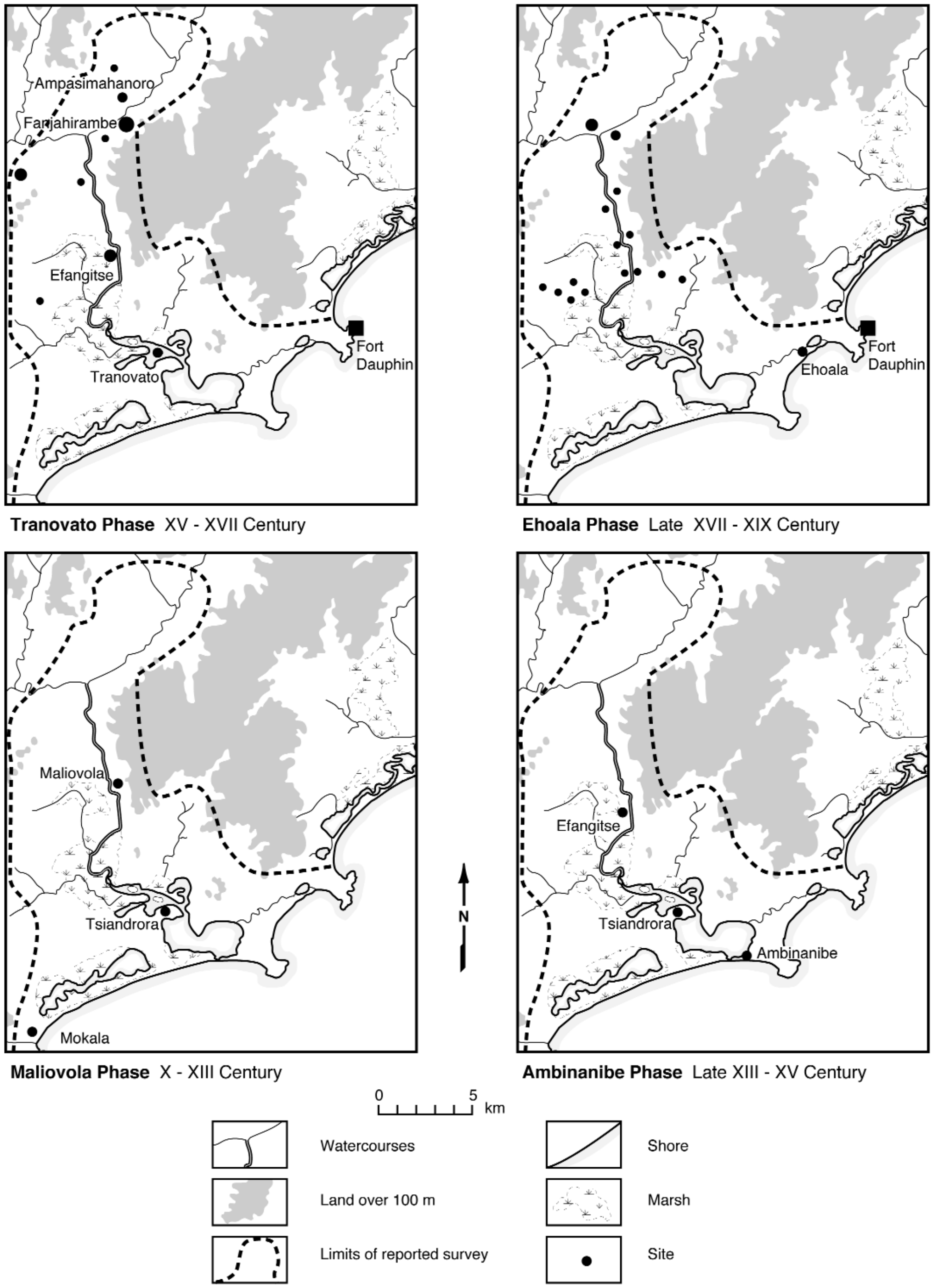

Figure 1. Phases of historical records of human settlements in the Anosy Region.

occupation in the Anosy Region was discovered by Andreas Nillson at the rockshelter of Ankadava 4 on the mountain slopes overlooking Tolagnaro (A. Nillson, pers. comm.). He collected fragments of heavy basins with thick walls, made from a clay containing quantities of coarse quartz fragments. These fragments lack any decoration. Similar ceramics farther north on the east coast have been dated as early as the VIIth-century A.D. (Dewar and Wright 1993, Wright and Fanony 1992). However, until similar ceramics are excavated in secure stratigraphic context with datable materials we cannot define an archeological phase of this period in the Anosy region.

Radiocarbon dates indicate that the Maliovola Phase flourished during the IXth to XIIth centuries. The few known sites are about 1 ha in size. Although larger sites of the Maliovola Phase may exist, they have not yet been located. Among the known sites, Mokala and several other coastal sites have evidence of fishing, Tsiandrora has evidence of both fishing and cattle herding, and others, such as Maliovola itself, lack such evidence but are ideally situated for valley bottom cultivation (Fig. 1). Given the available archeological evidence, one could infer a network of small settlements with complementary economic specializations (or perhaps occupied in seasonal rotation) indicating a relatively simple segmentary society. Potters produced plain basins and spherical jars with a coarse fabric, and finer bowls, often with a red slip, comparable to those from contemporary sites in the Androy to the west, the more distant Antongil area in the northeast, and Ampasindava area in the northwest (Dewar and Wright 1993). The fine bowls often have a form of decoration otherwise unknown, both within Madagascar and elsewhere, of imprints of the leaves of grass in the clay inside the rim. There is limited evidence of iron working at most settlements. A few sherds of chlorite schist vessels, as well as graphite-coated basins, which imitate chlorite schist forms, indicate participation in a local east coast exchange network, bringing chlorite vessels from the north. However, in contrast to other areas of Madagascar, ceramics imported from East Asia or the Near East are very rare suggesting that at the inception of village life, the peoples of the Efaho Valley were not in regular contact with the broader Indian Ocean. Given their isolation and the limited number of coastal communities, we expect the impact of Maliovola people on their environment to be relatively limited. Some of the wooded coastal dunes and terraces around the estuaries would be impacted by the cutting of fuel wood and clearing of gardens, and hunting may have had an impact on the vertebrate fauna.

By the XIIIth century, the earlier Maliovola ceramic assemblage, with its diversity of slipped bowls and basins, had probably been replaced by the Ambinanibe Phase, with a ceramic assemblage of few bowls and many spherical jars with textured decoration. The few known sites cover 1 to 2ha, suggesting that relatively simple social organization was still characteristic of the area (Fig. 1). However, it is still possible that archeologists will find more elaborate settlement sites in the future. The Ambinanibe sites are found to have the same diversity of microenvironments as the sites of the preceding Maliovola Phase. Evidence of fishing is common at Ambinanibe itself, and evidence of the butchering of herded cows is common at Tsiandrora. The interior site of Efangitse (see also below) is located in an area suited to valley bottom cultivation. The characteristic local ceramics have a coarse fabric. Locally made spherical jars were richly decorated with incised and appliqué designs. This pottery is similar to that of the southern interior of Madagascar, and it is possible that the change in ceramics indicates closer relations with herders of the interior plains. The few smaller bowls are distinguished only by crude notching of the lip. All sites have evidence of iron working. Sherds of chlorite schist from the north and of imported Chinese celadon show participation in both local and long-distance exchange. In sum, though there is suggestion of broader contacts with Indian Ocean exchange networks, there is little evidence of settlement hierarchy or social differences. Though settlements are only slightly larger indicating little change in population, increased use of cattle probably required more clearing of woodlands for pasture, and increased smelting of iron would have required more woodcutting for charcoal.

The succeeding Tranovato Phase of the XVth to XVIIth centuries is well known from surveys (Wright *et al.* 1993) and soundings (Vérin and Heurtebize 1974). The Tranovato Phase settlement is concentrated in the formerly sparsely inhabited middle and upper Efaho Valley. It was these Tranovato Phase settlements which were visited, and in some cases destroyed, by the French colonizer Flacourt and his allies (Wright and Rakotoarisoa 1997, 1998).

The archeological evidence shows that this period saw fundamental economic and socio-political changes. The settlement pattern was dominated by large fortified communities, often protected by multiple ditches covering up to 5 ha (Fig. 1 upper left). Smaller settlements of a hectare or less were also surrounded by single polygonal ditches. The larger centers had more elaborately decorated graphite coated serving bowls. They also had more imported vessels, as is detailed below. The evidence of both settlement hierarchy and varying consumer goods indicates stratified society with ranking figures living in the larger fortified settlements and directing military campaigns against their enemies. The locations of sites throughout the valleys indicate that exploitation of the river terraces and marshes was important. Additionally, test excavations have recovered carbonized grains of rice. As in earlier phases, there is also evidence of cattle herding. Local potters still produced spherical jars, but the combed decoration on these vessels represents a tradition long established on the northeast coast. The bowls are reduction-fired, coated with graphite and decorated with triangular impressions, like those used in many parts of Madagascar in the XVth and XVIth centuries. Only one Tranovato Phase site, the XVth century center at Efangitse, has a simplified form of the Ambinanibe incised ceramics. Unfortunately, our chronology is not precise enough to say whether this represents a late Ambinanibe Phase hamlet that preceded the Tranovato center, or a neighborhood of that center in which some people continued to use pottery developed from Ambinanibe Phase models. In either event, there was a cultural disjunction at the beginning of the Tranovato Phase. Evidence of iron-working is widespread. Spindle whorls indicating the manufacture of thread occur, as they do at many contemporary communities in the southwestern Indian Ocean. Efangitse and Tranovato, the earlier Tranovato Phase capitals, imported Chinese stoneware, celadon, and blue-and-white porcelain occur. Fanjahirambe, the documented capital of the mid-XVIIth century chiefdom, imported Chinese, Portuguese, English, and French ceramics indicating the broader relations of the political elite. The export of cattle is well-documented. It is likely that with increased population, continued iron smelting, and increased cattle herding for export, much lowland forest was severely impacted.

The Tranovato Phase developed into the succeeding Ehoala Phase late in the XVIIth century. The spherical jars became rare, being replaced by necked jars and iron pots. The graphite-coated bowls continue with the only difference being the shift of the imprinted design to the interiors, as in other parts of Madagascar's east coast. Historical accounts indicate that the subsistence economy was still focused on irrigated rice, though New World crops such as manioc became important. The basic settlement pattern continued, though sites were somewhat fewer and smaller, and they tended to be located in the upper valleys away from the coast (Fig. 1, upper right). Imported Chinese and European pottery was common and gunflints (and presumably guns) were imported from Europe. It seems that the Tanosy were able to maintain their socio-political patterns in the face of repeated attacks. Though there is little evidence of continued growth, documents show that the export of cattle and slaves continued. It is possible that during this time, with the removal of communities from the coast, there was less pressure on the coastal forests, but exploitation of the interior to allow for rice paddies continued, and cultivation of the high ridges for manioc may have increased.

In the Efaho Valley, there seems to have been a slow development of economically diversified, but socially simple local communities. These were followed by a sudden appearance of societies with marked socio-political stratification and cultural relations with societies farther north along the east coast. It is possible that these stratified societies developed concurrently in valleys to the north, and were therefore not produced by the local conditions in the Efaho Valley. It is also possible that they were merely more intensely honed in the Efaho Valley as a result of conquest and exploitation. These southeastern chiefdoms persisted in spite of profound disruption by invaders, but, isolated in their small- coastal valley, they did not become more complex states.

Discussion

What does our construct tell about the potential for future research in the Anosy region? First, the coastal regions of the Anosy can produce uniquely important information on the relation between early human communities and the ecosystems of the humid forests and coasts. We have suggested above that from the earliest settlement through the XIVth century A.D., a slow increase in human population, cattle herding, cultivation, and the smelting of iron ore diminished the coastal forests and their fauna. We can only evaluate such hypotheses with paleo-ecological evidence in the form of fossil remains of plants and animals taken from marshes and lakes. We need to contrast this evidence of changing later Holocene environments against paleo-economic evidence from the remains of collected marine and forest animals, herded domestic vertebrates such as cows, and from carbonized plant remains gathered through extensive excavation at archeological sites.

Second, the Anosy can produce unique information on the evolution of social and political complexity in human communities and the greatly amplified impact of these more complex communities on their environments. Our evidence indicates that beginning in the XVth century during the Tranovato Phase, ranked societies with richer and more powerful figures living in the larger centers developed. Such 'paramount chiefdoms' no longer exist, and our understanding of this import precursor to more developed states and empires depends on the archeological study of well-documented examples such as that of the Anosy. Only careful archeological excavation of sites would enable the documentation of details of life in these centers, both aspects mentioned by Flacourt and others not stated in written accounts, for example, the details of economic systems and the lifestyles of lower-ranking families. In addition, only careful excavation of the main centers focusing on the evolution of fortifications, buildings and their destruction, and of the debris of daily life would allow the testing of hypotheses about the complex process of competition between paramount chiefs, military conflict, and the shift from one capital to another. It is only with such research and paleo-ecological studies that we can assess the impact of larger populations, more diversified food production systems, and trade demands on the natural environment only hinted at in the Flacourt account and the traditional histories.

Just as the early documents richly reward restudy with new methods and new intellectual perspectives, the archeological record can be used to answer new questions, particularly with the rapid improvement in archeological techniques. However, the access of scholars - and through them the modern Malagasy, particularly the Tanosy - to the rich archeological record of the Efaho Valley may be definitively cut. The most important and best preserved sites of the early Maliovola and Ambinanibe Phases are on the great Pleistocene sand ridges soon to be exploited for heavy metals, totally destroying all their archeological sites. We believe that Ndrenani, at the mouth of Andohafotsy River, has already been badly damaged by port development, and we are deeply worried that Tsiandrora, at the mouth of the Efaho River, with its excellent preservation of bone and carbonized plant remains will be destroyed in the search for heavy metals. Thanks to the de Heaulme organization in Tolagnaro, one of the Tranovato Phase capitals is protected, but the better preserved Tranovato and Ehoala phase centers farther up the valley are subjected to intensive cultivation because of the high phosphate and nitrate concentrations in the archeological deposits. The more modest Tranovato sites, which may document the lives of the lesser known poor communities of the Tanosy, are no less threatened. Just as the priceless original copies of Flacourt's account are preserved in libraries and archives, so these unique archeological sites should be preserved for future research. If development absolutely requires that they cannot be preserved, they must be carefully excavated and recorded before they are destroyed. Preservation and research are worthy goals for the immediate future.

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Chapter 2.3
A Perspective on the Paleo-ecology and Biogeography of Extreme Southeastern Madagascar, with Special Reference to Animals

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Abstract

The southeastern portion of Madagascar contains a remarkable number of natural forest habitats overlaid on considerable topographic variation, including evergreen littoral, montane, sclerophyllous formations, transitional forests, and spiny bush. Associated with this habitat and variation in elevation, is a diverse and unique biota with a considerable number of micro-endemic forms. The north-south aligned Anosyenne Mountains act as a barrier for weather systems reaching the island from the east, and this rain shadow gives rise to very abrupt ecotones on the western flank of this chain. Given the biotic clines across southeastern Madagascar, with increasing aridity towards the west, the waning and waxing of different climatic shifts during the Pleistocene would certainly have had an important bearing on the biogeography of the region. Data from several different fields are used in this review chapter to interpret some of these patterns. Remains of plants and animals found at paleontological and archaeological sites across southern Madagascar, including the Andrahomana Cave in the Tolagnaro region, provide important insights into the timing and degree of these climatic shifts. Available information from these different deposits is summarized. Details are presented on the biogeography of a variety of land animal groups, including details on patterns of geographic variation, species turnover, phylo-geography, and aspects of the systematics of these organisms within the different natural formations of the region. One consistent pattern is the much greater species turnover within the short ecotone between humid forest and spiny bush than in the entire 1200 km eastern humid forest.

Résumé

Une perspective de la paléoécologie et de la biogéographie dans l'extrême sud-est de Madagascar, avec référence particulière aux animaux. La partie sud-est de Madagascar abrite un nombre étonnant d'habitats forestiers naturels distribués sur un gradient topographique remarquable en allant de la forêt sempervirente littorale et de montagne aux formations sclérophylles, aux forêts de transition et au fourré épineux. Un biote unique et diversifié est associé à cette variation de l'habitat et de l'altitude qui abrite souvent un grand nombre de formes marquées par le microendémisme. La chaîne des montagnes anosyennes qui s'étend sur un axe nord-sud joue un rôle de barrière sur les systèmes météorologiques qui affectent l'île depuis l'est et les effets orographiques sont extrêmement marqués avec des écotones abrupts sur les versants occidentaux de cette chaîne. Compte tenu des clines biotiques rencontrés dans le sud-est de Madagascar avec une aridification croissante vers l'ouest et en considérant les hauts et les bas des divers changements climatiques qui ont eu cours pendant le Pléistocène, la biogéographie de la région doit sans aucun doute être marquée. Des données issues de diverses spécialités sont utilisées dans ce chapitre de revue pour interpréter certains de ces schémas. Des restes de plantes et d'animaux trouvés dans les sites paléontologiques et archéologiques de la région méridionale de Madagascar, dont la grotte d'Andrahomana dans la région de Tolagnaro, fournissent des informations importantes sur le degré et la chronologie des changements climatiques. L'information disponible

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