Ministry of Mines & Steel Development
Nigerian Geological Survey Agency

The Federal Republic of Nigeria

TECHNICAL ASSISTANCE FOR THE INTERPRETATION OF AIRBORNE GEOPHYSICAL SURVEY

Contract No. SMMRP/C.2.1/CON/07/02

ZOGRIMA ARGUNGU (Sheet 6) 1:250,000 GEOPHYSICAL MAP SERIES AND INTERPRETATION

Prepared for

Federal Republic of Nigeria: Ministry of Mines and Steel Development

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1. INTRODUCTION

The Ministry of Mines and Steel of the Federal Republic of Nigeria and the World Bank, through the Sustainable Management of Mineral Resources Project (SMMRP) Nigeria, commissioned an airborne geophysical survey over the entire country of Nigeria. The data, which was collected in two phases, allowed Nigeria to gain near nationwide airborne geophysical coverage through high resolution horizontal gradiometer magnetic and radiometric surveys. The surveys were flown at 500 m line spacing and 80 m mean terrain clearance and total almost 2 million line-km, according to the following plan (Figure 1):

2003	Pilot Project	Ogun State
2005-07	Phase I	Blocks A+C and B
2007-10	Phase II	Blocks D1, D2, D3, D4 and D5

All surveys were carried out by Fugro Airborne Surveys on behalf of the Nigerian Geological Survey Agency. Phase II forms part of the World Bank-supported Sustainable Management for Mineral Resources Project. As part of Phase I, time-domain electromagnetic surveys were flown at 200 m line spacing in 2008-09 with the Tempest system over three blocks, totalling 24,000 line-km. To complete the airborne coverage, the Niger Delta block (D5) has been flown in 2010 with magnetics at 1 km line spacing. Separately, airborne gravity was flown over the Niger Delta at 4 km line spacing.

The data acquisition required as many as seven aircrafts at once. This, coupled with the multi-year and multi-season campaigns, required innovative approaches for survey planning, instrument calibration, data compilation and grid merging.

Phase I data was interpreted by Fugro Airborne Surveys. Paterson, Grant & Watson Limited (PGW) was commissioned for interpreting the Phase II data, and also to integrate both interpretations.

The interpretation has been carried out at 1:250,000 scale on Nigeria's standard map layout, with a nationwide synoptic interpretation at the 1:1,000,000 and 1:2,000,000 scales. Each map sheet incorporates two interpretation products:

1) Litho-structural geophysical interpretation – basement, intrasedimentary and sedimentary units evident in the geophysical data together with structure
2) Landform and regolith interpretation – surficial material and geomorphology.

This report discusses the geological and geophysical interpretation of the Zogrima Argungu sheet (Sheet 6) in Block D4. As such, only the geology of the Zogrima Argungu sheet is discussed. The synoptic 1:1,000,000 interpretation report discusses the regional contributions of the geophysics to the understanding of the geology of Nigeria.

Appendix A presents a brief discussion of the data sets used for the interpretation. Appendix B shows the main interpretation methodologies utilized, and Appendix C lists the maps that accompany this report.

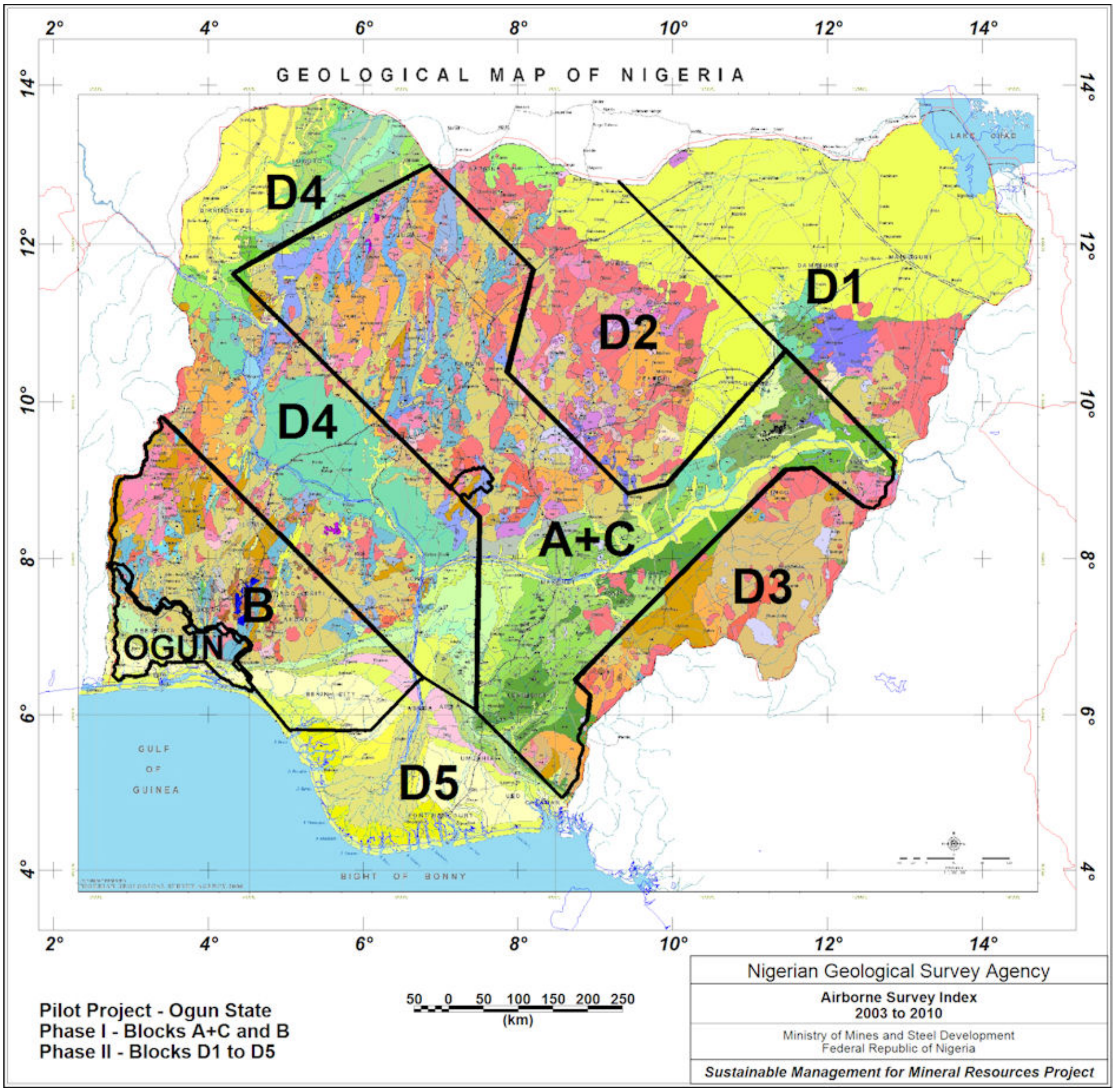

Figure 1 *Index map of the airborne survey blocks flown between 2003 and 2010 for the Nigerian Geological Survey Agency (electromagnetic surveys not shown). In the background is the 1:2,000,000 Geological Map of Nigeria (NGSA, 2006).*

1.1 Location

The Zogrima Argungu map sheet (Sheet 6) is part of the standard 1° x 1° Nigerian Geological Survey Agency 1:250,000 scale sheets, that however was extended further to the west in order to fit the western-most extension of the country. It is located in the northwest region of Nigeria and includes parts of Kebbi, Sokoto and Zamfara states. It comprises from approximately 3°30’E to 5°E, and 12°N to 13°N (Figure 2).

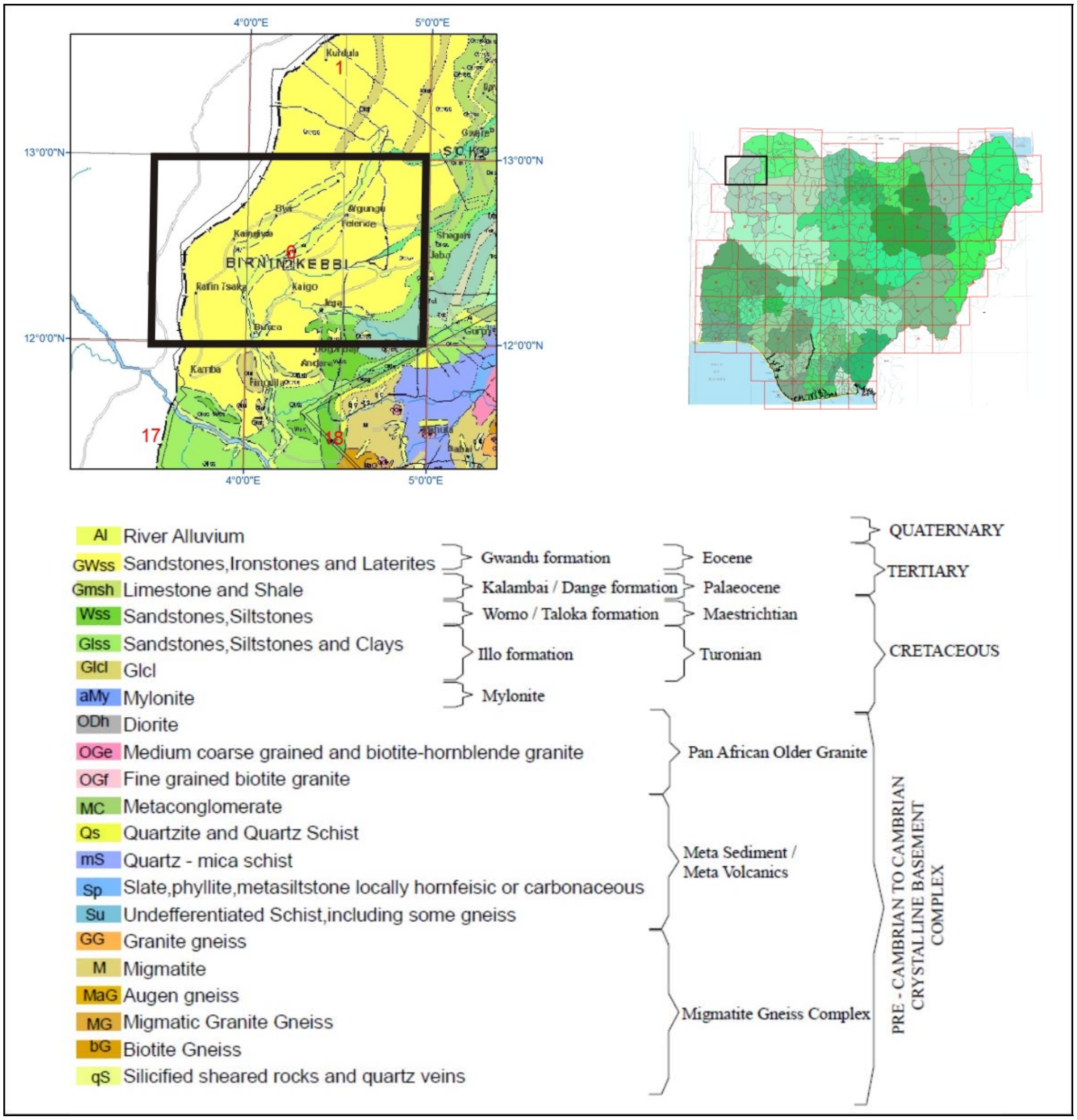

Figure 2: Regional geology over the Zogrima Argungu sheet (black rectangle) and surroundings. Geology from NGSA's 1:2,000,000 National Geology Map.

1.2 Regional Geology

The Zogrima Argungu sheet is located entirely within the Sokoto basin. The main exposed lithologies are Pre-Maestrichtian gravel and sand, moving to Maestrichtian clays, sandstone and sands from the Taloka formation and Quaternary alluvium (Obaje, 2009).

2. GEOPHYSICAL INTERPRETATION

The geophysical interpretation of the airborne magnetic and radiometric data involves the generation of three products:

- Structural interpretation from magnetic & radiometric data
- Lithological interpretation from the magnetic data
- Regolith mapping from topographic, satellite and radiometric data.

Appendix B summarizes the procedure for the generation of each of the above mentioned maps. The following sections outline the main products of the integrated interpretation. Most of the lithologies exposed here are non-magnetic (except the basalts), therefore the geophysical interpretation focused on mapping the basement lithologies under the young sedimentary cover.

2.1 Lithological interpretation

For the mineral exploration component of this project, one of the main goals of the geophysical interpretation is the recognition of younger (Mesozoic) intrusives within the Pan African granitoid series. This is because of their higher economic significance when compared with the older Pan African granites (Kinnaird, 1984). According to Obaje (2009), hydrothermal processes mainly affect biotite granites. Where these processes have been extensive, disseminated and vein deposits of Sn, Zn, W and Nb with Cu, Fem Bi, U and REE are developed in and around the roof and marginal zones of medium or fine grained granite cupolas, with veins extending up to 2 km out into the country rock (Obaje, 2009).

Despite the extensive sedimentary cover, a significant number of basement lithologies were recognized in the area. The main lithologies in the Zogrima Argungu sheet are migmatitic gneiss and migmatites from the Migmatite-Gneiss complex (MGC); quartz, biotite and muscovite schist and metavolcanics from the Metasedimentary series of the basement complex; and a few Pan African granitoids (OGd) intruding the MGC and schist belt, exposed predominantly at the north and south of the sheet.

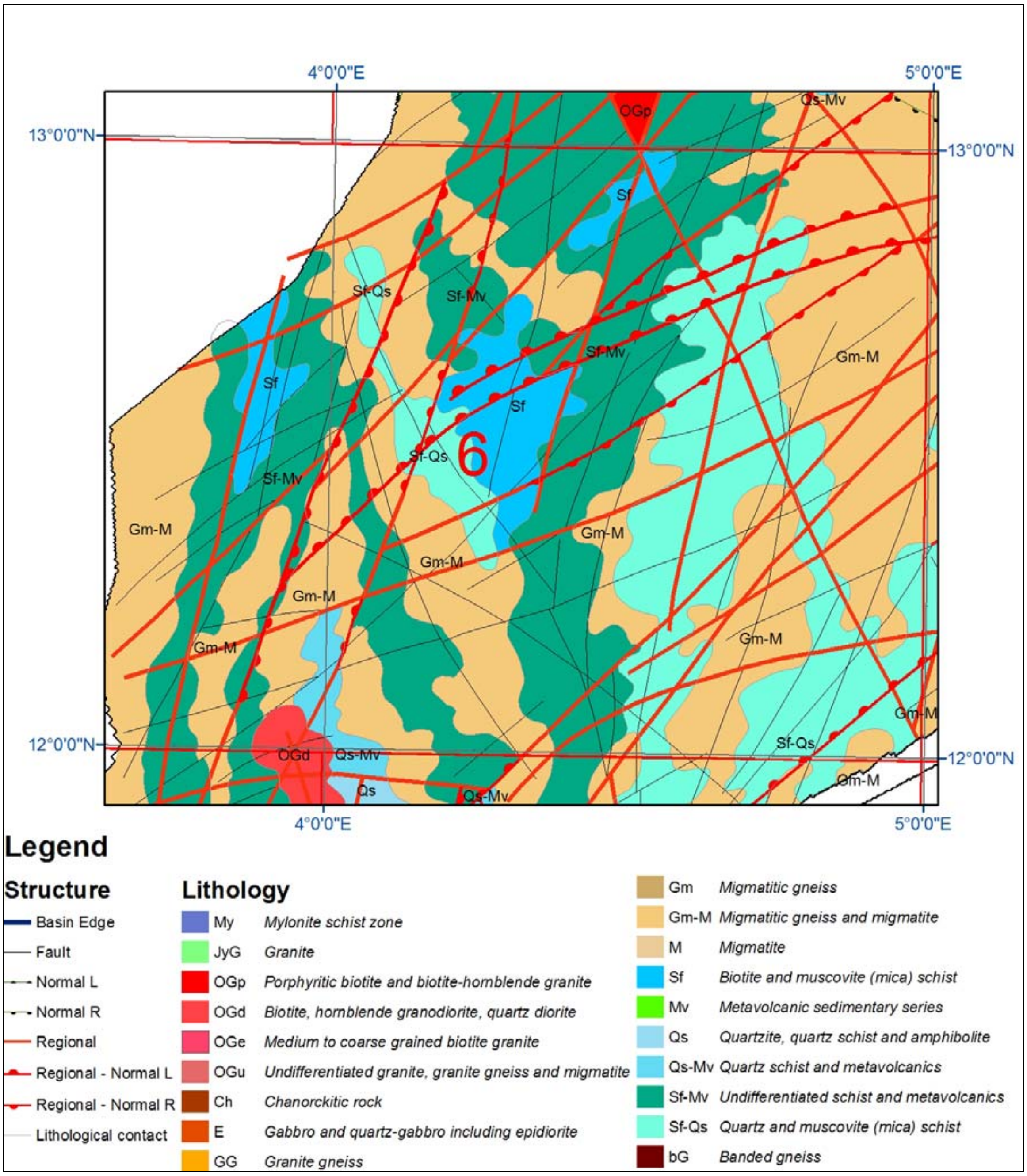

Figure 3: Lithological and structural interpretation of the airborne magnetic and radiometric data.

2.2 Structural interpretation

The Zogrima Argungu sheet shows a variety of regional faults, mostly trending NE and NW, and regional normal faults along the same predominant directions. At the local scale, there are abundant faults trending mostly NE and NW (Figures 3 and 4).

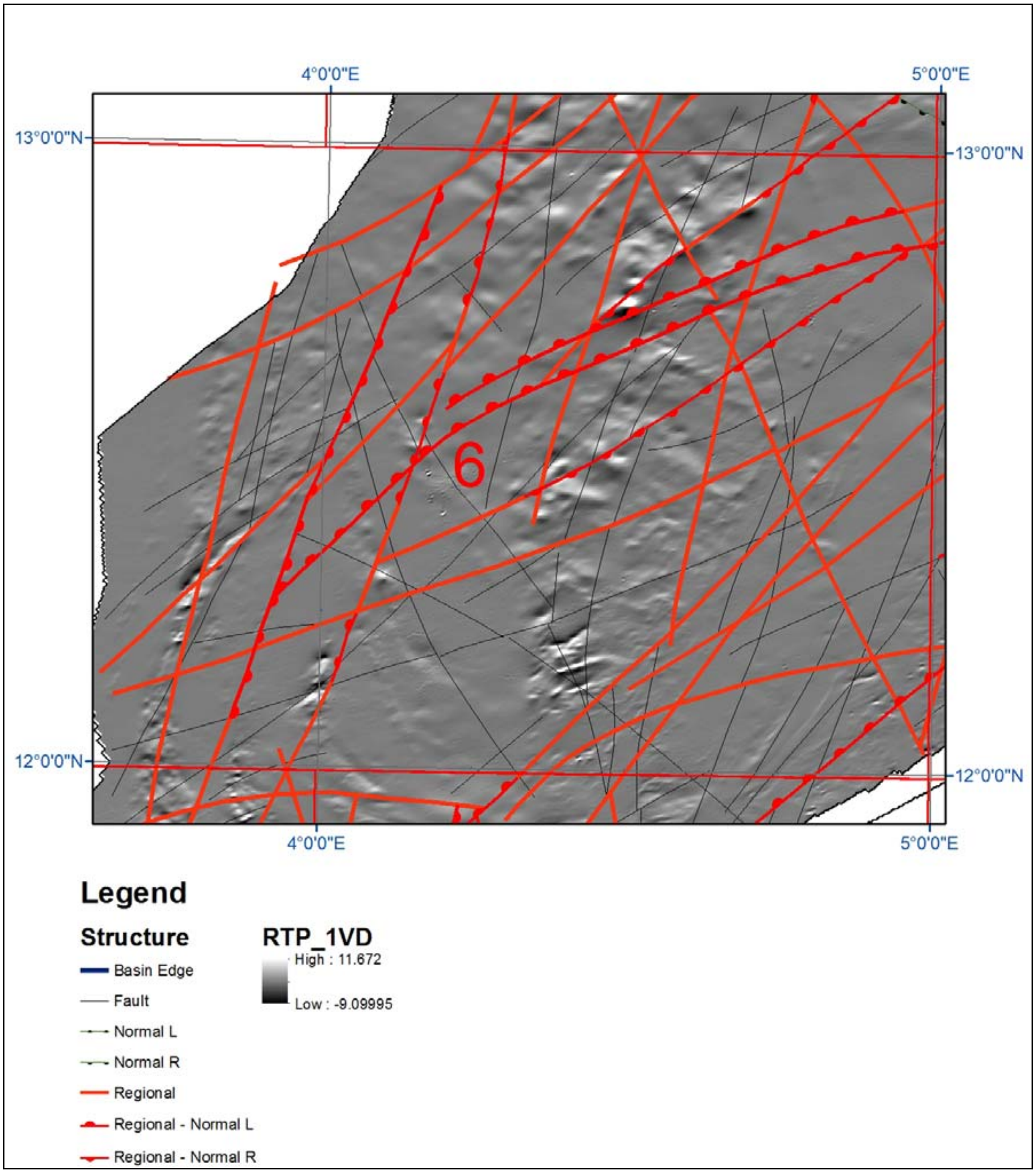

Figure 4: First vertical derivative of the RTP and associated structural interpretation.

2.3 Landform Mapping

The combination of SRTM elevation data, airborne radiometrics and Landasat ETM+ data allowed the generation of a landforms database. The landforms were generated from a classification grid of the SRTM done based on the algorithm of Batuk et al. (2008). The classified grid was then polygonized. Redundant polygons of 10 hectares or less were dissolved into surrounding polygons and subsequently smoothed. Drainage lines were generated for all of Nigeria from the SRTM elevation data.

The Zogrima Argungu sheet shows a mix of low plateaus and steep slopes (generally occupied by migmatites and schists), and some areas related of valley floors and plains, usually associated to schists and metavolcanics.

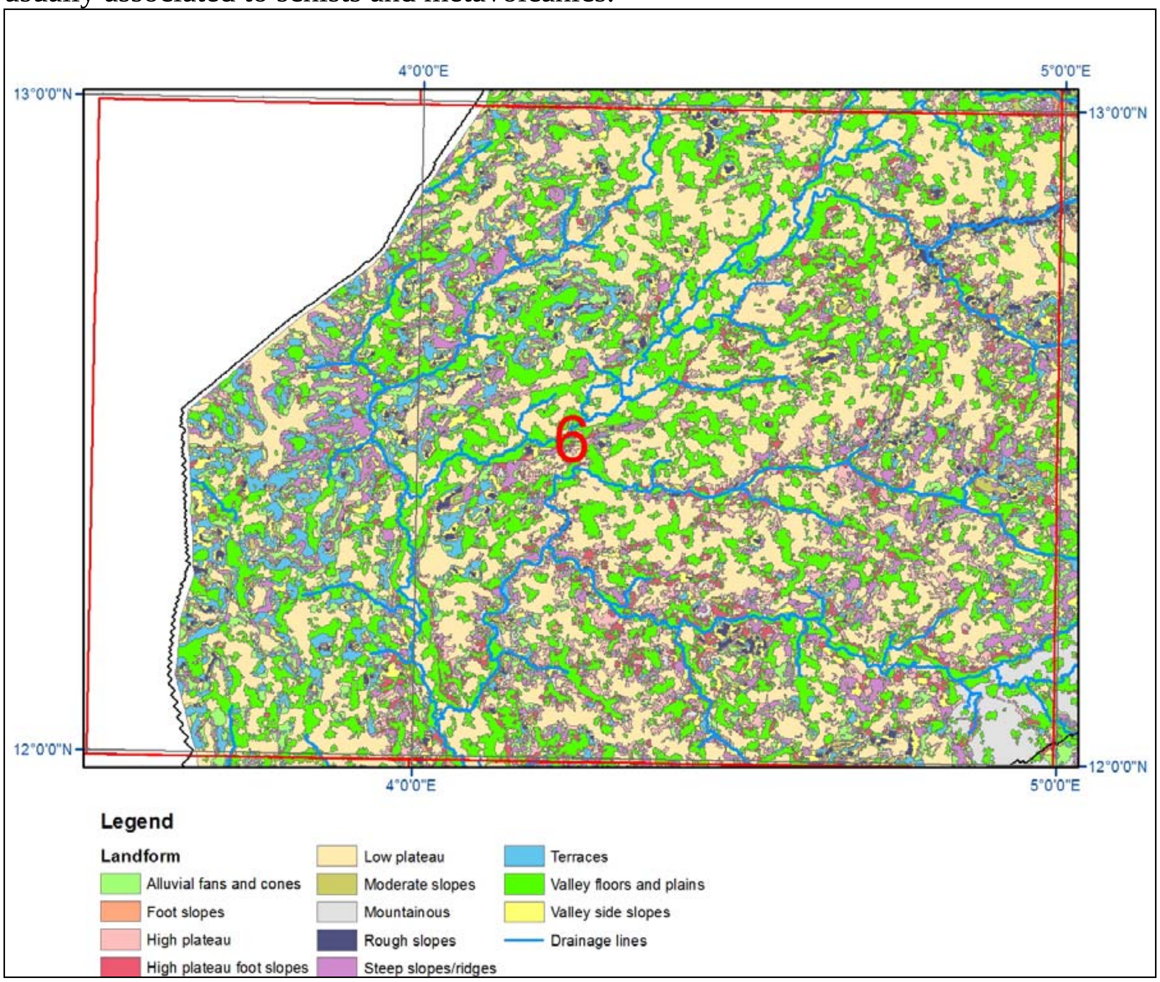

Figure 5: Landform interpretation from SRTM data.

2.4 Regolith Mapping

Regolith units were created by generating a three class classification of each of the potassium, thorium and uranium radiometric grids and then multiplying these grids by each other to generate a 13 class classification grid. As with the landform grid described above, this regolith classification grid was polygonized and redundant polygons of 10 hectares or less were dissolved into surrounding areas and smoothed for aesthetics. Finally, the integrated regolith-landform units were generated by intersecting both maps. Each of the 13 classes contains a unique radioelement combination, which is characterized by using the mean values for each element, for each class. Please note that for consistency, these statistics were computed for the entire country database. The table below shows the statistics of each class:

Table 1: Statistics for each Regolith class

	K (%)		Th (ppm)		U (ppm)	
Class	**Mean**	**STD**	**Mean**	**STD**	**Mean**	**STD**
0	0.47	1.04	11.12	9.48	1.93	2.21
1	0.29	0.14	4.83	1.68	1.00	0.83
2	0.73	0.20	8.04	1.48	1.50	0.77
3	0.27	0.11	8.79	1.48	2.41	1.32
4	0.33	0.17	13.49	1.60	3.72	1.40
5	1.04	0.25	12.09	1.71	2.35	0.86
6	0.95	0.27	6.06	1.49	1.38	0.70
7	2.28	0.98	7.81	1.65	1.89	0.68
8	2.64	1.05	11.18	1.59	2.27	0.87
9	2.52	0.96	15.15	1.64	2.73	0.89
10	0.37	0.22	22.23	7.09	5.01	1.56
11	1.21	0.31	20.43	6.12	3.80	1.25
12	3.02	0.92	26.54	9.66	4.17	1.59

The statistics of each radioelement across the entire country are summarized in Table 2, as well as with histograms for each radioelement in Figure 6. Thorium and uranium show a normal distribution whereas potassium has a much wider distribution towards the high end.

Table 2: Global statistics for each radioelement

Element	Min	Max	Mean	STD
K (%)	-1.02	7.92	1.35	1.23
Th (ppm)	-2.01	203.21	13.89	8.68
U (ppm)	-3.32	27.65	2.70	1.65

Although negative values for radioelement concentrations in the ground are physically impossible, this results from the statistical nature of radiometric data collection and reduction using a gamma-ray spectrometer.

Figure 7 shows the regolith map for the Zogrima Argungu sheet. The polygons are derived from the landform map; therefore the correlation between landform (Figure 5) and regolith (Figure 7) is substantial.

The Zogrima Argungu sheet is dominated by class 1 (mid-low K, low-Th, mid-low-U), in relation to the low plateaus and steep slopes occupied by migmatites and schists; and class 3 (mid-low K, mid-low Th, mid-U), mostly related to valley floors and plains associated to schists and metavolcanics.

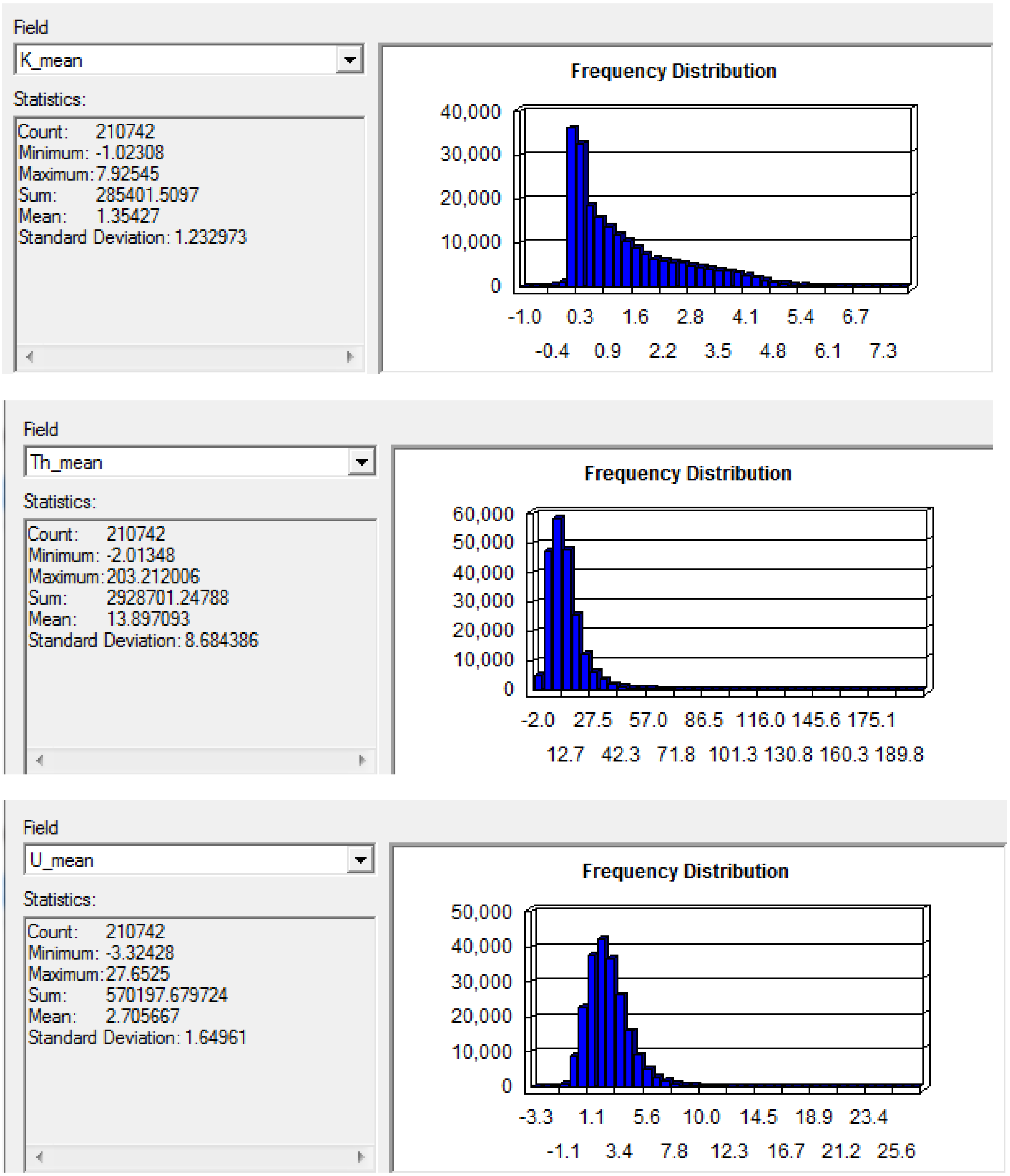

Figure 6: global histograms for potassium (top), thorium (middle) and uranium (bottom). These were calculated utilizing the entire country radiometric data.

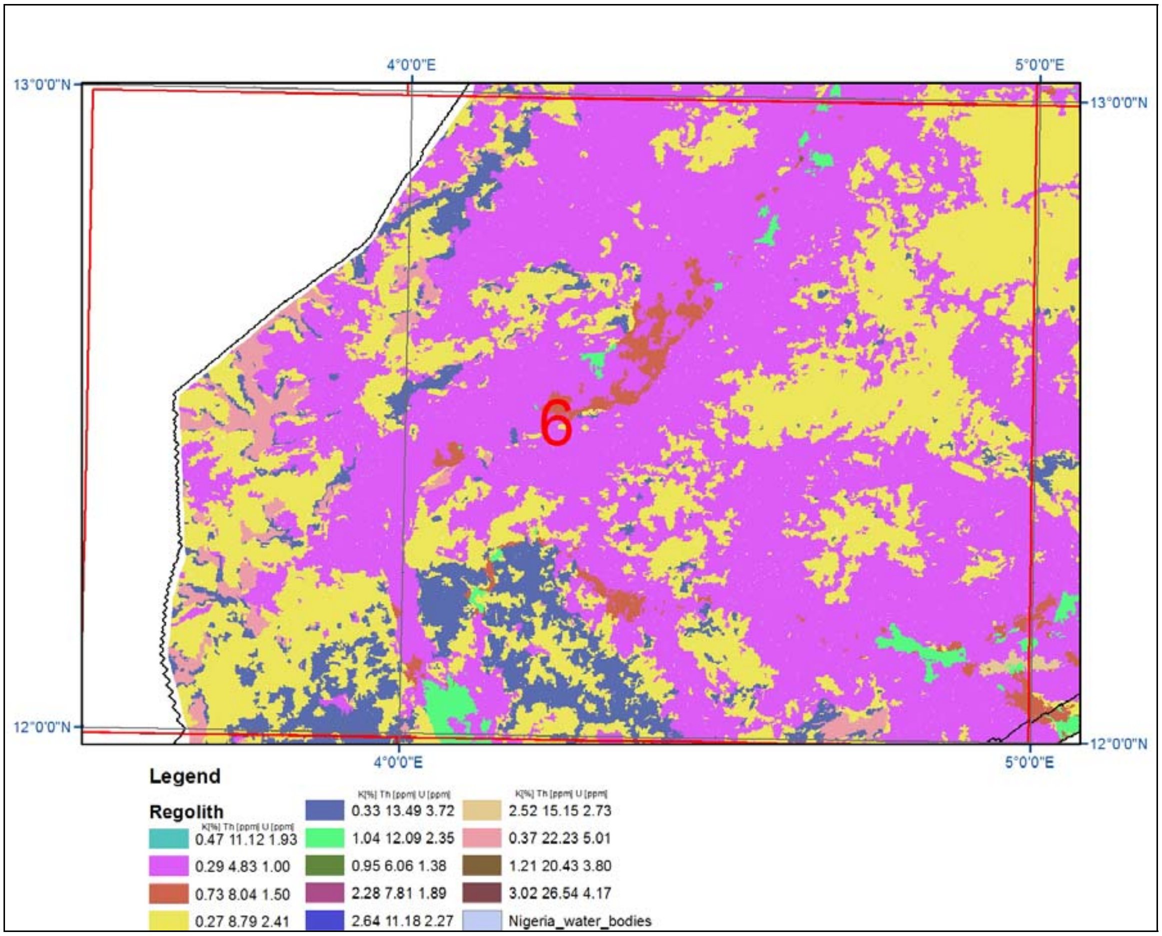

Figure 7: Regolith interpretation from the radiometric and landform data.

3. MINERAL POTENTIAL

The integration of all the geophysical data and its derived products and interpretation maps allowed a regional assessment on mineralization potential for this map sheet.

The prospects and mineralized areas within the Zogrima Argungu sheet are all related to the extensive sedimentary sequence at the Sokoto basin: brine on Tertiary sediments; limestone on white limestones and calcareous shales; and banded ironstone and ferrigenous pans with clays and grits (NGSA, 2006).

The extension of the intrusive bodies (both outcropping and buried) can be correlated with the radiometric data to look for consistent alteration patterns that could have significance for base metals exploration. It is also important to look for structurally favourable areas: normally intersection of faults or shear zones where mineralizing fluids can migrate. Industrial minerals will be associated to faulted/shear zones within the Migmatite-Gneiss Complex (MGC).

Figure 8 shows those areas that look auspicious under the above criteria for exploration of base metals and/or industrial minerals, marked in blue.

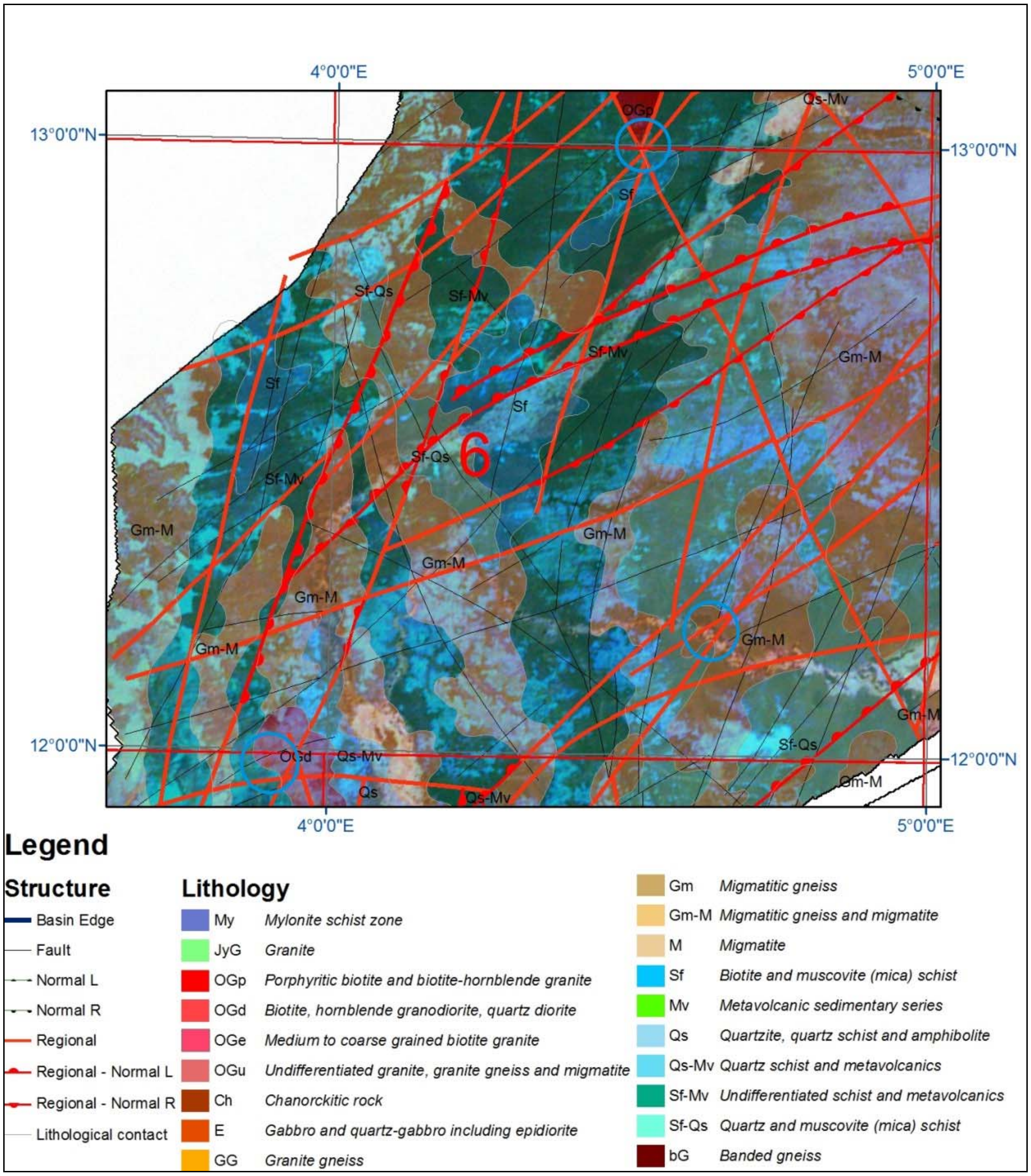

Figure 8: Ternary radiometrics over the geophysical interpretation (same as Figure 3, but with 60% transparency). The blue circles mark areas of potential for exploration of base metals and industrial minerals.

REFERENCES

1. Batuk, F., Emem, O., Gorum, T., Gokasan, E., 2008, implementation of GIS for Landforms of Southern Marmara, Proceedings, FIG Working Week 2008, Sweden, Abstract TS-71, P1-8. Electronic resource: http://www.fig.net/pub/fig2008/papers/ts07i/ts07i_05_batuk_etal_3030.pdf

2. Kinnaird, J.A., 1984, Contrasting styles of Sn-Nb-Ta-Zn mineralization in Nigeria, Journal of African Earth Sciences, 2:81-90.

3. Obaje, Nuhu George, 2009, Geology and mineral resources of Nigeria. Springer-Verlag, Berlin. 221 p.

4. Nigerian Geological Survey Organization (NGSA), 2006, Mineral Resources Map of Nigeria, 1 map scale 1:2,000,000.

APPENDIX A: DESCRIPTION OF THE DATA SETS UTILIZED

For the geophysical interpretation of the Phase II airborne magnetic and radiometric surveys, the following data sets were generated and/or utilized:

1. Magnetics
    a. Total Magnetic Intensity (TMI)
    b. TMI reduced to the magnetic equator (RTE), accounting for the variations in magnetic inclination and declination across the country.
    c. First vertical derivative of the RTE (RTE 1VD)
    d. Amplitude of the analytic signal from the TMI (AS)
    e. Magnetic tilt derivative of the RTE (TILT)
    f. Magnetic depth to sources, generated from source parameter imaging™ (SPI)
    g. Basement surface, computed by subtracting the SPI depth from the topographic surface
    h. Multiscale edges (“worms”)
    i. Anomaly boundaries from source edge detection (SED)

    Note: The reduced-to-pole (RTP) versions of grids b., c. and e. were computed by multiplying the RTE version by -1.
2. Radiometrics
    a. Individual radioelement maps: K, Th, U and Total Count (TC)
    b. Ternary radiometric image (R:G:B = K:Th:U)
    c. Radiometric ratios (Th/K, U/Th, U/K)
3. SRTM Topography
4. Landsat ETM+ satellite imagery

The individual grids provided by Fugro for each block were recompiled with the Phase I data, in order to generate merged data sets for the entire country.

APPENDIX B: SUMMARY OF INTERPRETATION METHODOLOGIES

This geophysical interpretation was prepared by using a combination of sub-products from the total magnetic intensity data recently acquired over the entire country (see Appendix A).
Magnetic trends, lineaments (structures) and domains of varying intensity and frequency content at varying depths were identified based on qualitative inspection or “zoning” of the magnetic data.

Various interpretation layers were derived from the magnetic data: magnetic boundaries and lineaments derived from source edge detection (SED) and multiscale edge analysis (“worms”), magnetic depth to basement (SPI) and basement surface relief. Input grids for these layers include total magnetic intensity (TMI), amplitude of the analytic signal (AS) and derivatives of the total magnetic field.

All these many interpretation layers were prepared in a GIS-environment (ArcGIS) and integrated for the generation of a final interpretation. As the magnetic trends and domains reflect lithological and petrophysical factors (magnetite content, magnetic remanence), they were assigned to geological units from the state geological maps of Nigeria. The radiometric data assisted in the lithologic identification of these units.

APPENDIX C: LIST OF GEOPHYSICAL AND INTERPRETATION MAPS PROVIDED

This report is accompanied by the following maps, both hard-copy and digital PDF files:

Map 6-1 - Colour-filled contours of the pole-reduced magnetic field.

Map 6-2 - Shaded colour image of the first vertical derivative of the pole-reduced magnetic field with source edges.

Map 6-3 - Shaded colour image of the second vertical derivative of the pole-reduced magnetic field.

Map 6-4 - Shaded colour image of the tilt derivative of the pole-reduced magnetic field.

Map 6-5 - Shaded colour image of the analytic amplitude of the total magnetic field.

Map 6-6 - Ternary colour image of the potassium, equivalent thorium and equivalent uranium.

Map 6-7 - Litho-structural interpretation derived from airborne magnetic and radiometric survey data.

Map 6-8 - Regolith and landform interpretation derived from radiometric, digital elevation and Landsat data.