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Report on a Visit to Madagascar for Geomorphological Mapping, Autumn 2005

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View over Morotolana.

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In Madagascar, I am grateful for the support and friendship of my counterpart geologist (homologue) Mamy Rabarimanana and driver Lala.

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Summary

This report describes the visit by Dr C J Jordan to Madagascar between 3rd September and 2nd October 2005. The purpose of the visit was to map the geomorphology of approximately 140,000km^2 of northern Madagascar.

1 Introduction

The contract for this project states that one of the final products required is "*cartes digitales (vectorielles) géomorphologiques de synthèse à l'échelle de 1:500,000*" i.e. a digital vector geomorphological synthesis map at 1:500,000. The mapping area was divided into two parts (Figure 1) with the BGS geomorphologist (Colm Jordan) tasked with mapping the northern 140,000km^2 in the first 20-day field season (September/October 2005) while the USGS geomorphologist (Jennifer Harden) will map the southern 115,000km^2 the following year.

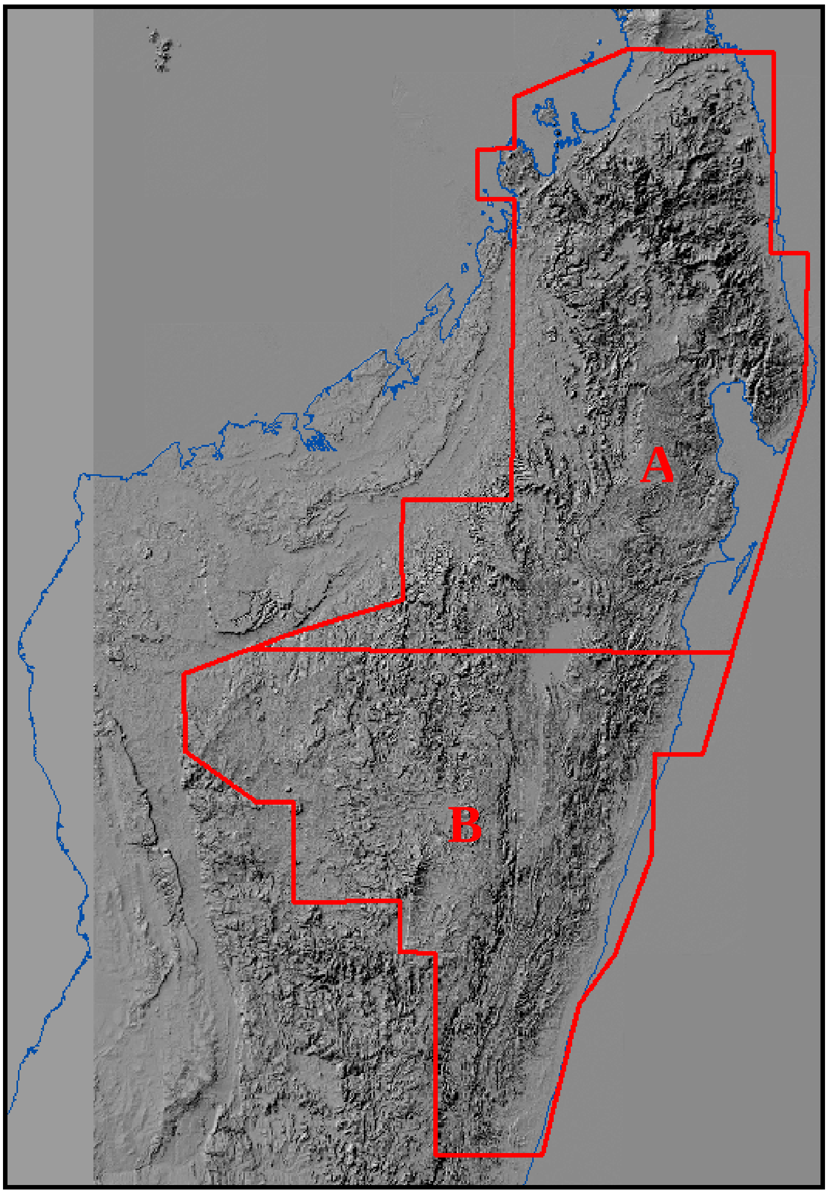

Figure 1 Outline of the project area. C Jordan was tasked with mapping Area A and J Harden was allocated Area B.

Prior to fieldwork, an initial geomorphological interpretation was undertaken in BGS Nottingham using Landsat Enhanced Thematic Mapper (ETM) imagery and the Shuttle Radar Topography Mission (SRTM) Digital Terrain Model (DTM). Aerial photography was unavailable and the Radarsat data was not georectified prior to my departure.

All coordinates quoted in this report are in the Lambert Conformal Conic (UTM) projection unless otherwise stated.

2 Schedule

I was given an allocation 44 days to the project, to be divided equally between preparation time in the UK and fieldwork. Twelve days of my ‘preparation time’ were used providing training to the Malagasy homologues while they were in Keyworth as well as undertaking image processing. This left 10 days to set up a GIS and carry out a geomorphological interpretation at 1:250,000 of approximately 140,000km^2.

Field mapping was undertaken between the Saturday the 3rd of September and Sunday the 2nd of October. The table below outlines the schedule of work and travel, illustrating that I worked 28 days, with 2 rest days.

Date	Activity
Sat 3rd September	2pm Travel to Birmingham airport (taxi). Fly Air France (AF5139) from Birmingham (dep 17:05) to Paris CDG (arr 19:25). Travelling with Jon Ford. Overnight Ibis Hotel (CDG airport)
Sun 4th Sep	Fly Air France (AF908) from Paris CDG (dep 10:15) to Antananarivo (arr. 21:55) travelling with Jon Ford, Bob Tucker and Cliff Taylor. Night at Le Manoir, Antananarivo.
Mon 5th Sep	Travel by Air Madagascar (MD 314) from Antananarivo 13:30 to Antsiranana. Excess baggage charge of £25.08 for 2 boxes of maps that had just arrived by DHL. Met at Antsiranana airport by Wilfried Bauer and travelled by 4X4 to base camp at Ambilobe.
Tue 6th Sep	Day of organisation at base camp. Allocated vehicle, driver (Lala) and homologue (Mamy). Equipped and tested GPS, satellite phone etc. Discussed viable transport routes with drivers and agreed reconnaissance mapping campaign with Wilfried. Given 2,000,000 Ariary petty cash for fuel, food and accommodation for driver and homologue.
Wed 7th – Sun 11th Sep	Depart Ambilobe 7am to map the east coast and northern highlands en route. Route passes through Daraina, Vohemar, Sambava and Andapa before returning to Ambilobe.
Mon 12th Sep	Rest day.
Tue 13th – Fri 16th Sep	Depart Ambilobe 7am for NW of mapping area including Ankarana, Ambanja, Tsaratanana, Morotolana. Returned to base camp (now situated at Ankaramibe) on Friday night.
Sat 17th Sep	Depart camp at 7:30 mapping new outcrop along the road that is currently under construction between Ankaramibe and Ambanja.
Sun 18th Sep	‘Office day’ at base camp.
Mon 19th and Tue 20th Sep	Depart camp at 7:30am for central region of the mapping area including Bealanana and Antsohihy.
Wed 21st – Sat 24th Sep	Coastal mapping of the Ampasindava Peninsula
Sun 25th – Wed 28th Sep	Load sacks with rock and stream sediment samples from base camp and pack onto 4X4 for transport back to Antananarivo. Map western and central extents of the project area including Befandriana, Mandritsara, Tsaramandroso, Maevatanana and Antsiafabositra.
Thur 29th Sep	Drive from Maevatanana to Antananarivo. Deposit samples and equipment at Willy’s store.
Fri 30th Sep	Re-bag and re-label the samples and arrange equipment in the store. Sum up the kitty and hand over remaining funds to Mamy. Note: C Taylor’s rucksack stolen from back

	of 4x4.
Sat 1st Oct	Rest day
Sun 2nd October	Depart Antananarivo at 00:50 by flight AF905, arriving Paris CDG 10:40. Transfer to flight AF5136 dep 15:35, arr. Birmingham 16:30. Travel to home by taxi, 17:30

Table 1 Schedule of work and travel in Madagascar

3 Image Interpretation

BGS Remote Sensing staff (including the author) acquired and processed optical (Landsat ETM) and Radarsat imagery along with the SRTM DTM. I subsequently interpreted these datasets at 1:250,000 to produce linework suitable for field checking and ultimately, final publication at 1:500,000. Approximately 10 days were spent on the interpretation (Figure 2), although this time also included setting up the GIS.

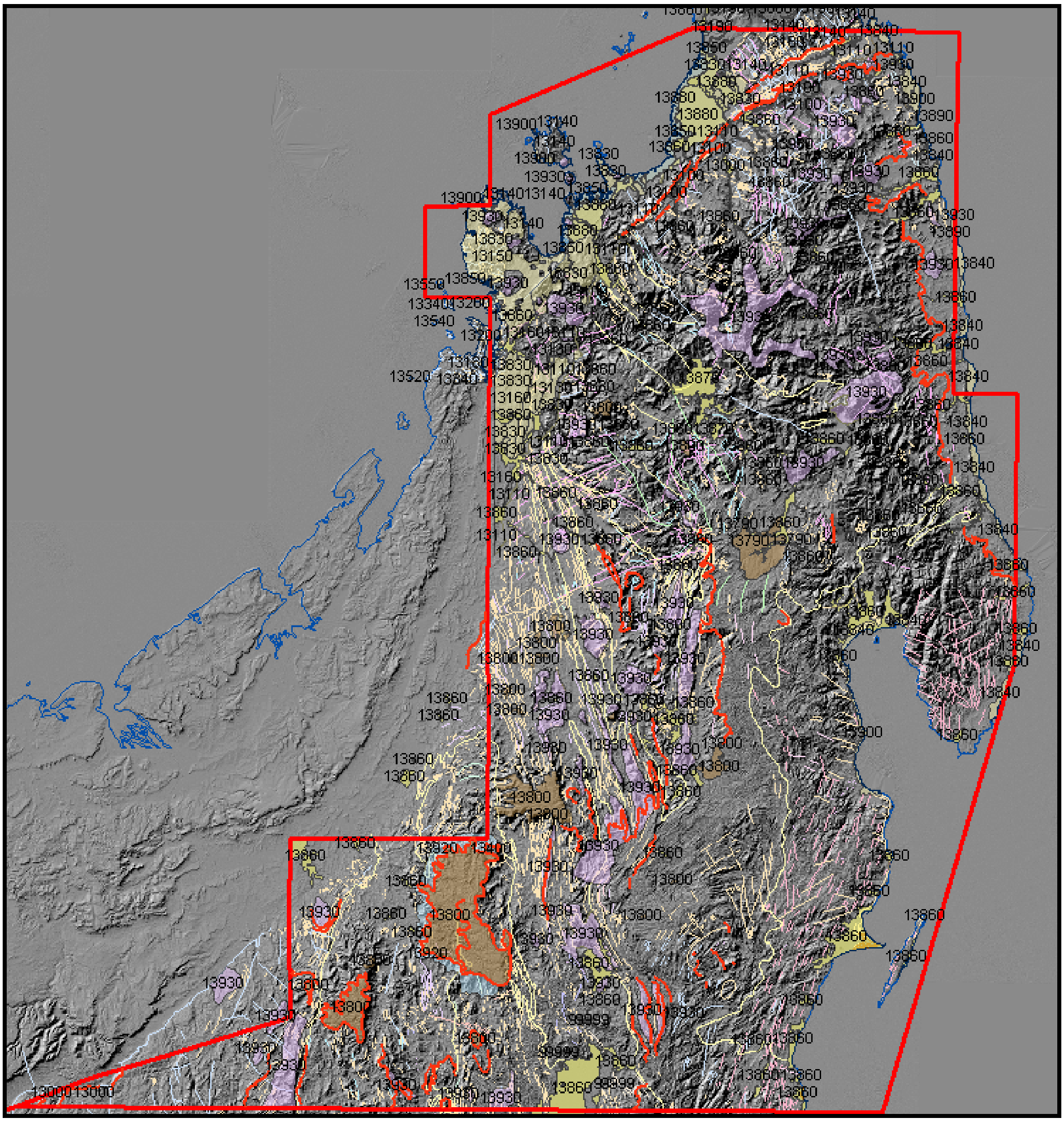

Figure 2 Preliminary remote sensing geomorphological interpretation.

Landsat ETM has a 15m spatial resolution so it is ideally suited to interpretation at 1:250,000. Various band combinations were used, though the most useful was bands 7,4,1 displayed through the red, green and blue guns respectively. A Normalised Difference Vegetation Index (NDVI) was also produced (Figure 3) to classify the amount of active vegetation, primarily as an aid to mapping, but also as an input to erosion models if time was available.

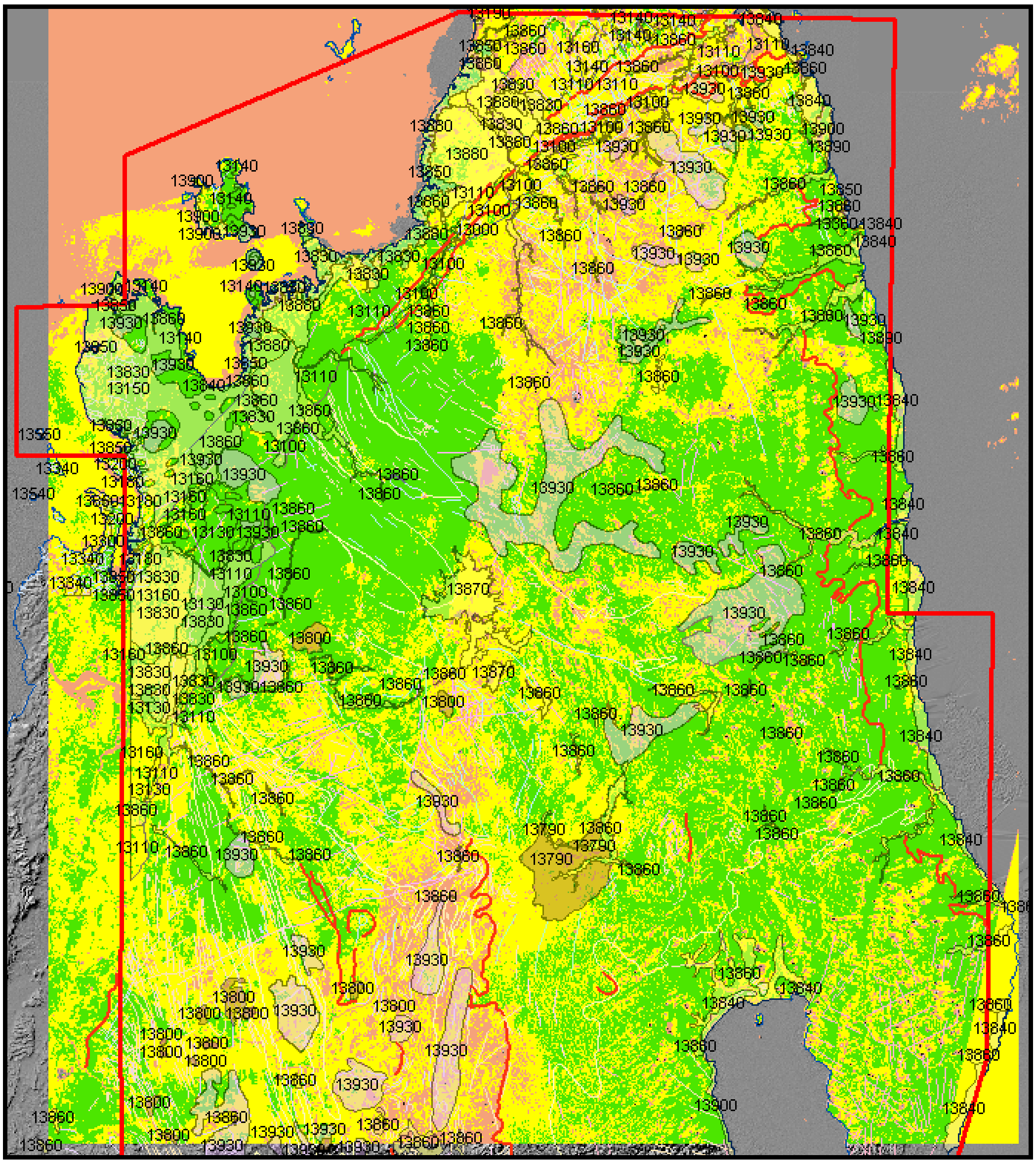

Figure 3 Normalised Vegetation Difference Index, plotting levels of active vegetation.

There was insufficient time to process the Radarsat data so it was unavailable for interpretation before departing for Madagascar.

A shaded relief image was produced from the SRTM data, shaded from the northwest, with a pixel size of 90m, the same as the raw data. This derivative image provided useful geomorphological information but was of further use when the ETM data were ‘burnt onto’ the SRTM to produce a hybrid that has the spectral information from the Landsat and the topographic information from the SRTM.

The digital raster data outlined above were compiled in an ArcGIS 9.0 Geographic Information System (GIS) for digital ‘heads up’ interpretation. The range of features (Table 2) recorded on the geomorphology map were already defined on the Base de Donnees Pour la Gouvernance des Resources Minerales (BPGRM) website at http://www2.gaf.de/bpgrm/.

Code	Description (French)	Description (English)
13950	Duricrust indifferencie	Undifferentiated duricrust
13930	Massif	Massif
13920	Zone a lavaka	Lavaka area
13910	Sediments Quaternaires indifferencies	Undifferentiated Quaternary sediments
13900	Depots cotiers indifferencies	Undifferentiated coastal deposits
13890	Depots de plages	Beach deposits
13850	Vases de mangrove	Mangrove swamps
13840	Sables, dunes	Sand, dunes
13880	Eventails alluvials; cones de dejection	Alluvial fan
13870	Depots lacustres	Lacustrine deposit
13860	Alluvions	Alluvium
13820	Alluvions anciennes (haute terraces)	Ancient alluvium, elevated terraces
13830	Carapace sableuse	Sand carapace
13810	Argiles lateritiques	Clay laterites
13800	Cuirasse lateritique	Laterite cover
13790	Cuirasse bauxitique	Bauxite cover
13940	Croute depologique indifferencie	Undifferentiated soil crust

Table 2 Geomorpholigical sediment types defined by the BPGRM.

In addition to the sediments above, landforms or features such as cuesta, escarpments, badlands etc. were delineated on the satellite imagery where time allowed.

From experience of mapping in other similar terrains, it was recognised that the vast majority of the landscape in Madagascar is covered by laterites so it was decided to categorise all the landmass as such and then delineate areas that consist of other sediments. Also, it is impossible to differentiate between different types of laterite remotely so this was not attempted. In fact the vegetation cover makes it impossible to differentiate many sediments remotely (even for an experienced geomorphologist) so the importance of field mapping in this terrain cannot be underemphasised.

3.1 DERIVATIVE GEOMORPHOLOGY INTERPRETATIVE MAPS

The BGPRM website (link below) contains a brief proposal suggesting that an erosion risk assessment be carried out by the GAF/BGR team working in the southern part of Madagascar (Appendix 1). The document notes that the risk of erosion is mainly dominated by three factors: i) terrain / geomorphology, ii) erodibility of the substrate, and iii) density of the vegetation cover (besides other factors with minor influence). Terrain could be classified as flat, undulating or steep; erodibility as low, medium or high; and vegetation cover as dense, sparse or poor. Using these categories in a 3x3 matrix one could produce a map with three erosion risk zones, consisting of low, medium and high risk. Unfortunately no guidance is provided on how to determine the thresholds for each of the three classifications of category above other than the suggestion that they could be determined in the field through observations.

http://www2.gaf.de/bpgrm/pages/membres/internal_pdf/Geomorphology_Web_3_.pdf

The 'terrain' can be extracted from the DTM by producing a slope analysis but this will need to be modified manually using an interpretation of the satellite imagery if it is to take account of geomorphology and not simply the steepness of the slopes. Lithological units can be used as a starting point to derive erodibility and the vegetation cover can be produced from the NDVI. All three can then be analysed in a GIS to produce a preliminary erosion risk assessment. However, it should be stressed that if the resulting risk assessment is to be exportable across mapping areas then the thresholds must be published or a workshop held to agree suitable thresholds.

4 Field Mapping

Supported by an homologue and a driver, and equipped with a 4x4 vehicle I had an allocation of 22 days to travel to/from Madagascar and to cover approximately 140,000km^2 on the ground. Most of the roads were unpaved and travelled over rugged terrain resulting in an average speed of ~20km/h, and much slower when conditions were wet. The scale of this task meant that I was restricted to recording data at exposures along drivable roads and tracks with little or no time for foot traverses. Figure 4 illustrates the distribution of my Observation Points collected by GPS and highlights the restricted nature of my fieldwork due to slow progress over the terrain.

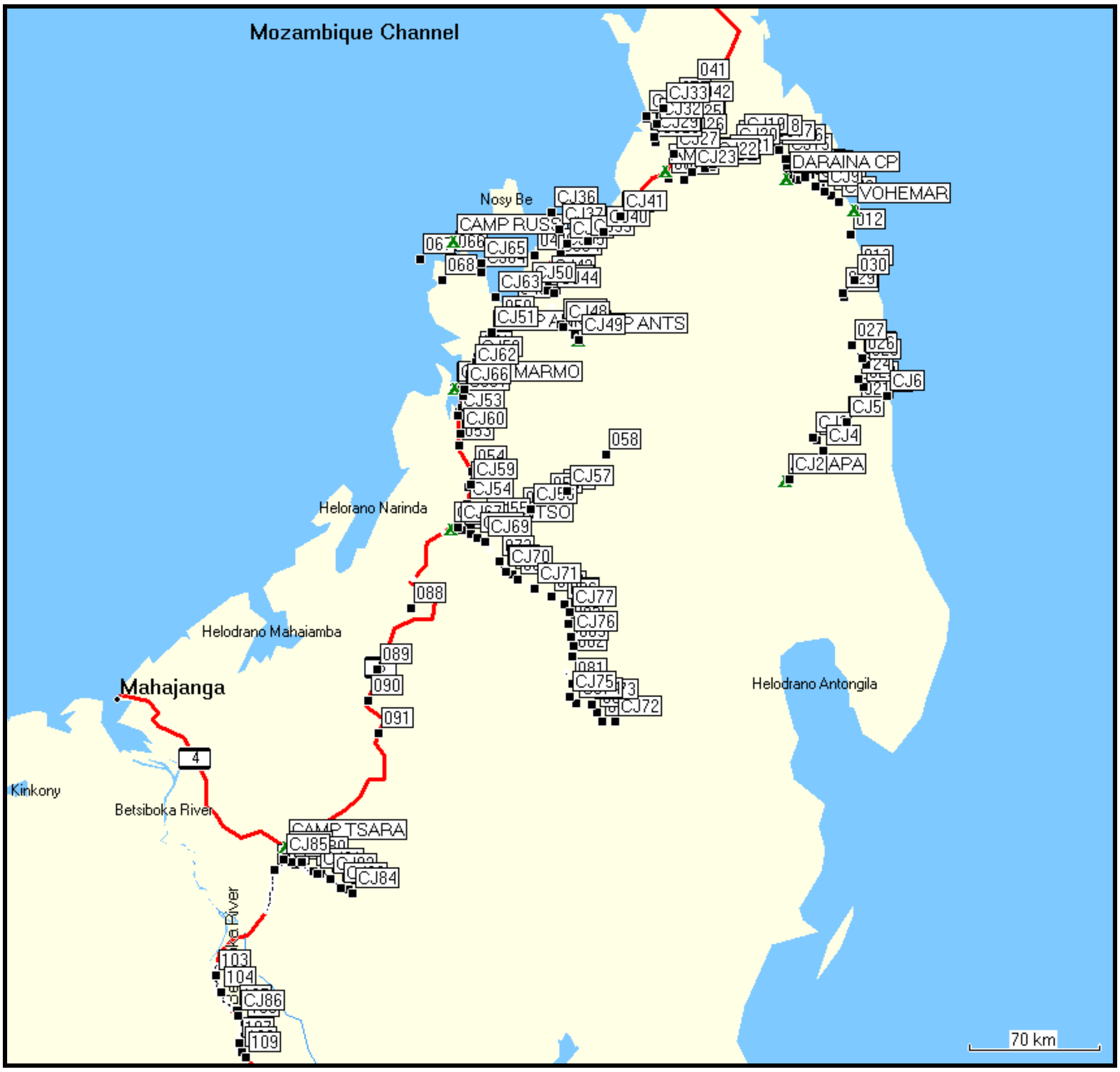

Figure 4 Distribution of GPS points, illustrating the area covered the Autumn 2005 geomorphological field campaign.

In my view it is not possible to conduct a geomorphological survey of 140,000km^2, even if it is only a reconnaissance survey, in the 20 day field allocation (bearing in mind that I actually worked 28 days. I would recommend that the mapping geologists should be asked to record basic geomorphological features and sediments as they map, except that they are already undertaking their own mapping as well as supervising the geochemical sampling.

A Garmin 72 Global Positioning System (GPS) was used in conjunction with topographic maps and 1:250,000 scale satellite imagery to locate myself in the field and to record data. Point information was recorded in a notebook. Furthermore, the GIS was brought into the field on a rugged Tablet PC with integrated GPS which served as a useful navigation and mapping aid.

There was a base camp with 3 or 4 BGS/USGS geologists mapping at 1:100,000 scale accompanied by homologues, students, drivers and cooks, but I mostly worked independently staying in a tent or other accommodation in an effort to cover as much ground as possible.

4.1 GEOMORPHIC LANDFORMS / FEATURES

This section briefly illustrates the main geomorphic landforms / features that were distinguished on the satellite imagery and delineated during field mapping for inclusion in the 1:500,000 synopsis map. Plate 1 is a photograph of a cuesta in the north of the mapping area, to the north of the track between Ambilobe and Daraina. The steep side faces the south (i.e. the left side of the photograph) and includes minor gullying with mass wasting or solifluction in the form of ‘soil creep’. The solifluction is highlighted in the fore ground by the terracettes.

Plate 1 Cuesta; steep side visible to the viewer with the gently dipping side extending away to the right.

Plate 2 is a detailed photograph of one of the solifluction terracettes. These terracettes are approximately 20 to 25cm high and are indicative of gradual downslope movement of laterites and the vegetation that is growing upon them.

Plate 2 Detail view of a ‘terracette’ in a laterite undergoing mass wasting.

Alluvium occurs in a number of forms, as illustrated below. Plate 3, taken from a ridge above the village of Morotolana, is a classic floodplain with a low energy braided stream depositing fine- to medium-grained sands. Plate 4 is a photograph of a road section cut into alluvium, consisting of matrix supported cobbles fining upwards, interpreted as a channel bar deposit. This deposit is approximately 8m above the current river level. There are 30cm of medium-grained sandy laterite above the cobbles forming a flat surface profile.

Plate 3 Floodplain with a braided stream at Morotolana.

Plate 4 Section in cobble alluvium covered by thin laterite deposit.

Massifs are generally restricted to the central highlands of the northern mapping area (Figure 1) but they also occur in outlying regions such as on the Ampasindava peninsula in the northwest. As their name suggests, massifs are commonly composed of a massive block of crystalline basement or younger plutons that are generally more rigid than surrounding rocks so they stand exposed relative to the surrounding terrain. The example below in Plate 5 is from the Marojezy Reserve.

Plate 5 An example of a massif, from Marojezy.

Similar to massifs are inselbergs (sometimes called bornhardts), which are also abundant in Madagascar, particularly in the region northwest of Mandritsara. Inselbergs differ from massifs in that they are residual hills rising abruptly from extensive flat lowland erosion plains in arid or semi-arid regions. The example in Plate 6 is from coordinate 596135, 1218772 near Mandritsara, rising approximately 30m above the surrounding landscape.

Plate 6 Inselberg northwest of Mandritsara

Vast areas of Madagascar are covered by savannah, a landscape characterised by sparse open woodlands and thorny shrubs with grass cover, as illustrated in Plate 7. Savannah terrain is of regional importance in Madagascar because it indicates subsurface weathering by groundwater, and slow fluvial incision. Furthermore, the landscape type tends to occur on tectonically stable cratonic plains undergoing very slow denudation (Bloom, 1991).

Plate 7 Savannah landscape

In simple terms, lavaka are gullies; but they are atypical gullies because they combine broad deep headscarps with narrow exits and they expand back and even through hillcrests. Moreover, they form on hillsides without initially being graded to the level of the valley floor and they have erosion rates that are estimated at seven times the global average (Wells & Andriamihaja, 2004).

The lavaka in Plate 7 include those at the early stages of development, forming headscarps and thalwegs, through to multilobate 'valley lavaka'.

Plate 8 Series of lavaka along hillcrests.

Escarpments are simply cliffs or steep/abrupt slopes. They can be controlled by several geological causes including tectonic, depositional or erosional, so the purely descriptive term of 'escarpment' or scarp on the synthesis geomorphological map must be taken in context. The escarpment in Plate 9 is a southwest-northeast aligned vertical cliff denoting the boundary between the Jurassic karstic limestone plateau of the Ankana Reserve and the Quaternary volcanics on the plain.

Plate 9 Vertical escarpment marking the edge of karst plateau of the Ankana Reserve

Tsingy is the Malagasy term for spitzkarren i.e. the limestone pinnacles that form in a karst terrain due to erosion of bedding grikes. Essentially the landforms are solution spikes that usually form in steep or vertially dipping beds. The examples in Plate 10 also display grooves, termed as rillenkarren.

Plate 10 Tsingy in the karst plateau of the Ankana Reserve

Stonelines, in the form of horizons of quartz pebbles in laterites (Plate 11) are prevalent in Madagascar. In this context the stonelines are buried alluvial and colluvial lag gravels denoting the profile of former valley and hill surfaces. Wells and Andriamihaja (1990) suggest that local differences in position between these former and modern landforms indicate that hills and valleys shift as the landscape is lowered by weathering. This implies that the landscape is at a relatively submature stage of development. The stonelines should not be confused with quartz pavements in saprolite, which are the remnants of the original structure of the rock.

Plate 11 Example of stonelines in laterite

Mangrove swamps are intertidal mudflats occupied by halophytic plants, as shown in Plate 12. They generally occur along deltaic coasts intersected by meandering tributaries. The mangrove swamps are particularly important in Madagascar because they enhance/initiate deposition, trapping much of the sediment that is carried by the rivers following the extensive erosion taking place on land. This stabilizes the sediment flow offshore and reduces the effect of offshore deposition on reefs and the marine life that inhabits them.

Plate 12 Mangrove swamp on the Ampasindava Peninsula

I was fortunate to be have had the opportunity to investigate a small portion of the coastal geomorphology by boat when a team was dispatched to map the Ampasindava Peninsula. The main vessel was equipped with sonar enabling me to gain an impression of the bathymetry when we got close to shore (Plate 13, a photograph of the sonar screen). From the sonar data it is clear that the mangrove swamps grade into extensive submarine deltaic fans and at times the silt levels suspended in the water were so high that the sonar could not operate.

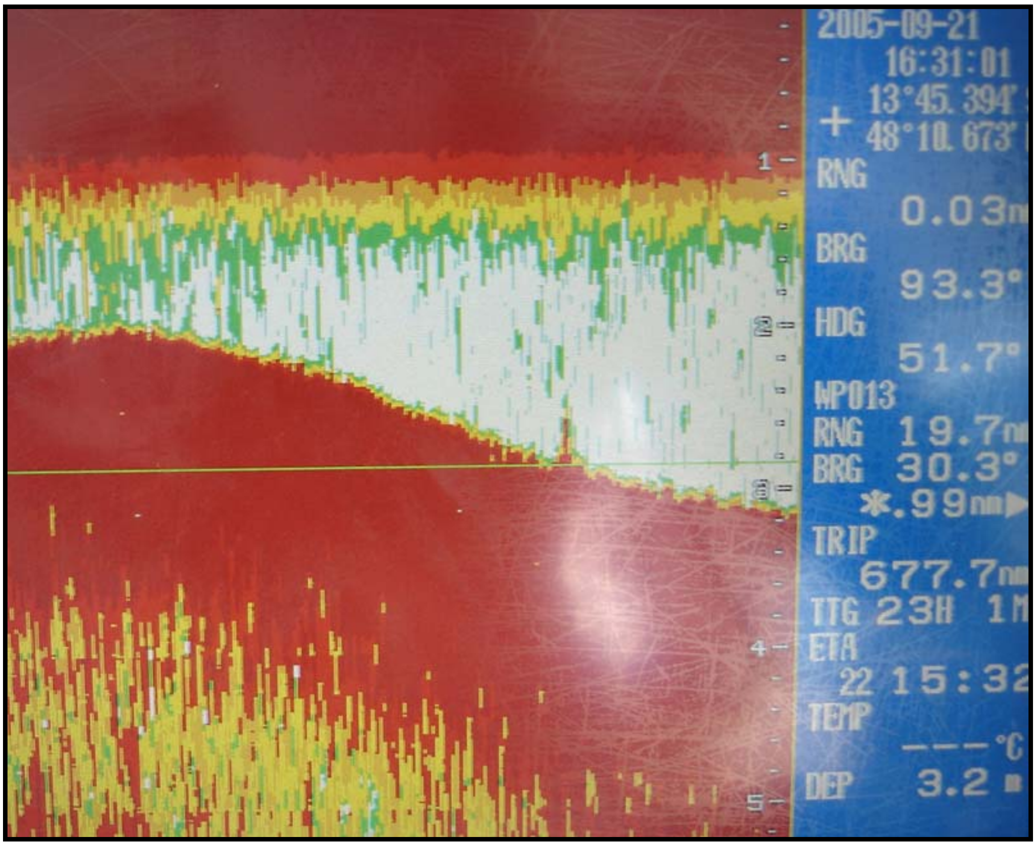

Plate 13 Sonar profile of an estuary in the NW of the Ampasindava Peninsula

5 General Issues including H&S

5.1 H&S ISSUES

Health and Safety is always of paramount importance whenever fieldwork is undertaken, be it in the UK or overseas. It is recognised that considerable efforts were made to ensure the safety of staff and minimise any risks, but at times these efforts were not entirely successful. On a basic level, I was never asked to sign a H&S plan for the project.

As a ‘specialist’ I worked independently from the main camp for most of the time, working with an homologue and a driver and choosing to camp or stay in a roadside ‘Hotely’ where appropriate in an effort to cover as much ground as possible in the given time. Working several hundreds of kilometres from the main camp meant that the VHF radio in the vehicle was of no use. The satellite telephone method of communication was also found to be inadequate and I only managed to complete three calls to other satellite phones during my entire stay, resorting to phoning KW so that a message could be passed to the main camp on my behalf. This is a serious issue for the specialist workers who will always be beyond the 30km range of the current vehicle radios.

I caught food poisoning from a meal taken at one hotely, which resulted in symptoms that made working for the next week very uncomfortable. This is expected in any overseas trip and I purchased broad-spectrum antibiotics to help cure the complaint.

I never felt unsafe or under any threat at any time either in the towns, villages or countryside, despite the stories told by ‘elders’ at some of the more remote camps that Vazaha (Europeans) have previously been robbed at knifepoint where we were camping. My bulky kitty of 2 million Ariary was generally stuffed in the bottom of my rucksack, as there was no facility for keeping it under lock and key in my tent. There was only one theft from ‘my’ vehicle; when I returned to Antananarivo and Cliff Taylor’s day sack was taken. We believe it was grabbed while we were loading equipment into the back of the vehicle outside Le Manoir Hotel.

5.2 GENERAL ISSUES

The 20kg baggage allowance on Air France flights is insufficient if we are expected to carry maps as well as our usual field equipment. Paying excess baggage costs is extremely expensive so I would recommend a greater allowance be purchased with the original ticket if possible.

I had to enter several national parks/reserves, which involved the obvious cost of entry as well as paying for an obligatory guide. However, a lot of the time was spent at ANGAP (Association Nationale pour la Gestion des Aires Proteégées) offices showing the Letter of Introduction and gaining permission to collect samples. I believe that a letter was sent to the central ANGAP office in Tana; I recommend that the letter is circulated to the regional offices to save valuable time in the field.

The fact that we were travelling so far along unknown roads was an issue for two reasons. We quickly learned that local advice on travel times was generally unreliable, with suggested journey times of 2 hours taking more than 5 hours on two occasions. This also meant that the fuel capacity of the Ranger was insufficient so I purchased plastic jerry cans and left funds (from my kitty) with the homologue to purchase additional cans in Tana for the rest of the project vehicles.

A very positive feature were the official stickers on the car doors as they certainly saved a lot of time at the many checkpoints into and out of many of the towns. Once the police or soldiers saw the sticker they invariably waved us on without the usual checks.

Appendix 1 Assessment and Integration of Erosion Risk

Proposed erosion risk assessment from GAF/BGR team:

The risk of erosion under the given climatologic conditions in the Southern part of Madagascar is mainly dominated by three factors: (i) terrain/geomorphology, (ii) erodibility of the substrate, and (iii) density of the vegetation cover (besides other factors with minor influence).

To determine risk zones for erosion, it is proposed to apply a 3x3 matrix:

Value Factor	1	2	3
Terrain	Flat	Undulating	Steep
Erodibility	Low	Medium	High
Vegetation cover	Dense	Sparse	Poor

The thresholds for the three numeric values for each single factor shall be determined in the field through observations - specifically at sites with existing erosion features - to calibrate the system. Further, mapping of existing erosion features (predominantly gullies, badlands, and extended sheet erosion) will serve as reference for the classification of erosion risk zones. Currently, it is proposed to map three erosion risk zones at 1:500 000 scale (through the application of these three basic factors while adding the three values for each factor):

- low risk (values 3 and 4),
- medium risk (values 5, 6, and 7), and
- high risk (values 8 and 9)

Revisions of the factors, values, and erosion risk zones (categories) should be considered at the time the project starts and coordinated with the other mapping zones.

It is proposed to include the observation categories erodibility, vegetation cover, existing erosion, and geomorphology into the standard observation classification form and to collect the data in the field. The terrain (esp. relief energy = slope steepness) will be extracted from the geomorphologic interpretation of satellite imagery (supported by field observations, the DTM, and the topographic maps). The erodibility can then be interpolated from the lithological units and the vegetation cover will be interpreted from the satellite data. Through GIS overlay operations zones of low to high erosion risks can be compiled.

Comment from Enrique Ortega on April 15:

The erosion risk layer must be combined/integrated with the erosion risk layers coming from the other mapping projects, but we can not “impose” any specific methodology to the agencies responsible for mapping in the other zones, because each one already provided its own methodology in the respective technical offer. But of course, we can suggest them to adopt your proposal and to uniform the methodology. This could be a nice discussion matter for the website and also, for the next June workshop.

Glossary

DTM Digital Terrain Model. A digital (computer) model of the landscape in three dimensions.

References

Most of the references listed below are held in the Library of the British Geological Survey at Keyworth, Nottingham. Copies of the references may be purchased from the Library subject to the current copyright legislation.

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