Geology

Remote Sensing Results of Gujareti-Khachkovi Ore Field (Adjara-Trialeti Folded Zone, Lesser Caucasus, Georgia)

Giorgi Mindiashvili[*], Keti Benashvili[**], Davit Makadze[*], Mirian Makadze[*], Vakhtang Bluashvili[§], Nika Momtselidze[**]

[*]*Department of Geology, Ivane Javakhishvili Tbilisi State University, Tbilisi, Georgia*
[**]*Department of Applied Geology, Georgian Technical University, Tbilisi, Georgia*
[§]*Department of Geo Engineering, University of Liege, Liege, Belgium*

(Presented by Academy Member Davit Shengelia)

This paper consists of interpretations of more than 40 data obtained by remote sensing analyses and techniques in order to detect geological features and potential of probable Gujareti-Khachkovi ore fields in the area located in South-East Georgia (Adjara-Trialeti folded zone, Lesser Caucasus) using Terra ASTER Multispectral satellite data. Technical specifications for the ASTER data used are as follows: Granule ID: AST3A1 0409160806091107270062, Processing Level: 3, Acquisition Date: 20040916, Scene ID: [171, 87, 1], Processed Bands: "01023N3B0405060708091011121314", Cloud Coverage: 2. According to the conducted works it was determined, that magmatic processes and hydrothermally altered zones have important roles within the frame of the studied area, which are represented by pyritized, oxidized and silicification rocks. These rocks are often highly fractured and cemented by quartz and quartz-gold veins of various sizes, shapes and orientations. Obviously, hydrothermal alterations and mineralization types cannot fully reflect the current geological processes of the study area, but as conducted works show, ore mineralization processes are genetically related to the magmatic activities of the region. *© 2023 Bull. Georg. Natl. Acad. Sci.*

ore field, remote sensing, hydrothermal alteration, pyritized, Gujareti-Khachkovi

In the Gujareti-Khachkovi ore field, targeted geological work has been carried out since the beginning of the fifties of the 20th century. In 1952-1954 Khachkovie's gold manifestation was studied in detail by V. Fantskhava. Conducted works on the Gujareti object started in 1955. In 1956-1959 started the above-mentioned work by G. Egadze. Prospecting work in the Gujareti-Khachkovi ore field was resumed in 1971 by B. Bregvadze and D. Arevadze. In 1980-1985, M. Tskhelishvili conducted exploration works in the Gujareti-Khachkovi ore field. In 2001 I. Narozauli and M. Gagnidze conducted research on the Dzama-Gujareti ore field. The study area is quite intensive in terms of vegetation, snow, glacier and cloudiness. Therefore, the best satellite data among all ASTER images have been ordered that could represent the area the best way and, which has the least snow and cloud cover. The acquisition date of the satellite data is 24.11.2021. It is noticeable that although the time of acquisition is autumn season, excess snow covers still remain on mountain tops. The ASTER image used in this study has approximately 2% cloudiness, 20% vegetation and 35% snow cover in the whole region. In this very highly vegetated territory, there have been detected different rock types covering 10% of the study area and lithological descriptions, mineral mapping techniques and analysis towards determination of geological features have been made. Ground truth studies on license area should also be made after all these analyses have been performed to check for the anomalies observed. Since the area is actually too small to run for such processes, all analyses have been carried out using the full ASTER image to detect all other geological features available in the region. Adjara-Trialeti was formed as a rift zone by the end of the Cretaceous, developed during the Paleogene, by the end of which it underwent folding [1, 2]. It is mainly constructed by trachytic and trachytic-andesitic volcanogenic-sedimentary rocks, though plutonic rocks also play an important role in the structure, which are mainly represented by syenite, monzonite and gabbro. Based on modern research data, syenite-trachytic magmatic activity can be developed at subduction zones [3], mantle plume activity regions [4], post-collisional tectonic areas [5] and also continental rifting environments. In all cases, formation of this type of magmatism is determined by the influence of the mantle magma on the lithosphere and the subsequent processes of hybridism, assimilation and metasomatism. Plutons of Adjara-Trialeti folded zone form different types and scale bodies that cut igneous sedimentary rocks. According to paleontological data, the volcanic-sedimentary formations are dated by middle Eocene. Some researchers think that Adjara-Trialeti zone plutonic bodies are synchronous with volcanic activity and therefore consider them as middle Eocene, while others distinguish several phases of intrusion. It is noteworthy that intensive processes of hydrothermal ore mineralization are often developed in the contact zones of igneous sedimentary rocks with plutonic bodies, resulting in formation of the most important ore fields like Merisi, Vakijvari [6], Zoti, Garta-Dzama [7, 8], Gujareti-Khachkovi etc. The object of our research is represented by Gujareti-Khachkovi ore field, which was investigated using Remote Sensing. The research is very important from both scientific and the practical point of view.

Brief Geological Characteristic of the Gujareti Occurrence

In the geological construction medium-fragmented tuff breccia, andesite flows (sheets) and dykes of mafic composition (Middle Eocene) take part. Approximately 80% of the area is covered by volcanogenic rocks which host mineralization. Andesite flows are mainly developed in the Northern and Southern parts and in some localities overlie on hydrothermally altered ore-hosting tuff-breccia's and ore bodies. Rate of alteration of andesite flows is insignificant. They are weakly silicified and propilitized only in the lower parts of the section. Dykes strike is often sub-latitudinal; dykes with sub-meridional strike are rare. Dykes are the least altered geological formations of the area.

Brief Geological Characteristic of the Khachkovi Occurrence

In the construction of Khachkovi ore occurrence Middle Eocene volcanogenic-sedimentary deposits, andesite flows, andesite, diabase and diabase-porphyry dykes, and gabbro diorite minor intrusive take part. The major part of the area (about 75%) is occupied by medium-fragmented tuff breccia and tuff conglomerates. Andesite flows (sheets) crop out mainly on the watersheds, in the Northern and Eastern parts of the area. Khachkovi area is characterized by sharply increased development of dykes among of which, age, petro chemistry and rate of hydrothermal alteration are distinguished with two series due to distribution features. Younger dykes which cross-cut middle Eocene andesite flows and gabbro-diabase minor intrusive, are represented by diabase and diabase-porphyries. Diabase and diabase porphyry dykes are the freshest formations in the area and are not influenced by hydrothermal alteration. Older dykes-andesite dykes are less widespread. They are mainly stretched in sub-latitudinal direction, though there are some dykes of other directions. They are thicker than diabase dykes (from 2.5 to 35m) and more separated spatially from each-other but at the same time they are rather thicker than the diabase dykes (from 2.5 to 35m). Andesite dykes are altered and especially strongly altered within the mineralized zone areas. In our opinion, these dykes are the roots of andesite flows. They even correspond to these flows by their composition. Alteration character in dykes (propylitic, silica, sericite, overprinted pyrite alteration) is similar to alteration observed in andesite flows from mineralized zone wall rocks (contacts), but in the latter alteration is weaker and becomes less in lateral direction from the contact and in the way-up section. Dykes and flows (sheets) of andesites are pre-mineralization formations. Andesite flows usually serve as screens for mineralization and hydrothermal mineralization dies out in them.

Method of Study

Terra ASTER satellite data have been developed for the detection of geological features on earth. According to the purpose of the study, several data can be detected about the area performing numerous analyses. Therefore, remote sensing method and analyses show differences depending on the purpose [9-11]. The whole ASTER image has been investigated and several analyses towards the determination of lithological differences and mineral mapping have been performed. Besides, several analyses have been carried out using different algorithms in order to reveal some details towards structural elements and to interpret the formation type of this study aims at exploring gold mine and related geological features in the proposed Gujareti-Khachkovi ore fields. Investigations performed are not directly related to analyses to reveal metallic minerals but to understand the environment of formation of the considered mine deposit. In addition to this, methods related to reveal the alteration of mineralogy and environment of formation have been applied too [12, 13]. ASTER data have three types of spectral bands as VNIR (visible near infrared), SWIR (short wave infrared) and TIR (thermal infrared) [14-17]. At first, these spectral bands have been added to each other to obtain one full data set. ASTER data have then been subjected to atmospheric correction processing in order to eliminate moisture content and particulars available in the air which could negatively affect the analysis. Then satellite image has been georeferenced adding UTM (Universal Transverse Mercator) and datum as WGS 84 system in zone 38. After preprocessing, certain international standards of remote sensing analysis and algorithms specially developed for mine exploration have been performed in all investigations. [18, 19] since majority of the area is intensely vegetated and covered with snow and wetlands those regions have not been used in image analysis and are eliminated. Therefore, vegetation, snow, cloud and wetlands have been masked. Only areas where rocks are observed on images were selected and image processing was performed. Thus, lithological and mineralogical [20, 21] features belonging to rocks observed in very narrow areas have been investigated. In doing so, regions where these features show continuity have been determined and interpretations have been made according to these areas. Therefore, not only the study area but the whole territory on the full image has been investigated.

Image Analysis and Results

It should be noted that the study was conducted for the first time in the study area by remote sensing

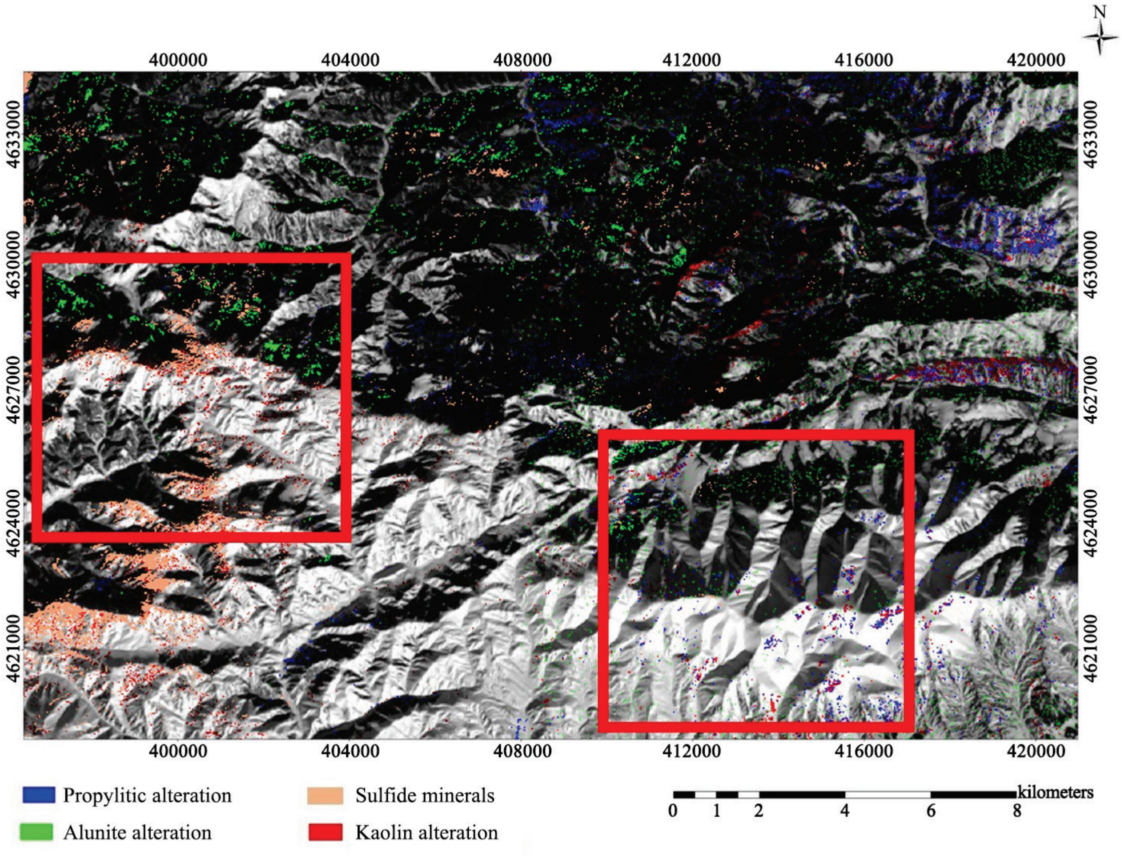

Fig. Complete picture of the survey conducted by the remote sensing method.

method. Obviously, hydrothermal alterations and mineralization types cannot fully reflect the current geological processes of the study area, but as conducted works show, ore mineralization processes are genetically related to the magmatic activities of the region. Remote sensing method, hydrothermally altered zones were distinguished and the areas of geochemical anomalies were contoured (Figure).

Conclusion

As conducted works show the data obtained by the method of remote sensing literally repeats the contours of the existing manifestations. Importantly, several new significant mineralization zones were identified using this method. Based on the interpretation of the conducted studies, we think that special attention should be paid to the northern side of the research object. In the end, we note that in the future, it is necessary to carry out complex geological works within the Gujareti-Khachkovi ore field, because there are already some data, according to which it is possible to detect a deposit of industrial importance in this region.

This research [PHDF-21-179] has been supported by Shota Rustaveli National Science Foundation of Georgia (SRNSFG).

გეოლოგია

გუჯარეთი-ხაჩკოვის მადნიანი ველის (აჭარა-თრიალეთის ნაოჭა ზონა, მცირე კავკასიონი, საქართველო) დისტანციური ზონდირების შედეგები

გ. მინდიაშვილი*, ქ. ბენაშვილი**, დ. მაქაძე*, მ. მაქაძე*, ვ. ბლუაშვილი§, ნ. მომცელიძე**

**ივანე ჯავახიშვილის სახ. თბილისის სახელმწიფო უნივერსიტეტი, გეოლოგიის დეპარტამენტი, თბილისი, საქართველო*
***საქართველოს ტექნიკური უნივერსიტეტი, გამოყენებითი გეოლოგიის დეპარტამენტი, თბილისი, საქართველო*
§ლიეჟის უნივერსიტეტი, გეო ინჟინერიის დეპარტამენტი, ლიეჟი, ბელგია

(წარმოდგენილია აკადემიის წევრის დ. შენგელიას მიერ)

წინამდებარე ნაშრომი მოიცავს ASTER-ის 40-ზე მეტი მონაცემის ინტერპრეტაციას, რომელიც მიღებულია დისტანციური ზონდირების მეთოდით. კვლევები ჩატარდა Terra ASTER მულტი-სპექტრული თანამგზავრული მონაცემების გამოყენებით, რომლის ტექნიკური სპეციფიკა-ციები შემდეგია: გრანულის ID: AST3A1 0409160806091107270062, დამუშავების დონე - 3, შეძენის თარიღი - 20040916, სურათის (Scene) ID - [171, 87, 1], დამუშავებული ზენდები: "01023N3B0405060708091011121314", ღრუბლებრივი დაფარვა - 2. ჩატარებული სამუშაოების მიხედვით დადგინდა, რომ საკვლევი ტერიტორიის ფარგლებში მნიშვნელოვანი ადგილი უკავია მაგმურ პროცესებს და ამ გზით წარმოქმნილ ჰიდროთერმული შეცვლის ზონებს, რომ-ლებიც წარმოდგენილია პირიტიზებული, გამოჟანგული, გასერიციტებული და გაკვარცე-ბული ქანებით. ხშირ შემთხვევაში, ეს ქანები ძლიერ დამსხვრეული, დანაპრალიანებული და შეცემენტებულია სხვადასხვა ზომის, ფორმის, ორიენტაციის და მცირე გამწეობის კვარცის და კვარც-ოქროიანი ძარღვებით. ცხადია, ჰიდროთერმული ცვლილებები და მინერალიზაციის ტიპები სრულად ვერ ასახავს საკვლევ ტერიტორიაზე მიმდინარე გეოლოგიურ პროცესებს, მაგრამ როგორც ჩატარებული სამუშაოები გვიჩვენებს, მინერალიზაციის პროცესები გენე-ტიკურად დაკავშირებულია რეგიონის მაგმურ აქტივობასთან. უნდა აღინიშნოს, რომ საკვლევ რეგიონში, პირველად ჩატარდა მადნიანი მინერალიზაციის დისტანციური ზონდირებით კვლევა, რომელიც მნიშვნელოვნად ამცირებს მადნიანი საბადოების ძებნა-ძიებაში დახარჯულ ფინანსებს და საგრძნობლად ზრდის ჩვენ მიერ ჩატარებული სამუშაოების ეფექტურობას და საიმედოობას. მიგვაჩნია, რომ აღნიშნული კვლევა შემდგომში ხელს შეუწყობს დისტანციური ზონდირების მეთოდის უფრო ინტენსიურ გამოყენებას და მადნიანი ველების ძებნა-ძიებითი პროცესების ეფექტიანობის ამაღლებას საქართველოში.

REFERENCES

1. Gamkrelidze I. (1986) Geodynamic evolution of the Caucasus and adjacent areas in Alpine time. *Tectonophysics*, 127: 261-277.
2. Duggen S., Hoernle K., Bogaard P. et al. (2005) Post-collisional transition from subduction- to intraplate-type magmatism in the westernmost Mediterranean: evidence for continental-edge delamination of subcontinental lithosphere. *J. Petrology*, 46: 1155-1201.
3. Ashwal L., Torsvik T., Horvath P., Harris C. et al. (2016) A mantle-derived origin for Mauritian trachytes. *J Petrology*, 57: 1645-1676.
4. Chung S.-L., Chu M.-F., Zhang Y. et al. (2005) Tibetan tectonic evolution inferred from spatial and temporal variations in post-collisional magmatism. *Earth-Sci. Rev*, 68: 173-196.
5. Peccerillo A., Barberio M. R., Yirgu G. et al., (2003) Relationships between mafic and peralkaline silicic magmatism in continental rift settings: a petrological, geochemical and isotopic study of the Gedemsa volcano, central Ethiopian rift. *J. Petrol,* 44: 2003-2032.
6. Okrostsvaridze A., Bluashvili D. (2014) Petrology of the Vakijvari sienite plutone and characteristic of their ore field, Lesser Caucasus. Proc. of the 3rd Int. Conf. of Ore Potential of Alkaline Magmatism, pp. 41-43. Turkey, Antalia.
7. Okrostsvaridze A. Sun-Lin Chung, Yu-Han Chang, Gagnidze N., Boichenko G., Gogoladze S. (2018) Zircons U-Pb geochronology of the ore-bearing plutons of Adjara-Trialeti folded zone, Lesser Caucasus and analysis of the magmatic processes, *Bull. Georg. Natl. Acad. Sci.,* **12,** 2: 90-98.
8. Bluashvili D., Benashvili K., Mindiashvili G., Makadze D. (2020) New data on the Dzama-Gudjareti ore knot (Georgia), *Bull. Georg. Natl. Acad. Sci.,* **14,** 3: 94-99.
9. Jong S.M.., Meer F.D.., Clevers J.G. (2004) Basics of remote sensing. In: Jong S.M.D., Meer F.D.V. (eds.) Remote sensing image analysis: including the spatial domain. Remote sensing and digital image processing, vol 5. Springer, Dordrecht. https://doi.org/10.1007/978-1-4020-2560-0_1
10. Yamaguchi Y. & Naito C. (2003) Spectral indices for lithologic discrimination and mapping by using the ASTER SWIR bands. *International Journal of Remote Sensing,* 24: 4311- 432.
11. Van Der Meer, F. (2002) Basic physics of spectrometry. In: F.D. Van Der Meer & S.M. De Jong (Eds.), Imaging spectrometry. Basic principles and prospective applications, pp. 3- 16. Hingham (MA), USA: Kluwer Academic Publishers.
12. Rowan L., Hook S., Abrams M. & Mars J. (2003) Mapping hydrothermally altered rocks at Cuprite, Nevada, using the advanced spaceborne thermal emission and reflection radiometer (ASTER), a new satellite-imaging system. *Economic Geology*, 98: 1019-1027.
13. Alimohammadi M., Alirezaei S., Kontak D.J., (2015) Application of ASTER data for exploration of porphyry copper deposits: a case study of Daraloo–Sarmeshk area, southern part of the Kerman copper belt, Iran. *Ore Geology Reviews* 70: 290–304.
14. Galley A.G., Hannington M.D., Jonasson I.R. (2007) Volcanogenic massive sulphide deposits. In: GOODFELLOW W. D. ed. Mineral deposits of Canada: a synthesis of major deposit-types, district metallogeny, the evolution of geological provinces, and exploration methods. Geological Association of Canada, Mineral Deposits Division, special publication no. 5: 141-161. St. John's, NL, Canada.
15. Hosseinjani Zadeh M., Tangestani M.H., Roldan F.V., Yusta I., (2014a) Spectral characteristics of minerals in alteration zones associated with porphyry copper deposits in the middle part of Kerman copper belt, Iran. *Ore Geology Reviews* 62: 191–198.
16. Mars J.C., Rowan L.C. (2006) Regional mapping of phyllic- and argillic-altered rocks in the Zagros magmatic arc, Iran, using advanced spaceborne thermal emission and reflection radiometer (ASTER) data and logical operator algorithms. *Geosphere* 2: 161–186.
17. Mars J.C., Rowan L.C. (2010) Spectral assessment of new ASTER SWIR surface reflectance data products for spectroscopic mapping of rocks and minerals. *Remote Sens. Environ*. 114: 2011–2025.
18. Ninomiya Y. (2004) Lithological mapping with ASTER TIR and SWIR data. *Proc. SPIE* 5234: 180–190. 19.
19. Ninomiya Y., Fu B. (2002) Mapping quartz, carbonate minerals and mafic–ultramafic rocks using remotely sensed multispectral thermal infrared ASTER data. *Proc. SPIE* 4710: 191–202.
20. Ninomiya Y., Fu, B., Cudahy T.J. (2005) Detecting lithology with advanced spaceborne thermal emission and reflection radiometer (ASTER) multispectral thermal infrared "radiance-at-sensor" data. *Remote Sens. Environ*. 99 (1–2): 127–139.
21. Yujun Z., Jianmin Y., Fojun Y. (2007) The potentials of multi-spectral remote sensing techniques for mineral prognostication — taking Mongolian Oyu Tolgoi Cu–Au deposit as an example. *Earth Sci. Front*. **14** (5): 63–70.

Received December, 2022