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The Application of Airborne Geophysics Data for Rapid Regional Geological Mapping in Northwestern Angola

(Aplikasi Data Geofizik di Udara untuk Pemetaan Geologi Serantau di Barat Laut Angola)

HONGRUI ZHANG*, PENGFEI JIA, XU ZHANG & ZHIGANG WANG

ABSTRACT

Airborne prospecting (spectrum, magnetics) measurement is an effectively auxiliary approach for geological mapping. It effectively measures the magnetic field characteristics and the surface contents of the most common three radioactive elements (K,eU and eTh) of nature in the research area. Given the significant diversities of magnetic characteristics and the radioelements' contents of different lithological units, these can be applied into the mapping of shallow overburden area. Ternary MAP is a compound imaging technology, providing the radioelements contents a simultaneous display on the same pixel. Based on colour differences, this technology can identify different lithologies and clithofacial changes in the same lithological unit effectively in a certain area. With aeromagnetic data conversion and integrated spectrum images, a good effectiveness of 1:250,000 lithological-structural mapping has been achieved in the research area of Northwestern Angola.

Keywords: Aeromagnetics; data processing; rapid geological mapping; spectrum; 1:250,000

ABSTRAK

Pengukuran prospeksi (spektrum, magnetik) di udara adalah pendekatan tambahan yang berkesan untuk pemetaan geologi. Ia secara berkesan mengukur ciri medan magnet dan kandungan permukaan tiga elemen radioaktif (K, eU dan eTh) yang paling biasa di kawasan penyelidikan. Memandangkan ciri kepelbagaian magnetik yang ketara dan kandungan radiounsur daripada unit litologi berbeza, ini boleh digunakan dalam pemetaan kawasan tebukan cetek. Ternari MAP adalah teknologi pengimejan kompaun, memberikan kandungan radiounsur suatu paparan serentak pada piksel yang sama. Berdasarkan perbezaan warna, teknologi ini dapat mengenal pasti pelbagai lapisan dan perubahan klitomuka dalam unit litologi yang sama secara berkesan di kawasan tertentu. Dengan penukaran data aeromagnet dan imej spektrum bersepadu, keberkesanan yang baik 1: 250,000 pemetaan struktur litologi telah dicapai di kawasan penyelidikan Barat Laut Angola.

Kata kunci: Aeromagnet; pemetaan geologi yang cepat; pemprosesan data; spektrum; 1: 250,000

INTRODUCTION

Deductive lithological-structural mapping of airborne prospecting data (spectrum, magnetics) is conducted according to the different geophysical field characteristics reflected by different geological bodies over airborne prospecting. Gamma Ray Spectrometry (GRS) can be used to directly measure the surficial radioelements distribution of K, eU and eTh, and aeromagnetic prospecting measures the distribution characteristics of magnetic field in the research area. They were used to prospect mineral resources primitively. Now they are extended into the spectrum of geological mapping (Anderson 1999; Ridzuan et al. 2017; Xiong 2009) and mineral prospecting (Li et al. 2016; Lo & Pitcher 1996), providing important geophysical information for rapid geological mapping.

As different rock types are made up of rock-forming minerals, containing varied amounts of radioactive elements, the contents' differences of radioactive elements may reflect different lithological units (Graham & Bonham-Carter 1993). Due to this, we can use GRS to obtain the surficial distribution of different radioactive elements, and then rapidly deduce the lithological-structural map (Jaques et al. 1997; Saidin et al. 2016). The mapping's reliability depends on the componential differences of detectable radioactive elements among different lithological units. Darnley and Ford (1987) thought that under many circumstances, GRS directly provided more effective geological mapping information than any other single airborne prospecting technologies or remote sensing.

In comparison, aeromagnetic survey data is a comprehensive reflection of magnetic field information of geological bodies with different depths, forms and scales on the observation surface. Through conducting potential field conversions such as reduction to the pole, first vertical derivation and analytic signals for the original survey data, we can enhance the capacity to distinguish aeromagnetic anomalies and highlight more useful information. The conversion plays an important role in studying structural characteristics, classifying faults, delineating hidden magmatic rocks, outlining regional structure units, researching the internal structure and metallogenic background (Xiong et al. 2016).

Through lithological-structural map which is deducted by airborne prospecting in shallow overburden or low work extent areas, we can significantly assist the mapping personnel with rapid classification of lithological units and reducing the workload of field mapping, thus decreasing accidents in high-risk areas like high altitude zone, African jungles and prairies.

Materials and Methods

GENERAL GEOLOGICAL SITUATION

The research area outcropped various basements and sedimentary rocks ranging from Precambrian to Quaternary (Figure 1). The outcropped stratigraphies were occupied by gneiss, amphibolite and biotite schist ($AR_1^1$and AR_1^2) of Paleoarchean, conglomerate and sandstone (PR_1*on*) of the Group Oendolongo (Paleoproterozoic), limestone and dolomite ($R_{2\text{-}3}$*xc*) of the Group Xisto-Calcario (Neoproterozoic), felsic sandstone and clastic conglomerate (R_3-V*xg*) of the Group Xisto-Gresoso (Neoproterozoic), arkose ($K_2^{s\text{-}t}$*kw*) of Cretaceous (Mesozoic) and the Paleocene-Eocene($P_{1\text{-}2}$), Eocene-Pliocene(P_2-N_2*kl*), and Quaternary (aQ_{iv} , apQ) of Cenozoic.

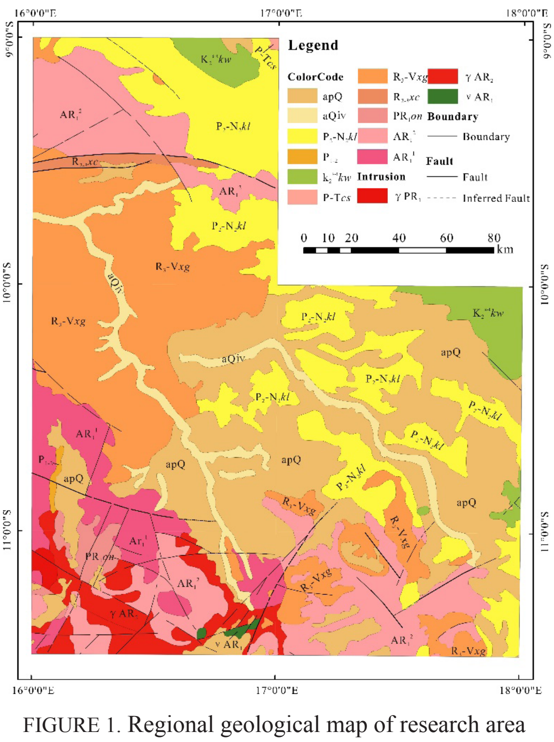

FIGURE 1. Regional geological map of research area

Large scale of intrusions was mainly exposed in the southern and southwestern research area and was dominated by granite and diorite (γAR_2) of Neoarchean. Sporadically gabbro-norite(vAR_1) of Paleoarchean and biotite-granite (γPR_1) of Paleoproterizoic. The basement was mainly developed in southwesernt Angola shield and northern Cuanza host. Deep faults were generated along them. The eastern territory was covered by Phanerozoic with non-manifest structures.

AIRBORNE PROSPECTING DATA

In 2015, with the support of the National Geological Survey Program of Angola (PLANAGEO), airborne Gamma Ray Spectrum data within high precision were obtained via CESSNA208B fixed-wing boarded with 512-channel type RS-500 spectrometer. Given PLANAGEO is about to produce geological mapping with scale of 1:250,000 for the whole Angola territory, in view of the known major structure orientation of the research area, North-South flight direction with scale of 1:100.000 was adopted. The actual flight height ranges from 80 to 120 m and the sampling point interval of the spectrum survey line is round 80-90 m/point. The atmospheric radon and cosmic radiation for affecting data precision and the radioactive background of aircraft and devices had been corrected, as well as further calibration of the attenuation coefficient and Compton scattering coefficient. Finally, the surficial contents of K, eU and eTh were calculated according to them and gridded data with 250 m interval by minimum curvature method (Figure 2).

Under normal circumstance, the contents of K, eU and eTh are relatively stable and the elements have correlative relationship with each other. Only under special conditions of hydrothermal activities and alteration, etc., certain elements migration results in concentration or dilution relatively. Therefore, the ratio variety may indicate special geological effects of alteration and mineralization. The processed ratio data proceed with mapping for special geological units in order to enhance the classification precision (Figure 3).

The aeromagnetic sampling point interval is about 6-8 m/point. The raw data were corrected by magnetic diurnal variation and IGRF, and then converted by potential fields' conversion like reducing to pole, first vertical derivation and analytic signals. These conversions significantly increased the capacity for distinguishing geological boundaries in magnetic fields and could significantly enhance the mapping effect of aeromagnetic data (Figure 4).

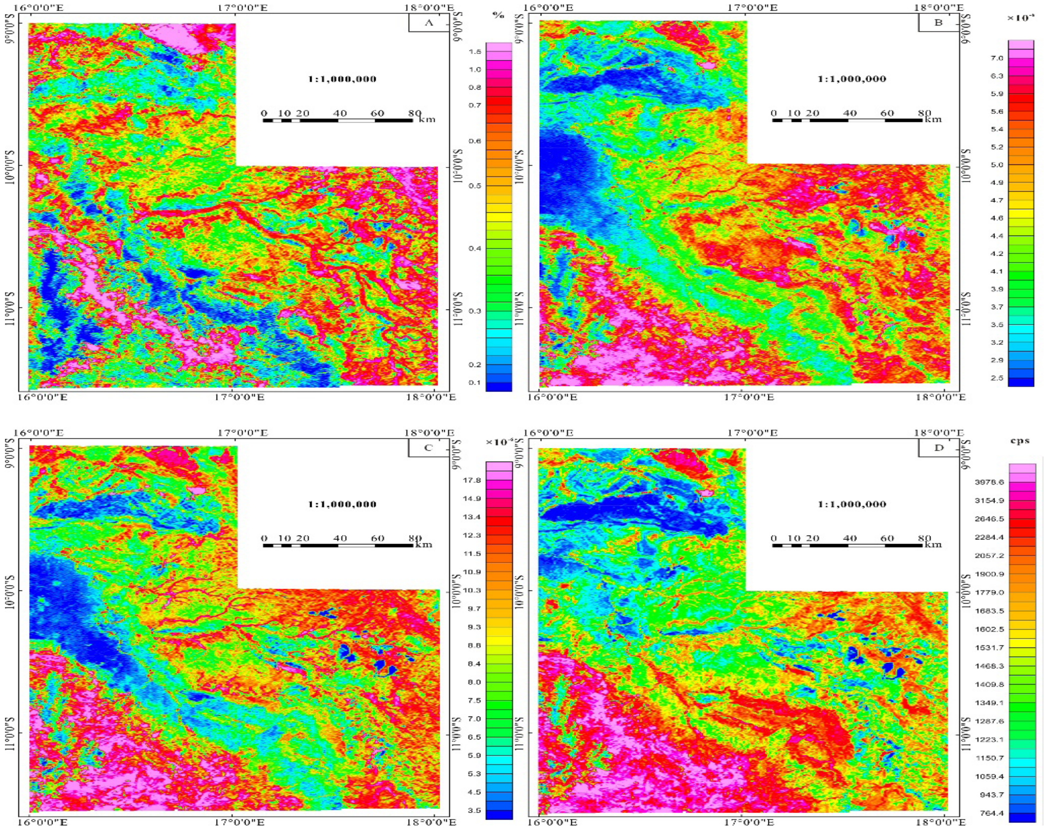

FIGURE 2 Radiometric element content map of research area: A. Potassium(K) content map; B. Uranium (eU) content map; C. Thorium (eTh) content map; D. Total Count(Tc) map

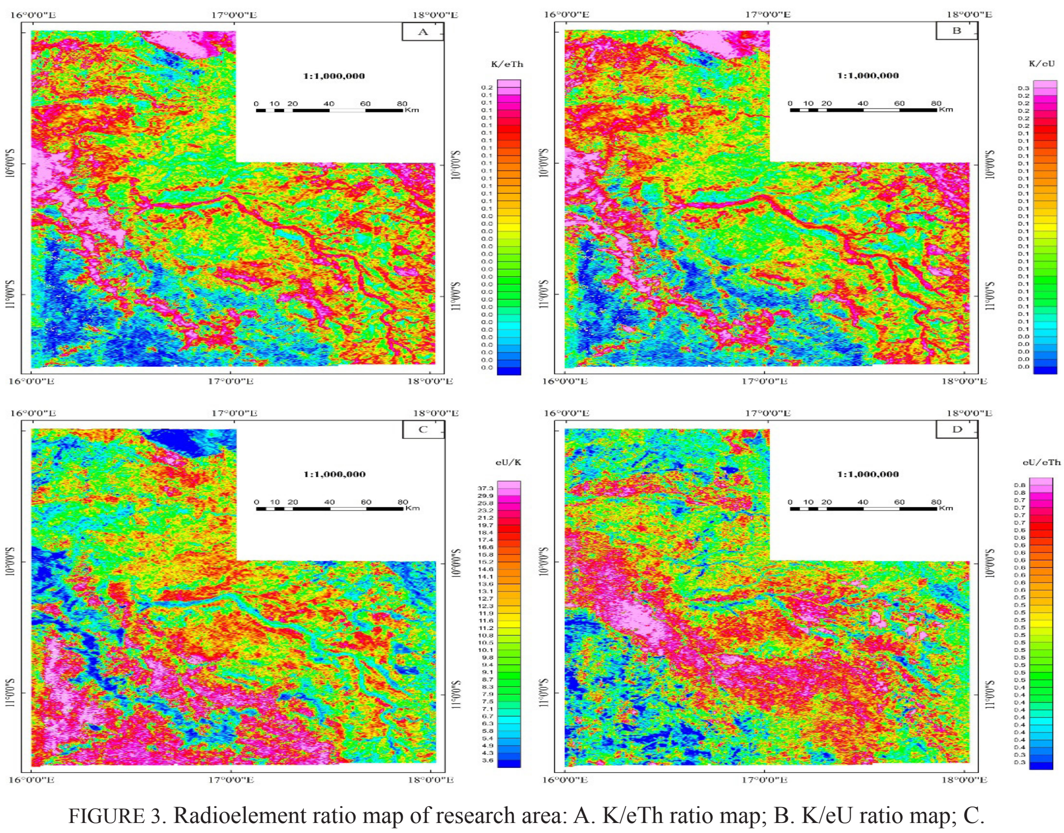

FIGURE 3. Radioelement ratio map of research area: A. K/eTh ratio map; B. K/eU ratio map; C. eU/K ratio map; D. eU /eTh ratio map

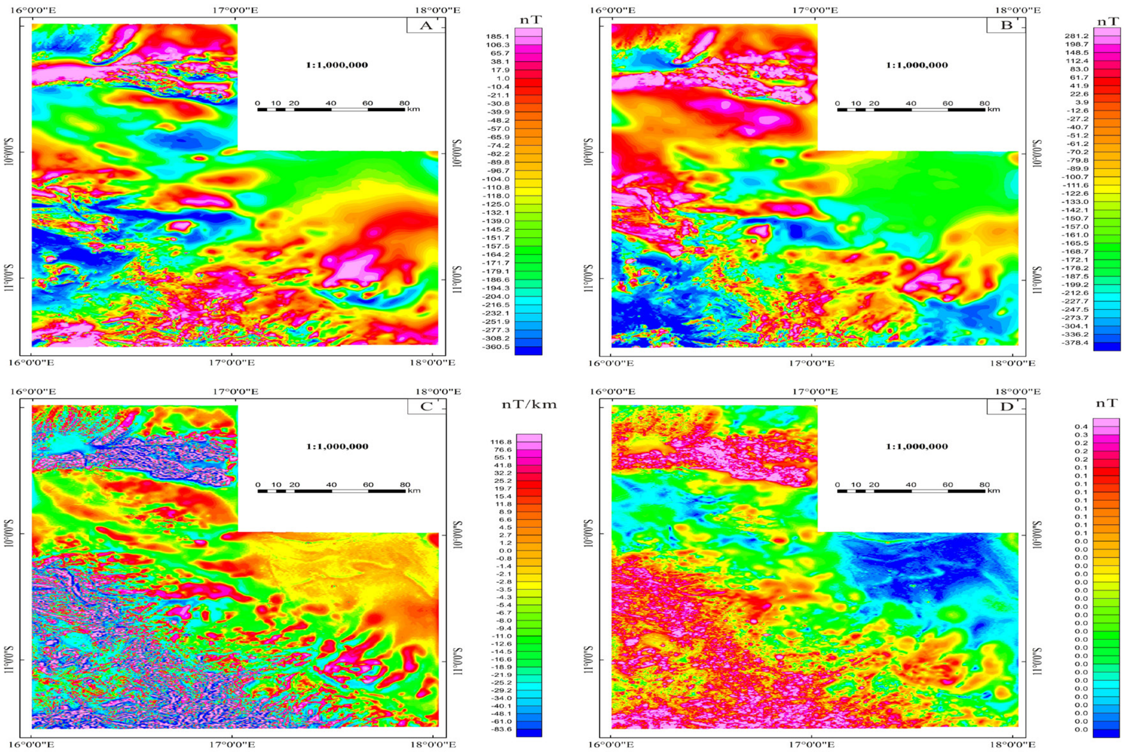

FIGURE 4. Aeromagnetic serial maps of the research area: A. Aeromagnetic rawdata (IGRF correction); B. Aeromagnetic reduction to pole data; C. First vertical derivative of aeromagnetic; D. signal of analysis

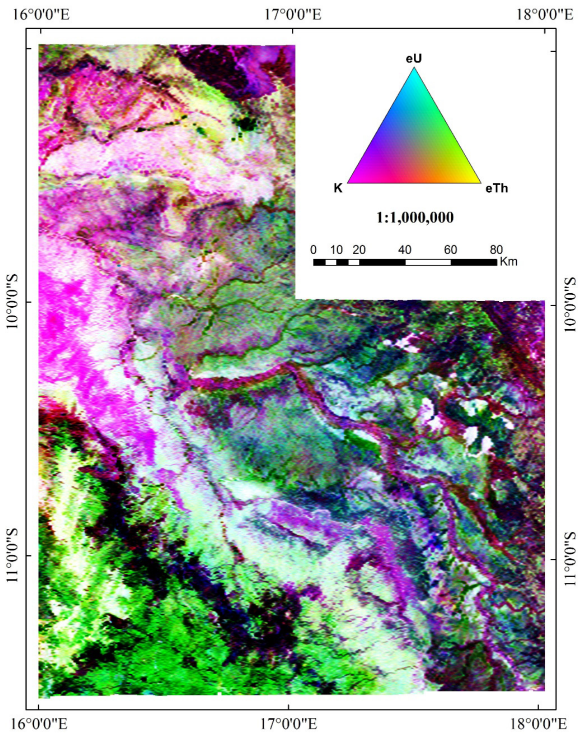

FIGURE 5. eU-K-Th Ternary MAP of research area

TERNARY MAP SPECTRUM MAPPING METHOD

Ternary MAP Spectrum Mapping is applied to display contents or ratio parameters of the three radioelements on a single pixel in a compound image. It can integrate colorful images by matching K, eTh and eU with red, green and blue, respectively (Figure 5). The principle is using colorful digital grid images consisted of energy extents (color) and spatial information to indicate the variety of radioactive amounts. The data can be used for statistical analysis and synthesizing colorful images via integration with other data. Ternary MAP can vary lithologies (Ford et al. 2001; Yasin 2017) based on the different colors. Compared with conventional content images of K, eU , eTh and Tc, this approach can visually show the three radioelements' relation and a better convenience (IAEA 2003; Reeves et al. 1997) for interpretation. Ternary MAP can refine spatial distribution simply and rapidly, thus increase the capability of distinguishing different lithological units.

During practical data processing, considering that low contents area commonly matches low Signal-to-Noise, a shielded threshold can be set up according to the total count grid in order to preserve a better chroma space and strengthen the capability of displaying the residual valid data. As shown in (1), the pre-imaging relative contents of K, eTh and eU can be accounted with the summing normalization (IAEA 2003):

$$U_n = \frac{U}{K+U+Th}$$
$$K_n = \frac{K}{K+U+Th}$$
$$Th_n = \frac{Th}{K+U+Th} \quad (1)$$

In addition, due to CMYK mode for multicolor printer, pinkish red, yellow and cyan are chosen to respectively correspond to K, eTh and eU for the final Ternary MAP. Figure 4 indicates the Ternary Map made by the 1:100,000 high precision airborne Gamma Spectrum data.

This conversion transferred the radioelement contents to relative abundance. The summing normalization can reduce vegetation influence or soil moisture on gamma rays attenuation. Through the linear extension of summing normalization, the variety of hue and saturation were made to correspond in proportion to the relative abundance of K, eTh and eU, and the color variety correspond to the quantificational legends of Ternary Map (Figure 5).

Potassium is a major constituent of most rocks, while uranium and thorium are trace elements and the contents' variation lays a physical foundation for delineating and classifying acid igneous, metamorphic rocks, particularly ultra-basic rockoid with elements of special radioactive proportion, which can be identified much easier.

The application of GRS can be extended to low radioactive environment as well, such as sedimentary basins, volcano-sedimentary areas, large scale of glacial or tropical weathering areas, etc. The subtle differences of the radioelement contents provide vigorous support for mapping. The classification of lithological units is affected by the following factors: The comparison in radioelement contents among lithological units; the extent of outcropping bedrock and overburden; the nature and type of regolith; and the soil moisture and vegetation cover. Compared with remote sensing, Gamma Ray Spectrum (GRS) shows an obvious advantage of identifying lithological variety in area of dense vegetation and shallow overburden (Aspin & Bierwirth 1997).

Due to showing three parameters on the single image, Ternary MAP facilitates various displays of different radioelements' data which are correlative in the same area. Meanwhile, given the advantage of radioelement ratio in identifying special geological units, the following combinations can be developed according to the comparison of the spectrum data:

Compound image combination of K (Figure 6(A)): K (red), K/eTh (green) and K/eU (blue); Compound image combination of eU (Figure 6(B)): eU (red), eU/eTh (green) and eU/K (blue); Compound image combination of eTh (Figure 6(C)): eTh (red), eTh/eU (green) and eTh/K (blue); and Compound image combination of ratio (Figure 6(D)): eU/eTh (red), eU/K (green) and eTh/K (blue).

The integrated distributions of all the radioelements above were displayed on the single image. The image color varies the lithologies.

THE COMBINED MAPPING OF AEROMAGNETIC AND GAMMA RAY SPECTRUM DATA

As most of structures are able to control the surficial lithological and lithofacial variation, the GRS data can be used for auxiliary interpretation of regional structures (Zhang 2004). Through the integration of GRS and magnetic Tilt gradient, some inferred structures with inconspicuous gravitational and magnetic characteristics can be deduced from the images (Figure 7).

RESULTS

Rapidly deducing lithological map is mainly to classify lithology and delineates geological bodies' boundaries by Ternary MAP. Firstly classifying the major lithological units according to radioactive differences displayed on the compound images and then for further subdividing based on the compound images of K, eTh and eU respectively as well as the ratios (Figure 6).

Magnetic body boundaries and faults can be confirmed primarily based on the aeromagnetic raw and converted images (Figure 4), secondly geological, spectrum and magnetic field integration maps (Figure 7). They were delineated with the gradients of RTP map, the zero value curves of RTP-VD1 and signal analysis.

In this study, when the geological bodies' distribution on the 1:100,000,000 old geological map (Figure 1) was in

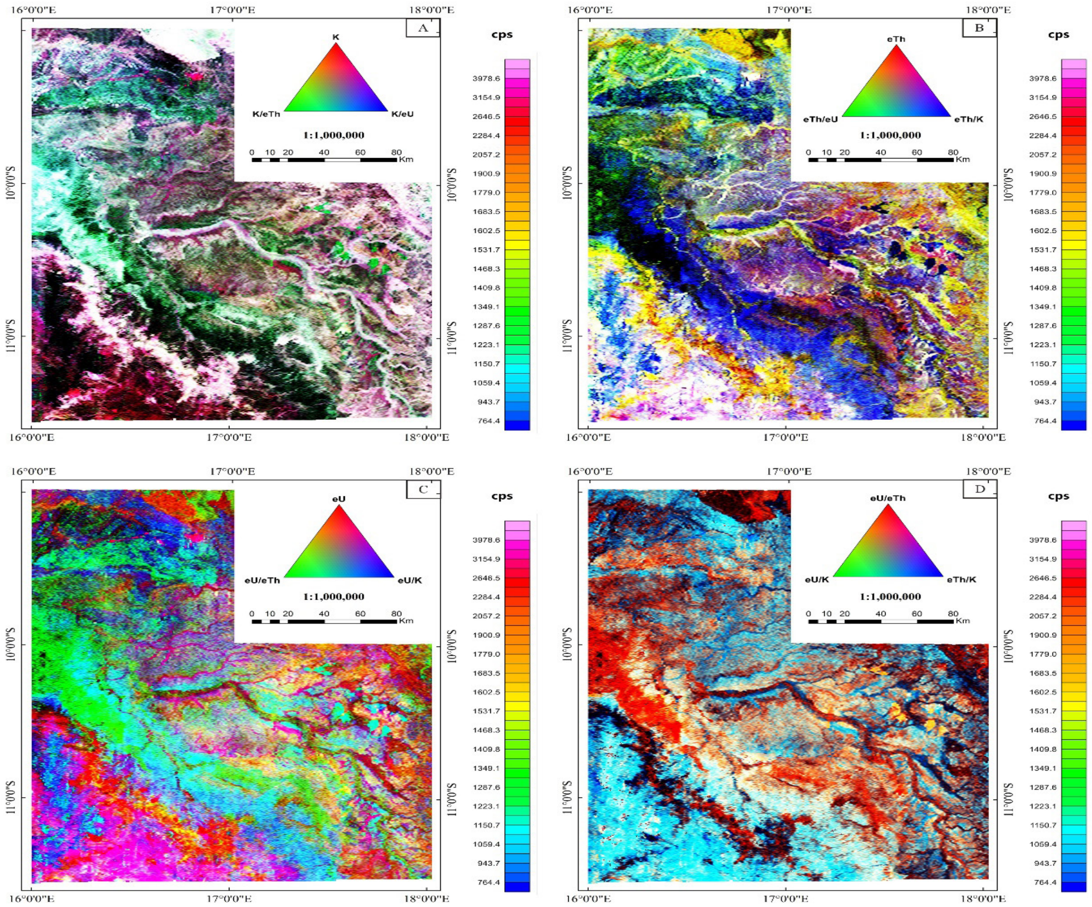

FIGURE 6. Ternary map of different image combination of research map: A. Potassium composite image; B. Uranium composite image; C. Thorium composite image; D. Radioelement ratio composite image

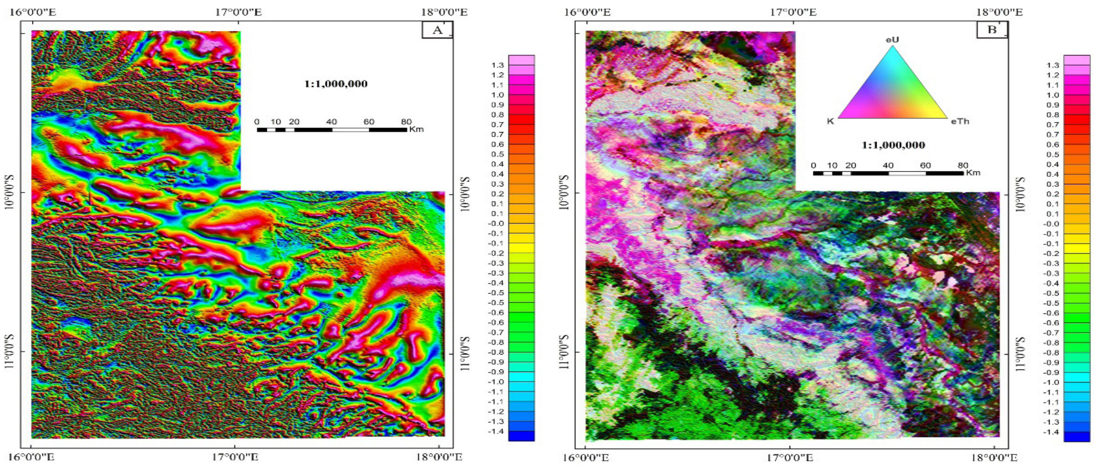

FIGURE 7. Shallow merge map of Ternary and Magnetic Tilt gradient of research area: A. Tilt gradient map of aeromagnetic filed; B. Shallow merge map of Ternary and Magnetic Tilt gradient

a good corresponding relation with the image combination on Ternary Map, the original geological bodies' lithologies would be preserved. When the distribution or outcropping was different from the image combinations, particularly lithological or lithofacial variation for large scale of geological bodies, the manifest physical differences would be delineated and detailed by using Ternary MAP. Re-delineating would be conducted when geological boundaries varied ternary MAP more obviously (Figure 8).

Discussion

EFFECTIVELY IDENTIFYING DIFFERENT LITHO LOGICAL UNITS

Geological bodies vary rock compositions, mineral components and structure characteristics, this variation can be reflected by physical properties in the geophysical field. Therefore, airborne prospecting can be used to accurately distinguish geological bodies with significant differences but barely to do with little or no physical differences. The lithological-structural map reflects the distribution of different rocks and combinations but except for a certain stratigraphic unit. This is different compared with geological mapping.

However, given the unique characteristics between stratigraphies and rock bodies formed in different geological periods, they also can reflect the differences and regulations of physical property, therefore, some mapping units based on airborne prospecting tend to be identical or similar to practical geological units.

Just because of this, the lithological-structural map abstracted from Ternary Map with significant practicability can solve many geological problems in the geological field, even rare or unsolvable problems like shallow overburden and hidden geological bodies.

The compound images of K, eTh, eU (Figure 5) and the ratio compound image (Figure 5d) with consistent extents on old map (Figure 9) facilitate to identify the distribution of Group Kwango (Figure 8) compared to the 1:100,000,000 geological map of Angola (Figure 1).

Pre-Cambrian stratigraphy on the radioelement compound image (Figure 5) as example is mainly in white but in pink and pinkish purple (Figure 5) in shallow overburden areas, where the white indicates the relatively low contents with obvious boundaries, they distributed in the middle and northwest of the research area, mainly expanded with North-West direction (Figure 8) and were dominated by Group Xisto-Gresoso, Neoproterozoic (R_3-V*xg*) and Upper Group, Paleoarchean (AR_1^2).

EFFECTIVE IDENTIFICATION AND CLASSIFICATION OF INFERRED FAULTS

Most of faults are obviously reflected on the aeromagnetic and Gamma Ray Spectrum fields. In this study, the lineated characteristics were refined from the aeromagnetic and gamma ray spectrum fields as faults, combining with known geological information, these faults were effectively classified and confirmed with direction and extent and furtherly inferred their properties, improved and accomplished the deficiency of existing geological documents (Figure 8).

It is worth noting that geophysical materials reflect the most obvious differences of faults' belt. Therefore, it is not necessarily consistent with the geological faults' positions. The faults on the lithological-structural map are certainly reflected on the aeromagnetic and spectrum (Milligan & Gunn 1997).

The F7 (Figure 10) is a banded negative anomaly on the RTP map, with a notable North West direction; the linear anomalies are more significant and the anomaly tilt largely on VD1 and Residual-RTP; Combined with the airborne gamma ray spectrum map and previous geological materials, F7 extended to North-West of Angola and dissected Congo Craton and Okavango Craton from North to South. It is estimated that a deep fault cut the magnetic basement, and this discovery is significant for studying Angolan tectonics and worthy for further work.

Conclusion

Airborne prospecting data play an important role in the lithological mapping of magmatic, intrusive and metamorphic rocks, as well as faults classification and delineation of volcanic structures. Particularly available for inferred information in the overburden area, and effectively enhances the high-tech degree and efficiency for regional geological survey.

The application of Ternary Map of high precision airborne gamma ray spectrum data, and combining different single element spectrum and ratio compound images can obtain the characteristics of various multiple compound images. This facilitates using the subtle differences of radioelement contents and ratios to distinguish and delineate the lithological units. Aero geophysical data is also obviously helpful in classifying faults and delineating magnetic geological bodies. The integrated interpretation of the two types of data may reduce the multiple-interpretation property of the prospecting method by fully tapping into the multiple measuring parameter performances, with unique feature for significantly increasing the precision in rapid mapping.

It has been approved in practice that airborne prospecting is a simple, convenient and rapid auxiliary geological mapping method for rapid deduction of geological mapping. It can be used to distinguish lithologies with certain physical nature differences and reduce the workload due to few occurrences, thus increase the precision of geological mapping. The inferred geological map obtained by this method may well correspond with the lithological units of the geological maps and with better reliability and reasonability.

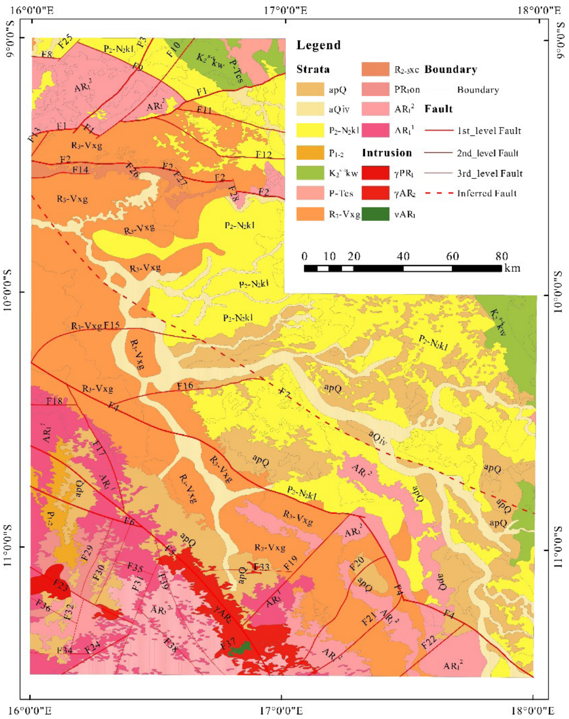

FIGURE 8. Rapidly deduced map based on Ternary research map

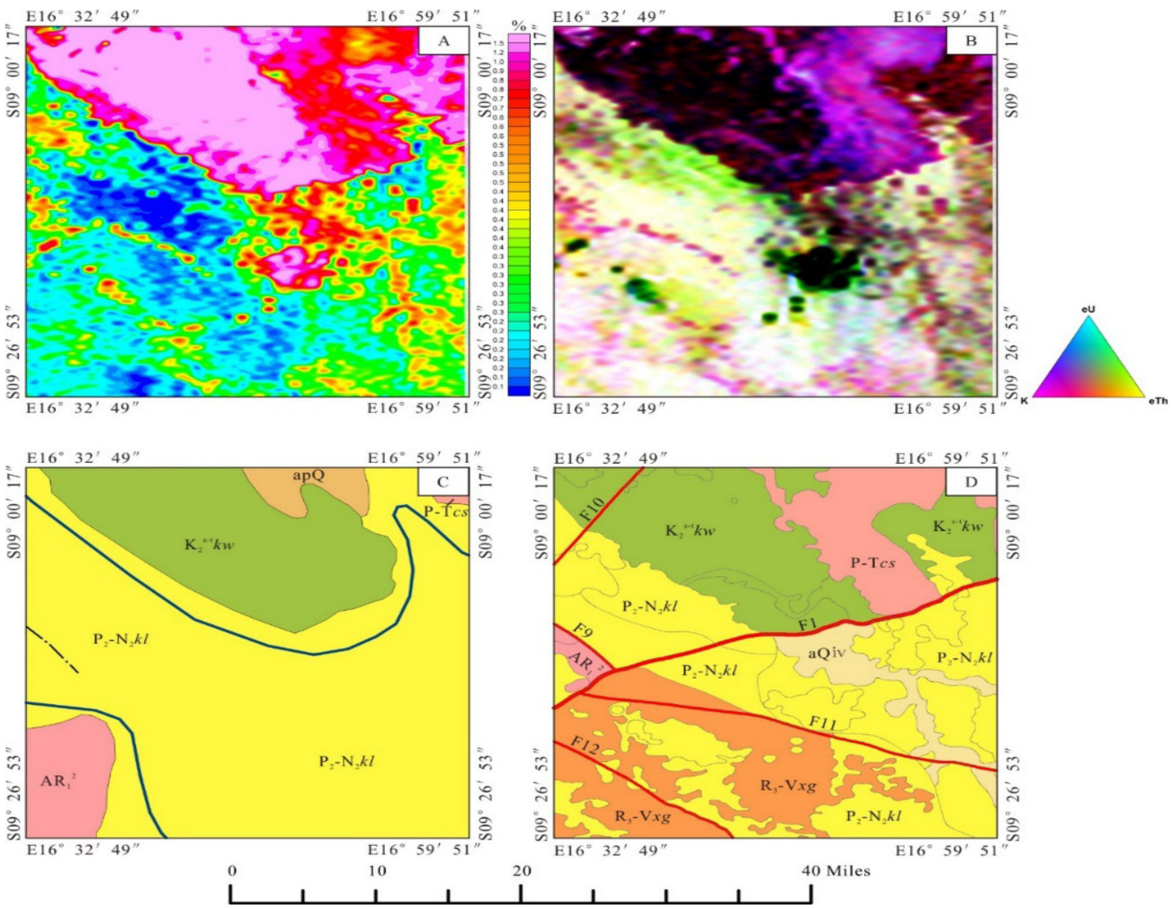

FIGURE 9. Inferred sketch map of Formation Kwango based on radiometric field:
A. Potassium content map; B. U-K-Th Ternary map; C. Geology map; D. Inferred lithology-structure map; Note: AR_1^2 - Upper Group,Plaeoarchean; ; R_3-Vxg - Group Xsito-Gresoso; P-Tcs - Group Cassange; $K_2^{s\text{-}t}$kiw - Formation Kwango; P_2-N_2kl - Group Kalahari; apQ - Alluvial-Proluvial Deposit, Quaternary; F - Fault

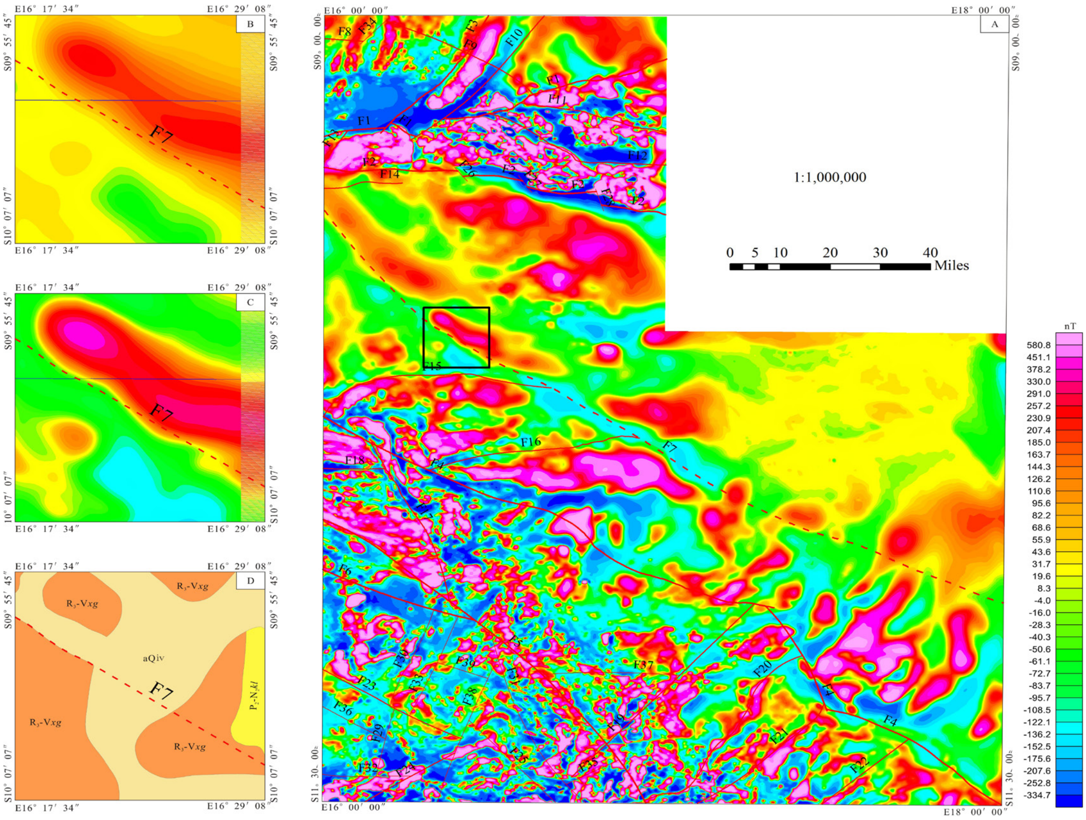

FIGURE 10. Sketch map of F7 hidden fault inferred by airborne prospecting: A. CITIC-4 regional aeromagnetic residual RTP plane contour map; B. F7 fault RTP plane contour map; C. F7 fault aeromagnetic first vertical derivative plane contour map (VD1); D. Geological mapping. Note: R_3-Vxg Xisto-Gresoso Group; P_2-N_2kl Kalahari Group; aQiv-Quaternary alluvium; F7-Fault

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