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# Geophysical-Geological Integration Map the of Boa Vista Grid (NA.20-X-D), Central Portion of Roraima state, Brazil.

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## Abstract

The map Boa Vista chart (NA.20-XD) is part of Geophysical-Geological Integration Project of Northern Amazon (PIGG-NAM) which includes ten maps charted at a scale of 1:250,000, covering the south-central portion of Roraima and northeast of the Amazon, over an area of 181,500 km². The integrations involved geophysical data from Eastern-Central Roraima project (CPRM – 2011), geological reports arising from doctoral theses and mapping reports. This region arouses the exploratory interest of enterprises by the occurrence of rare-earth elements, titanium, gold, phosphate, diamond, columbite-tantalite, cassiterite, among other mineral commodities.

## Introduction

In the last decade the country, through the Geological Survey of Brazil – CPRM, has been conducting airborne geophysical survey (magnetometry and gammaspectrometry) covering 95% of the Brazilian crytalline basement. It aims to increase the cartography and geological knowledge of areas where traditional mapping finds complicators such as difficulty in logistics displacement, rainforest conditions, Indian lands, scarcity of outcrops and weathering mantle.

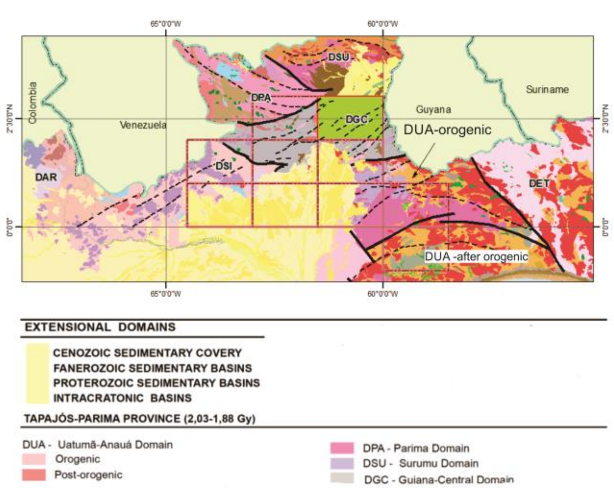


Figure 1 - tectonic context of the state of Roraima, Guiana Shield. In red, articulation of the maps 1: 250,000 Geological-Geophysical Integration Project North Amazon (CPRM, 2014). In green, the Boa Vista map (NA.20-X-D). (source: Reis et al. 2003) .

The use of such data has strategic role by the low environmental impact, greater control of the territorial situation and hence boost mineral resource in the country.

## Geology

The Boa Vista map is located in the Amazonian Craton, Rio Negro Province, portion that covers the Central Guyana Domain, DGC (Reis et al. 2003; Figure 1), whose geological framework, with ages from Paleozoic to Mesoproterozoic and Phanerozoic, records an arrangement tectonic in NE-SW.

The main unit of the Domain is Rio Urubu-CRU Complex, which includes foliated granitoids and gneisses, whose ages are in the range 1.94 to 1.93 Ga. With the predominace of amphibolites facies rocks, the complex also adds rocks with high metamorfic grade (Barauana Granulite).Para-derived from the Cauarane Group, with minimum age established by the intrusion of sin-colisional granitoids, form lenticular bodies or portions amid the orthogneiss rocks Rio Urubu.

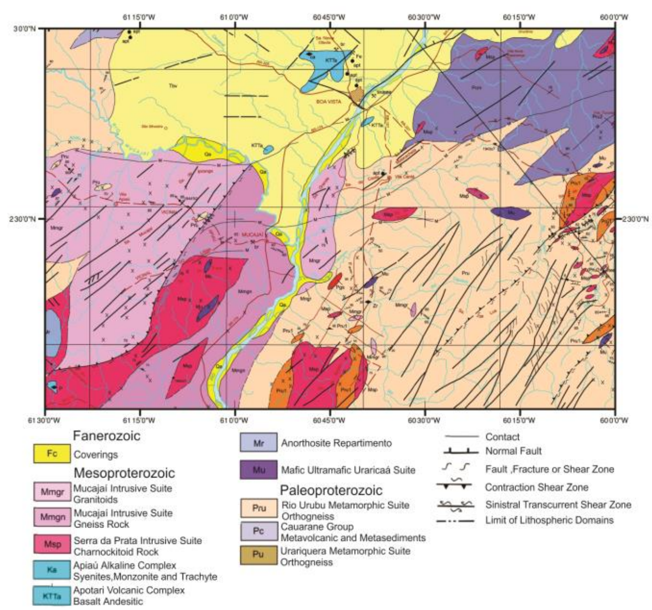


Figure 2 - Geologic Framework of the Boa Vista map (source: CPRM 1999).

The sin-colisinal granitoids, represented on the map by the Granite Curuxuim, contain xenoliths of paragneiss and their age at 1.99 Ga is assigned to that of related bodies from other region of Roraima.

Also occur charnockítes bodies (to the hypersthene and igneous texture) gathered in Serra da Prata Suite, inside the complex. The ages established for the suite indicates the range from 1.94 to 1.93 Ga, common to Rio Urubu lithologies.

Mafic bodies (gabbro and hornblendite), with unknown chronostratigraphic establishment, gather in Uraricaá Suite.

At the extreme west of the map, the CRU is the basement for Mesoproterozoic units that, grouped in geological time, form na anorthosite-mangerite-rapakivi granite complex (AMG; Fraga 2002). The accepted age range for this complex is 1.56 to 1.53 Ma. The interval from 1.43 to 1.42 Ma, gather charnockites and rapakivi granite of Serra Grande region (Santos et al. 2011).

At the Phanerozoic, there are the basaltic and andesitics flows of the Apoteri Formation (Ar-Ar at 150 Ma;. Reis et al, 2008) related to the opening of the Tacutu Graben.

A wide Cenozoic sedimentary cover related to Boa Vista Formation and deposits of wind and alluvial dunes, complete the geological setting of the map Boa Vista (CPRM, 2014).

## Data

There were used the Oasis Montaj 8.3 and 10.2 Arcgis software, for quality control and raw data processing.

The grids (CPRM, 2014) were provided with 125 m of unit cells, which is ¼ of the spacing between the flight lines. The data were resampled to the database and interpolated in regular meshes by the two-way method with cells of 100 m, which is the new value of resolution.

In intent to highlight the geological features, fixes have been applied in order to decrease the variations in the acquisition and pre-processing of data (Reeves, 2005). Among the fixes is the micro levelling by employing the algorithm Blum (1999) and Minty (1991) technique . The remaining steps are summarized in the flowcharts of Figures 3 and 4.

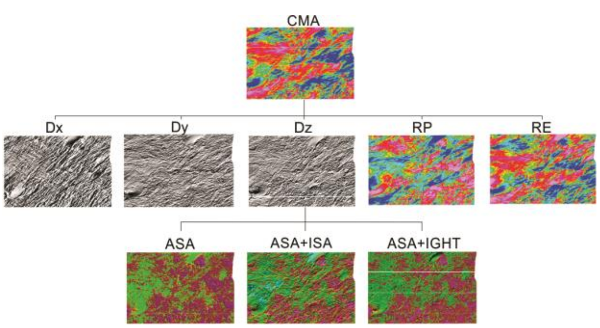


Figure 3 – Flowchart processing of Magnetometric data where: CMA (Anomalous Magnetic Field), DZ (Vertical Derivative), DY (Horizontal Derivative Y), DY (Horizontal Derivative X), RP (Reduction to Pole Magnetic), RE (Reduction to Ecuador Magnetic) and ASA (Analytical Signal Amplitude). Grids with composition of more than one product as ASA color with the ISA texture (Analytical Signal Slope) and ASA color with the texture of IGHT (Tilt the Total Horizontal Gradient).

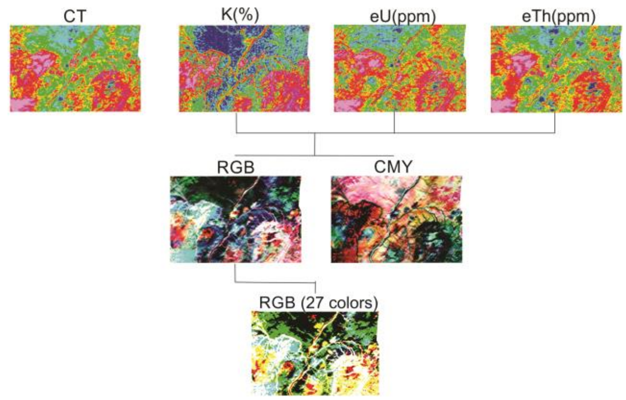


Figure 4 - Flowchart processing of gamma ray spectrometric data where: TC (Total Count), K (Potassium Channel), eU (Channel Uranium), eTh Channel (Thorium), RGB (Ternary, where red is Potassium, green is Thorium and Blue is Uranium), CMY (Ternary, where cyan is Uranium, magenta is Potassium and Yellow is Thorium) and RGB 27 colors (Simplified Ternary).

In the images shading and false color techniques were employed, which assisted in the qualitative interpretation.

## Methods

### Magnetometry

Geophysical method in that measures the Earth's magnetic field. This tool is used in mapping to characterize structures and kinematic features that present susceptibility contrast. With the information listed on magnetometry's flow chart (Figure 3), the lineaments and magnetic fields were extracted.

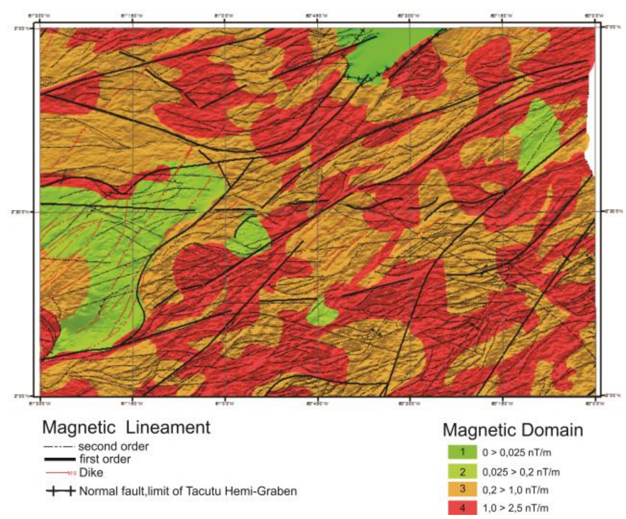


Figure 5 - Interpretation of magnetic domains in four intervals, magnetic lineaments classified into first-order and dikes into second-order. Featured, an extension of failures that delimit the Tacutu Graben.

### Gammaspectrometry

Geophysical method in that uses gamma radiation naturally present in the composition of the rocks.

The gamma ray spectrometric data (Figure 4) were submitted to statistical methods that allowed to define anomalous values and normalize potassium (K%), thorium (eTh in ppm) and uranium (eU in ppm) channels, thus defining high, average and low concentrations standards (Figure 6).

Traditionally, works with ternary images with 24 bit per pixel, resulting 256 ($2^3$ x $2^3$ x $2^2$) different possible color tones for each gamma domain to be interpreted.

An adaptation of the method is to simplify the palette of colors so that each channel (potassium, thorium and uranium), present only 3 colors:

- 1-Low
- 2-Middle
- 3-High

Each tonality is directly correlated with the concentration of the element in the channel, for this, the gamma ray spectrometric data (Figure 4) were submitted to statistical treatments which allowed to define anomalous values and normalize potassium (K%), thorium (eTh in ppm) and uranium (eU in ppm) channels, thus defining the high (3), medium (2) and low (1) concentration ranges (Figure 6).

With the new three colors palette, the domains limits are well defined and the direct relationship with the concentrations of the element in each channel allows a quick quantitative analysis.

It was decided to use the ternary map of false-color RGB simplified with the 3 colors palette, presenting only the spectrum of 27 shades (3 x 3 x 3), ie, for each channel there are three colors possibilities (high, middle and low) and their combinations can generate 27 different colors and concentrations as shown in table 1 and table 2, respectively.

*Table 1 - Combination RGB (3 x 3 x 3).*

| GAMAESPECTROMETRY CHANNELS [K]* | [eTh]* | [eU]* | COMPOSITION R.G.B** | COLORS |
|---|---|---|---|---|
| 1 | 1 | 1 | R= 0; G= 0; B= 0 | 111 |
| 1 | 1 | 2 | R= 0; G= 0; B= 128 | 112 |
| 1 | 1 | 3 | R= 0; G= 0; B= 255 | 113 |
| 1 | 2 | 1 | R= 0; G= 128; B= 0 | 121 |
| 1 | 2 | 2 | R= 0; G= 128; B= 128 | 122 |
| 1 | 2 | 3 | R= 0; G= 128; B= 255 | 123 |
| 1 | 3 | 1 | R= 0; G= 255; B= 0 | 131 |
| 1 | 3 | 2 | R= 0; G= 255; B= 128 | 132 |
| 1 | 3 | 3 | R= 0; G= 255; B= 255 | 133 |
| 2 | 1 | 1 | R= 128; G= 0; B= 0 | 211 |
| 2 | 1 | 2 | R= 128; G= 0; B= 128 | 212 |
| 2 | 1 | 3 | R= 128; G= 0; B= 255 | 213 |
| 2 | 2 | 1 | R= 128; G= 128; B= 0 | 221 |
| 2 | 2 | 2 | R= 128; G= 128; B= 128 | 222 |

| GAMAESPECTROMETRY CHANNELS [K]* | [eTh]* | [eU]* | COMPOSITION R.G.B** | COLORS |
|---|---|---|---|---|
| 2 | 2 | 3 | R= 128; G= 128; B= 255 | 223 |
| 2 | 3 | 1 | R= 128; G= 255; B= 0 | 231 |
| 2 | 3 | 2 | R= 128; G= 255; B= 128 | 232 |
| 2 | 3 | 3 | R= 128; G= 255; B= 255 | 233 |
| 3 | 1 | 1 | R= 255; G= 0; B= 0 | 311 |
| 3 | 1 | 2 | R= 255; G= 0; B= 128 | 312 |
| 3 | 1 | 3 | R= 255; G= 0; B= 255 | 313 |
| 3 | 2 | 1 | R= 255; G= 128; B= 0 | 321 |
| 3 | 2 | 2 | R= 255; G= 128; B= 128 | 322 |
| 3 | 2 | 3 | R= 255; G= 128; B= 255 | 323 |
| 3 | 3 | 1 | R= 255; G= 255; B= 0 | 331 |
| 3 | 3 | 2 | R= 255; G= 255; B= 128 | 332 |
| 3 | 3 | 3 | R= 255; G= 255; B= 255 | 333 |

* concentration index gamaespectrometry
1 = low 2 = middle 3 = high
** channels concentration R.G.B

*Table 2 - Concentration Ranges of Boa Vista Map.*

| Concentration of eU(ppm) | | Concentration of eTh(ppm) | | Concentration of K(%) | |
|---|---|---|---|---|---|
| 1-Low | < 0.93 | 1-Low | < 5.68 | 1-Low | < 0.065 |
| 2-Middle | 0.93 - 1.57 | 2-Middle | 5.68 - 10.21 | 2-Middle | 0.065 - 0.37 |
| 3-High | 1.57 < | 3-High | 10.21 < | 3-High | 0.37 < |

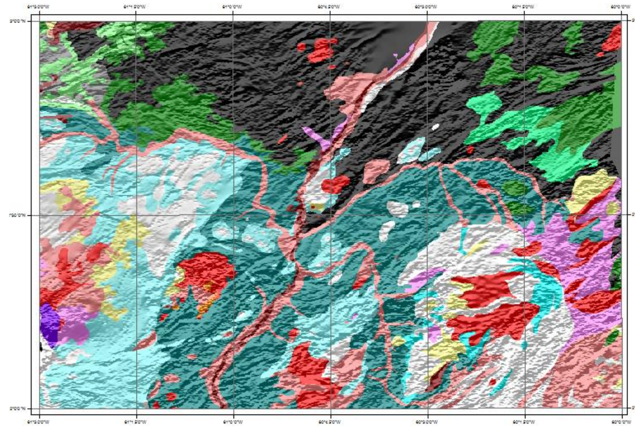

Figure 6 - Interpretation of gamma colorful domains from the combination of colors in tables 1 and 2. Texture of the first vertical derivative (DZ).

**Geophysical-Geological Integration**

The gamma ray spectrometric domains (Figure 5) extracted from the ternary map RGB simplified, consisting of K channels (%), eTh (ppm) and eU (ppm), respectively, are correlated to the data of magnetic domains and lineament (Figure 6), terrain digital images and outcropping rock types which are specific geological data from the CPRM activities.

Anomalous areas were defined from calculated isovalue of anomalous amounts for each channel gamma ray spectrometric and magnetic anomalies, indicating possible areas for prospective purposes

Also, was held compiling geological stations CPRM previous projects in order to develop a database consisted in a GIS environment that would allow adjustments in geological mapping.

Then, extended a phase of field check, where scarce areas outcrops/stations were selected to check for anomalies, proceeding the taking of ground geophysical data (magnetic susceptibility and gammaspectrometry) in order to establish comparable criteria to signatures recognized in the integration of data from airborne survey.

All information was interpreted and finally gathered on maps at a scale of 1: 250,000, published on the site of the Geological Survey of Brazil in December, 2014 (Figure 7).

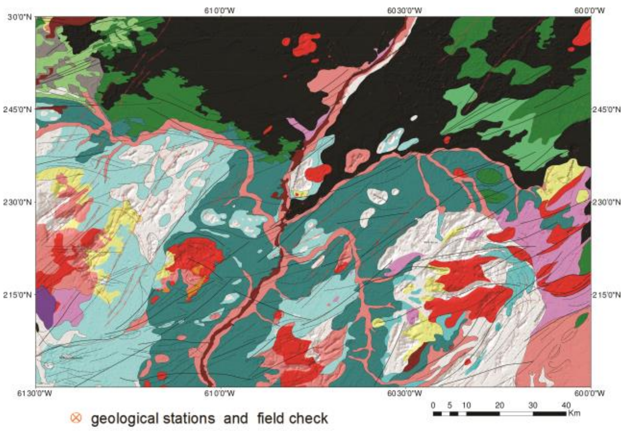


Figure 7 - Geophysical-geological integration map, from information of Figures 5 and 6, with geological information of Figure 2, geological stations and field check. (Simplified map CPRM, 2014)

## Discussion

The integration of geophysical and geological data for the map Boa Vista allowed the identification of gamma ray spectrometric and magnetometric signatures associated with the main geological units which allows establishing standards within them, that would enable subdivision in lithofacies and corresponding dominance areas (Figure 7).

At integration of data, recognized stratigraphic domains showed more than one gamma signature, being indicative to such domain the presence of lithologies subject to receiving compositional differences from the set. However, there is always a subscription that best describes, as a percentage of the area, the geological unit.

The set of procedures and results obtained in geophysical-geological integration of Boa Vista map allowed to outline (Figure 8):

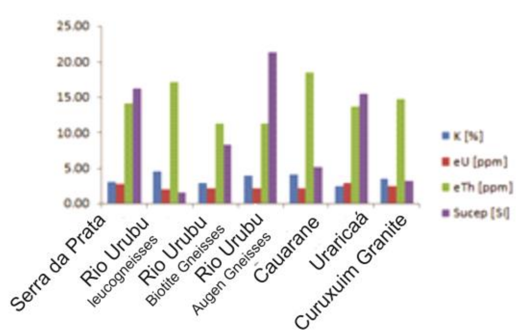


Figure 8 - Graphic with ground geophysics signature to lithounits or facies of the main geological units of Boa Vista map.

Boa Vista Formation (Nbv), easily identified in gamma images, the signature of low concentration of the standard elements (111) and present a smooth texture in SRTM. The magnetic data shows a magnetic field between 3 and 4(Figure 6), texture rough except in the region where is located the Tacutu Hemi graben where the magnetic surface is smooth, but both cases, bodies, structures and lineament has a strong trend in NE-SW direction.

Alkaline Complex Apiaú (J3λa), was charted as an only one body at Central Roraima map (Figure 2), but on integration, we observed a second body, with the same characteristics. Where both bodies are placed together near an lineament in the EW direction and high concentration for three elements, standard (333).

Apoteri Formation (JK1βδap), high magnetic signature, high concentrations of potassium and low concentrations for the other elements, standard (311) show us that the bodies are smaller than was charted at 1: 1000.000 (Figure 2).

Anorthosite Repartimento (MP1δr), were indentified new bodies in the Serra Grande region, with standard (311) and high magnetic. Such signature led us initially the classification of bodies as charnockítes, however, in the field check, the geological descriptions with the terrestrial geophysical survey, made it clear that it was not a charnockítes but anorthosite. Comparing the geophysical signature found with the geophysical signature of the known anorthosite body, next to Serra da Prata, with standard gamma (213) is observed difference in potassium and uranium concentrations.

Mucajaí Suite (MP1 γum_), set out three main groups of gamma signatures (233 333 323), which are mixed with the signatures of the complex Rio Urubu. The magnetic data is what sets the Mucajaí Suite of the other units, since it is in a magnetic field of low intensity, with smooth surface, cut by some dikes in the direction NE-SW.

Uraricaa Mafic-Ultramafic Suite (PP4 μδur), bodies that stand out in the magnetic data, with gamma patterns (121) and ellipsoidal shape.

The Serra da Prata Suite (PP34 γsp) represented by charnockites gathers a signature gamma where the potassium stands out in relation to other elements, with high magnetic domain. The pattern (311) was evident in several situations where outcrops were formed by small lenses within Rio Urubu rocks or large mountain ridges (eg, Serra do Porco). In areas of outcrops scarcity, the gamma standard allowed the progress in the characterization of lithological domain, a role of importance in areas where different sets of rocks show up tectonically superimposed (eg, Serra Cigana).

In more complex units such as Rio Urubu (PP3r-), the interpretation of the varied signatures represents a major challenge. However, it was possible to differentiate four facies, which leucogneisses stand out by the gamma standard and geological association with the Serra da Prata charnockites.

Cauarane Group (PP3ca), initially recognized in the Serra region of the Moon with gamma signature standard from complex Rio Urubu (133). At check in the field, we identified that the Serra da Lua belongs to the Rio Urubu unit with the gamma standard (333), with lenses of Caurane unit with standard (133).

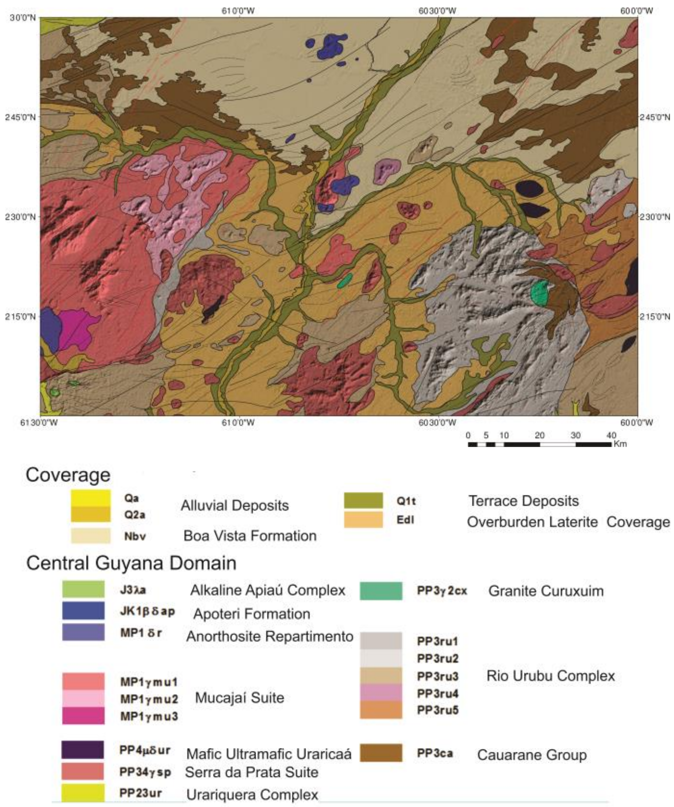


Figure 9 - Map of PIGG-NAM's suggestions for future geological maps.

**Conclusion**

The geophysical-geological integration allowed the joining of information in a single database (GIS), which was added elements of different work scales.

The geophysical-geological data integrations for the Boa Vista map allowed the identification of gamma ray spectrometry and magnetometric signatures associated with the main geological units, establishing standards within them that would enable subdivision in lithofacies and corresponding areas of dominance.

New bodies were delimited in areas with scarce outcrops, where the gamma standard allowed the progress in the characterization of lithological domain, a role of great importance in areas where different sets of rocks show up tectonically superimposed.

The final product of the studies (Figure 8), is not intended to create a new geological map but instead, a map with geophysical information correlated with geological information that can put forward suggestions and inconsistencies. Providing knowledge and subsidy to the selection of sites for detailed geological mapping and mineral prospecting.

The next stages of work include geophysical studies by geologic unit to better classifying their facies, weathering influences and evaluation of anomalous areas for mineral exploration.

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