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Integration of geophysical and satellite imagery data from the Alto de Ligonha pegmatite fields, northern Moçambique: implications for the control of mineralisation

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ABSTRACT

Major parts of Mocambique were flown a few years ago to acquire high resolution magnetic and radiometric data. It has been since then the intent of the National Geology Directorate of Moçambique to interpret these data generating value-added maps that are easier to use by the exploration and mining industries than mere airborne geophysical grid data and maps.
The National Geology Directorate of Moçambique and the Council for Geoscience have joined with the financial support of the National Research Foundation of South Africa to conduct an example study case in the Alto de Ligonha pegmatite fields, northern Moçambique, with a special view to support the small scale-mining sector of the region. Analysis of the airborne geophysical, satellite imagery and geology data, in combination with ground geophysical data acquired over specific mineral showings, reveals that the occurrence of pegmatites is mostly confined to amphibolitic gneiss, which is part of the meso-Proterozoic Namama Thrust Belt.
Generation of the respective value-added map was achieved using crisp exploratory K-means clustering of the airborne geophysical data. The map is the result of clustering 850,000 four-element samples (Th- and K-surface concentration, apparent magnetic susceptibility and the vertical magnetic gradient) into a number of classes. It clearly enhances the outcrop area of the amphibolitic gneiss where the occurrence of mineralised pegmatites is the most probable. The automated integration of airborne geophysical data using the well known K-means algorithm proved to be a fast, objective and effective tool to generate a value-added integrated map. The experience made in the Alto de Ligonha pegmatite fields encourages the adoption of this methodology over other parts of the Moçambique Fold Belt. This makes it an integral part of geological mapping ongoing in the country.

Key words: Airborne geophysics, satellite imagery, data integration, K-means clustering, pegmatite, Namama thrust belt

INTRODUCTION

Only a few years ago, major parts of Moçambique had been covered by a high resolution airborne magnetic and radiometric survey in the framework of a World Bank funded project.

In a joint effort to contribute to extraction and assessment of mineral exploration related information from these newly acquired data, the National Geology Directorate of Moçambique, the Geology Institute of the Maputo based Eduardo-Mondlane University, and the Council for Geoscience of South Africa agreed to conduct a research case study over the Alto de Ligonha pegmatite fields with the financial support of the South African National Research Foundation (NRF).

A current problem of the Moçambican mineral exploration sector is that most of the mineral resources are discovered sporadically by local prospectors and small-scale miners with hardly any geological guidance. The Government wants to channel and optimise this process by procuring this sector value-added information beforehand.

The overall objective of the project is therefore to demonstrate how to add value to the newly acquired airborne geophysical data, make the data more attractive to investors and promote the Moçambican mineral exploration and mining industries.

The National Geology Directorate as the National Geological Survey Organisation administers, not only the newly acquired airborne geophysical data sets, but also regional geochemical and remote sensing data. Data integration is therefore considered the track to create value. Our case study from the Alto de Ligonha pegmatite fields is to provide a master example.

This will be achieved by analysis of satellite imagery, airborne magnetic and radiometric as well as geophysical ground follow-up data. A fully automated synoptic integration procedure for large airborne geophysical data sets based upon crisp clustering technique (Eberle, 1993; Stettler et al., 1998, Eberle et al., 2005) has successfully been used to delineate the pegmatite fields. A few ground geophysical traverses across the pegmatite zone and local mineral showings were carried out to verify and detail the airborne geophysical data. The ground geophysical data have been necessary to study the relation of mineral showings and geophysical anomalies in detail.

GEOLOGICAL SETTING

The study area falls in the Zambézia and Nampula provinces in northern Moçambique (Figure 1).

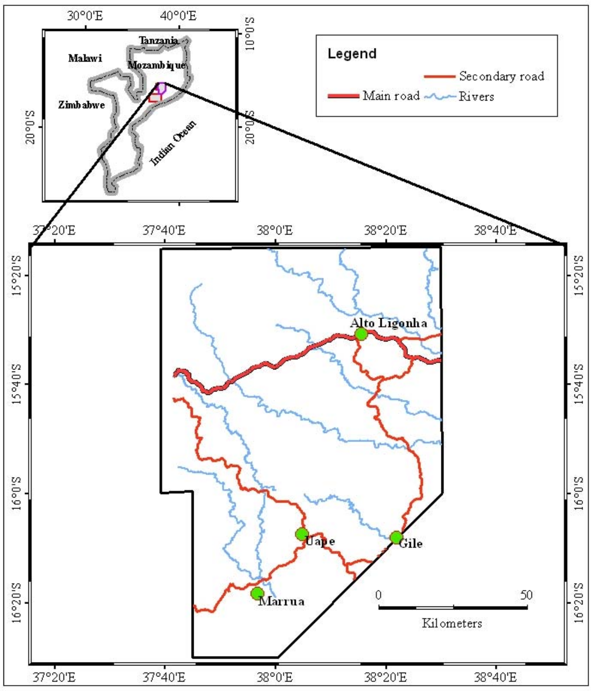

Figure 1. Location map of the study area.

Geologically it is situated within the Pan-African Moçambique Mobile Belt. Two metamorphic cycles, the first pre-Lurian (Mesoproterozoic) and the second Lurian (Pan African), have been recognised in the area. Polydeformed, banded and strongly migmatitic tonalitic-trondjemitic-granodioritic (TTG) Mocuba orthogneisses probably form the basement upon which

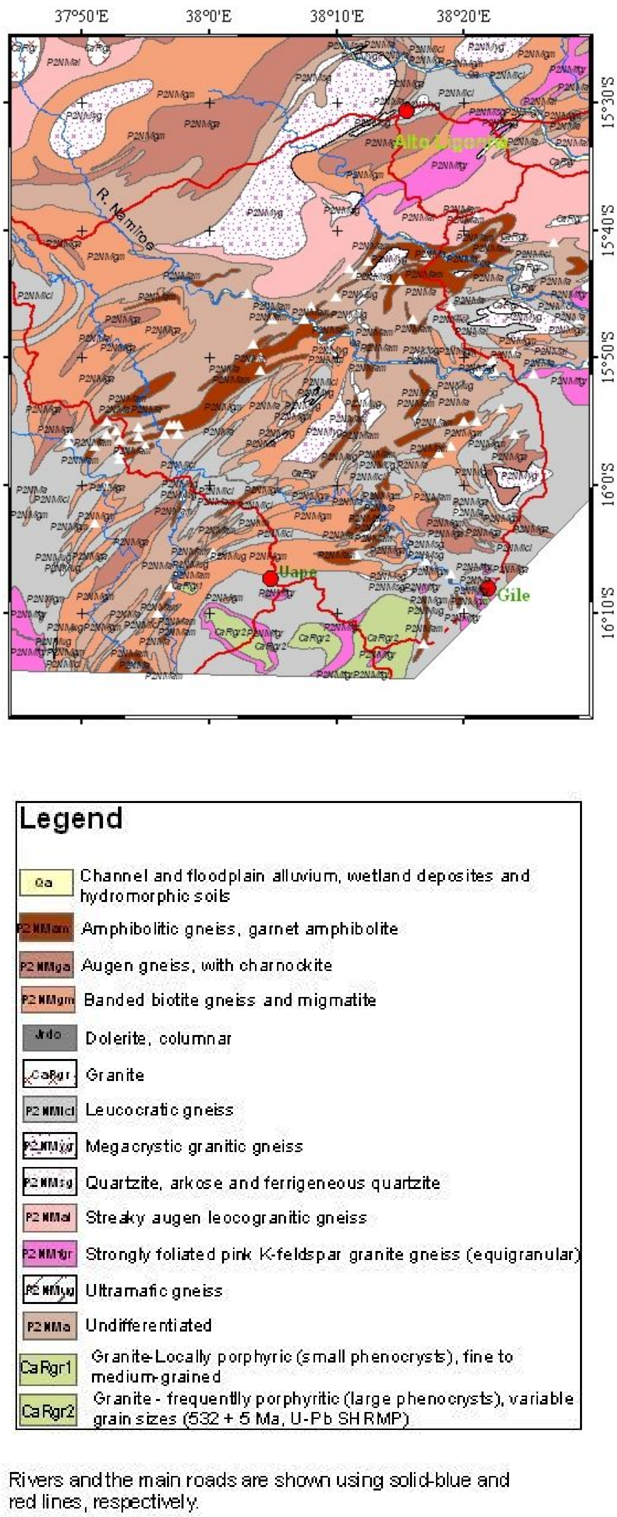

Figure 2. Geological map of the study area (Direcção Nacional de Geologia and Council for Geoscience, 2007). The white solid triangles indicate known mineral occurrence. The Namama Thrust Belt extends SW-NE in the centre of the map section.

the supracrustal gneisses of the Moloqué Group were deposited. The Moloqué Group represents an interlayered sequence of metapelitic, calc-silicate and felsic, mafic and ultramafic metavolcanic supracrustal gneisses and is locally restricted to the Namama Thrust Belt (NTB). Following an initial phase of deformation and migmatisation, the Mocuba orthogneisses were intruded by A-type granitoid plutons of the Culicui Suite. The Culicui Suite (cf. Figure 2) consists of weakly migmatitic to non-migmatitic granitic and leucogranitic augen and streaky gneisses (Cadoppi et al., 1987; Kröner et al., 1997).

The Mesoproterozoic gneisses were later deformed during the intrusion of Pan African - age granite plutons and dykes of the Murrupula Suite. The Pan-African magmatism was related to regional-scale thrust tectonics. At least two generations of pegmatites intruded the rocks of the Nampula Subprovince (Laechelt, 2004).

MINERAL OCCURRENCE

The Alto de Ligonha pegmatite field falls within the study area. The pegmatites contain complex mineral assemblages of which the following are of importance: rare metals (tantalite); rare-earth and radioactive elements, gemstones; raw materials for the glass and ceramic industries, e.g quartz, feldspar, kaolin; and industrial minerals such as mica, beryl, gold etc. (Lächelt, 2004).

Most of the gold-bearing pegmatites occur in the Morrua area between rocks of the Morrua Formation (Moloquè Group) which mainly comprises amphibolites, amphibole gneiss, garnet-bearing pyroxenite and mafic granulite (Lächelt, 2004). Alluvial gold occur in the Xilopane tributaries of the Namirroe River. In the area, gold is also found within quartz-sulphide veins associated with banded iron formation within the amphibolites of the Morrua Formation.

Although the occurrence of pegmatites in this region has been known for a long time (since 1926), geophysical and geological exploration and systematic mining were hampered by a number of factors, including the long period of civil war (1977 – 1992).

DATA ANALYSIS

High Resolution Airborne Geophysical Data

High resolution airborne magnetic and radiometric data had been acquired during the years of 2002/03 over northern Moçambique with nominal line spacing of 500 m and flight height of 120 m a.g.l. Flight line direction was NW-SE oriented at more or less right angles to the general geological strike. Tie lines were flown every 5000 m.

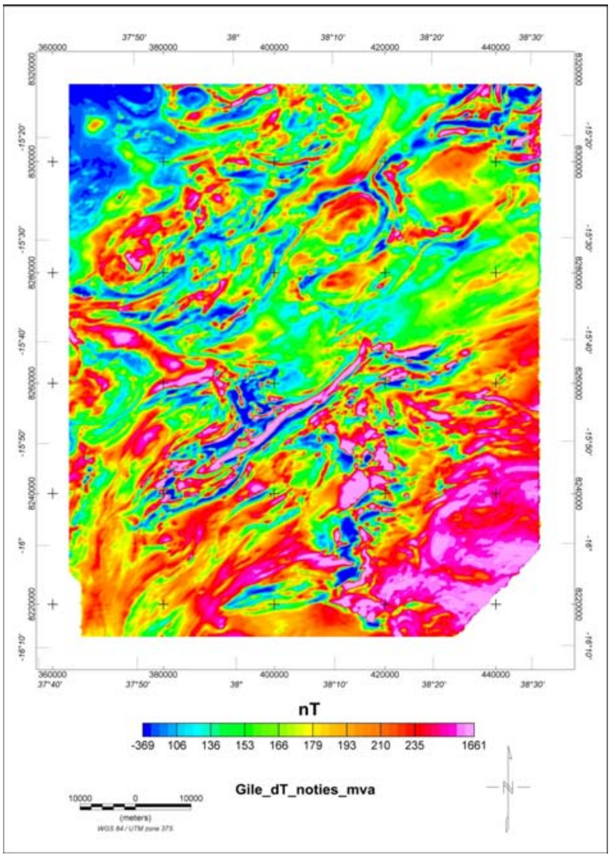

Figure 3. Anomalies ΔT (nT) of the total magnetic intensity over the Alto de Ligonha pegmatite fields.

The image of the Earth's total magnetic intensity anomalies is shown in Figure 3 and covers the area of the Alto de Ligonha pegmatite province. Figure 4 displays a ternary image of the natural radioelements U, Th, and ^{40}K as occurring in the Alto Ligonha pegmatite province. The ternary image clearly indicates a terrain in the northwest of the study area, where thorium reveals high surface concentrations. Predominance of potassium can, however, be observed over the southeast of the study area. It is the Namama Thrust Belt (NTB) that separates these two different radiometric terrains. The NTB itself can be identified as a roughly mushroom-shaped, low radiation area (dark brown) and notably lies still within the area of potassium predominance. Magnetically, the NTB is reflected by a belt of narrow, but elongated high magnitude anomalies (cf. Figure 3).

Ground Geophysical Data

To verify and detail specific airborne geophysical anomalies magnetic and radiometric data were acquired on the ground, mostly following gravel roads trying to associate typical anomalies with road-side lithology. Other ground geophysical data were collected over known mineral occurrences, such as tantalite, beryl, gold and gemstone to study the relationship between mineralisation and geophysical observation. This latter

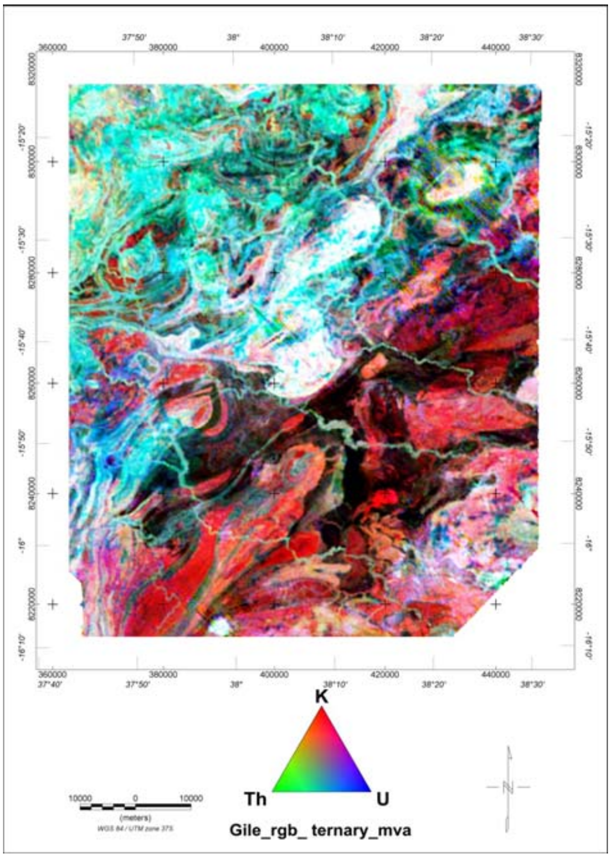

Figure 4. Ternary RGB image of the natural radioelement concentrations modulated by the total count magnitude. Dark brown patterns illustrate areas where radioelements have been depleted.

approach proved to be promising as most of the mineral occurrences studied on the ground are associated with a specific magnetic or/and radiometric anomaly pattern, respectively, indicating an option how technical support to the small-scale mining sector in the Alto de Ligonha pegmatite province would be viable.

Satellite Imagery

Image enhancement techniques that include ratioing, differencing (band 4 subtracted from band 1, Figure 5) and colour composite (band 7: red, band 4: green, band 2: blue) were applied trying to identify additional lithology and tectonics features that were not possible to retrieve from the airborne geophysical data. The coloured circular symbols in Figure 5 indicate the occurrence of rare minerals and rare Earth elements.

Major features, such as the Namama and Luiro Thrust Belts that control the pegmatite distribution, are reflected by satellite imagery, but enhanced images do not provide contrasting spectral signatures that would differentiate the pegmatites from their host rock.

The strong magnetic anomalies and the radiometric lows coinciding with known mineralised rock within the Namama and Luiro Thrust Belts suggest that gemstone-bearing pegmatites are spatially associated with mafic-ultramafic and amphibolitic rock as can be observed in the Gile and Marrua pegmatite fields. Other known mineralised pegmatites, however, occur in areas with increased potassium surface concentration and low amplitude magnetic anomalies and characterise granite or granite-gneiss host rock. They are located mostly in the southern part of the study area where the Uape, Marupino and Mutala pegmatite fields extend.

The distribution of the pegmatites as revealed from the analysis of geophysical and satellite imagery is controlled by two major thrust belts and largely confined to amphibolitic gneiss. Occasionally they occur within the granite-gneiss.

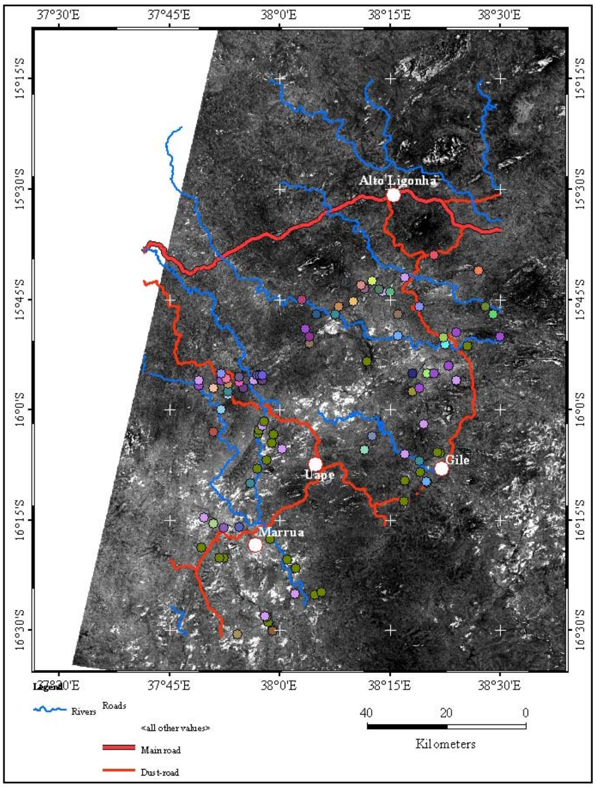

Figure 5. Gray-scale enhanced Landsat image derived from subtraction of band 4 from band 1 showing the SW-NE trending Namama Thrust Belt.

AUTOMATED DATA INTEGRATION

A rapid method of objective data integration is provided by unsupervised classification. Currently crisp and fuzzy clustering techniques are mostly used (Eberle et al. 2005, Eberle et al. 2009, Paasche and Eberle 2009), in particular to compile pseudo-geology maps from large multi-method airborne geophysical data sets.

To obtain the pseudo-geology map of the Alto de Ligonha case study area, four standardised variables (mean: 0; standard deviation: 1) were introduced to enable the classification. These are the apparent

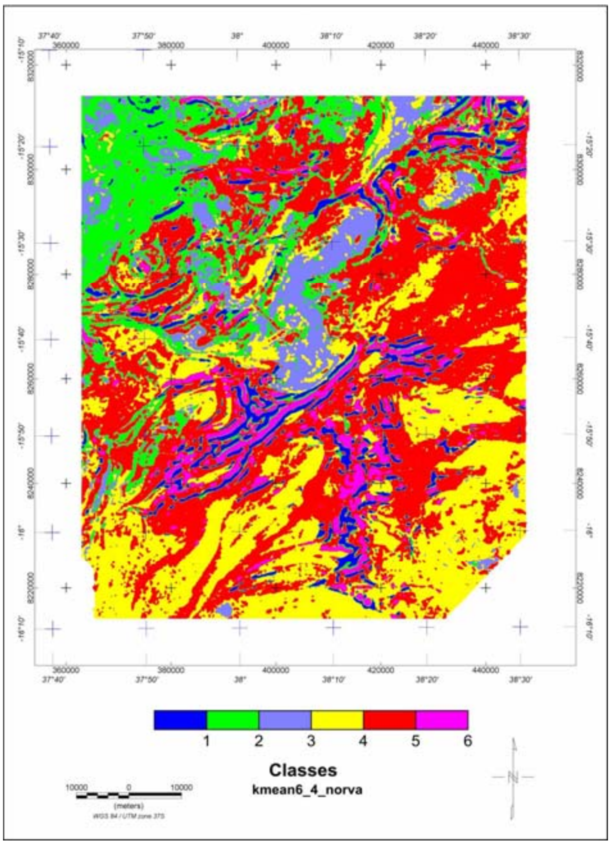

Figure 6. Classification result for six classes obtained from crisp K-means clustering of airborne magnetic and radiometric data from the Alto Ligonha project area.

magnetic susceptibility and the first vertical magnetic gradient computed from the ΔT data set (see Figure 3) and the potassium and thorium surface concentrations as obtained from the airborne radiometric data. The multivariate sample spacing has been 100 m rendering a total of 850,000 multivariate sample vectors. The optimum number of groups may be determined by guess, prior to classification. Alternatively, the Xie-Beni Index (Xie, X.L. and Beni, G., 1991) can be determined from successively computing a few classification cases with increasing group numbers. The smallest index then indicates the case with the optimum number of groups.

The classification result for six classes is depicted in Figure 6. The challenge posed to the user is to establish the association of these six objectively determined classes with the geology of the study area. The image shown in Figure 6 reflects geology/lithology of the study area from a more holistic view as the magnetic data reflect information the sources of which are buried at sub-surface.

From comparison with mapped geology, satellite imagery and ground geophysical data, the above six objective classes can be ascribed to geo-logical/geophysical attributes as follows from Table 1.

Class	Geology/Lithology Attributes
1 - blue 6 - pink	Ampibolitic gneiss, charnockite delineating the pegmatite fields
2 - green	Banded biotite gneiss and migmatite in areas of thorium predominance
3 - light blue	Megacrystic granitic gneiss
4 - yellow	Mostly leucocratic gneiss in areas of potassium predominance
5 - red	Augen (leucocratic) gneiss, charnockite

Table 1. Geology/lithology attributes of six objectively identified classes from airborne magnetic and radiometric data.

Most importantly, classes 1 and 6 reflect the area where most of the known pegmatite fields occur. The classification result depicted by Figure 6 is considered an example of a value-added map which is user-friendly and easier to understand than, for example, the airborne magnetic map (cf. Figure 3).

Table 1 might reflect too coarse a categorisation of the geology of our study area. However, automated objective classification has laid the basis of how to recognise still unknown pegmatite fields occurring in the Moçambique Fold Belt from the newly acquired high resolution airborne geophysical data. Linear stepwise discriminant analysis using the same variables (K– and Th-surface concentrations, apparent susceptibility and the vertical magnetic gradient) would be the step ahead to establish a set of linear equations tuned to recognise unknown pegmatite fields under the geological conditions of the Moçambique Fold Belt.

CONCLUSION

Automated objective data integration in combination with field observations and analysis of various data sets made available for this study have established a successful methodology to compile a user-friendly value-added integrated map that sites the pegmatite fields of the Alto de Ligonha study area. Our approach is therefore considered most favourable to delineate the major structures and lithology units that control the spatial distribution of pegmatite fields occurring in the Moçambique Fold Belt. Based on this case study, it is suggested to introduce automated objective data integration routinely as integral part of geological mapping ongoing in Moçambique.

Results achieved are encouraging to extend the principle of automated data integration not only on additional airborne geophysical data, such as variables derived from electromagnetic data, but also on satellite imagery. To do so, some preparatory processing of satellite imagery sets appears necessary and is currently in the experimental stage.

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