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Evaluation of geochemical analyzes in complex geological structures in GIS environment: Maden (Elazığ) district

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Abstract
Geochemical analysis results are one of the most significant indicators that reveal the characteristics of the geological structures in a region. In particular, the differences in the composition of complex geological structures can be evident in field and Geographic Information Systems (GIS) studies. Turkey includes a character consisting of quite complex features with its geological structure. The Maden (Elazığ) complex has also attracted the attention of many researchers with its complex structure. Thematic maps are created to make the geological interpretations in this region cleaner and the field data more predictable. These maps also allow the correlation of major oxides and trace elements. In this study, the geochemical data obtained in the Maden Complex were analyzed in the QGIS program. The geochemistry of the region has been made more understandable and interpreted with heat maps. The diversification of thematic maps, which gives a new perspective to geochemical data, will provide more support to geological studies.

1. Introduction

The Southeast Anatolian Orogenic Belt (SAOB) constitutes the eastern part of the Taurus Orogenic Belt, which is one of the most critical tectonic belts in Turkey, located between the Arabian platform and Anatolian micro-plate (Şengör and Yılmaz 1981; Ertürk et al. 2018, 2022; Sar et al. 2019) This belt is a complicated part of the Alpine–Himalayan Mountain range with numerous distinct characteristics. This region has a complex geodynamic history, with northward subduction and closure of the Tethyan Ocean branch and the collision of various continental blocks. The Southeast Anatolian Orogenic Belt has been studied by many researchers in three belts from south to north (Yılmaz 1993; Yılmaz et al., 1993; Yılmaz 2019). (1) During the period from Precambrian to Early Miocene, the "Arabian Platform" consists of a thick autochthonous sedimentary sequence accumulated in the marine environment together with the base volcanic rocks (2) The "Zone of Imbrication", which occurs in the north of the Arabian Platform, which forms a reverse fault zone developed in the Late Cretaceous-Early Miocene interval, about 5-10 km in width (3) The uppermost central tectonic unit, which includes the Middle Eocene Maden Complex, is the "Nap Zone". These zones are separated from each other by thrust faults. The study area is located north of the Bitlis–Zagros suture zone. It covers the most widespread and the best-observed regions of the Maden Complex, which have an important place in understanding the geodynamic evolution of the region.

Geochemical inputs are applied to clarify many geological problems. One of the powerful practices of these data is statistical and spatial approaches. As it is recognized, many geological studies have been supported by remote sensing and geographic information systems in recent years. These studies are carried out with advanced programs in a computer environment with technology development. Now, many GIS programs are used, and an open source coded QGIS program was used in this study.

The Maden Complex is an extraordinarily significant structure for the geology of Turkey. Major oxide and trace element analyzes were carried out of the samples compiled from the field in this region, which has many complex geological characteristics. The geochemical distribution of this complex region and the relationship between the elements can become more visible with

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thematic maps in the GIS environment. Heat maps of some of the analysis results of the sample points were created, and discussions on the geological structure were prepared.

2. Method

The samples collected from the field study are detected via XRF and ICP-MS methods. The major oxides and trace element analysis detected by Ertürk et al. (2018) was digitized in the GIS environment, and sample points were located. Afterwards, heat maps dwelling on major oxide and trace elements were made.

2.1. Geological Background

The Maden Complex is situated in the Bitlis-Zagros Suture Zone, including the Zone of Imbricate and Nappe Zone. In the study are the Upper Cretaceous Guleman Ophiolite and the Maastrichtian Lower Eocene Hazar Group thrust over the Maden Complex. The Guleman Ophiolite crops widely in the east and southeast of Hazar Lake and presents its most typical outcrops around the Alacakaya-Maden districts. Regarding the formation of the Guleman ophiolites, many researchers have stated that the Guleman Ophiolites are products of the Neotethys oceanic crust that began to open from the Upper Triassic between the Pütürge Metamorphites and the Keban-Malatya massifs (Michard et al. 1984; Yazgan and Chessex 1991; Beyarslan and Bingöl 1991; Turan et al. 1995). The Guleman ophiolites emplaced on the continental crust towards the south with the closure of this ocean in the Late Cretaceous. Rizeli et al. (2016) accept that the Guleman Ophiolite was formed in the fore-arc basin at the beginning of the northward subduction of the southern branch of Neo-Tethys. According to Kaya (2004), the Hazar group consists of a red-brown basal conglomerate at the bottom, and grey, green and light brown coloured sandstone, siltstone, mudstone, shale, marl and limestone towards the top. For the formation of the unit, researchers such as Özkan (1982), Perinçek and Özkaya (1981), and Aktaş and Robertson (1984) stated that the environment initially presented terrestrial conditions. The units at the base of the Hazar group represent this terrestrial environment and are laterally associated with the Simaki Formation. They stated that the deposition basin gradually deepened with block faults, and the formation was deposited under marine conditions. In contrast, the uppermost Gehroz Formation was pelagic limestones deposited in the shelf environment.

The Maden Complex cropped out over extensive regions in the Eastern Taurus. The Maden Complex also contains basalts, basaltic andesite, andesite, dacite, diabase and pyroclastic rocks, which are intercalated and lateral-vertical transitive with all these sedimentary successions (Fig 1). The brecciation is widespread due to tectonism. Also, the region observes intensive alterations depending on the thrusts and imbrications. Basalts largely crop out in the study area. Basalts are generally greenish, brownish and bearded in colour, massive, ellipsoidal-shaped pillow lavas, and broken pillow basalts. Basalts are intercalated mainly with red cherts and mudstones. Basaltic andesites and andesites are in grey colours compared to basalts, and it is challenging to distinguish macroscopically from basalts. However, it is possible to make this distinction according to petrographical and geochemical features. The dacites are macroscopically lighter, grey, whitish, and darker than the mafic volcanics and are fine-grained volcanic rocks. The diabases often cut the basalts. The diabases greenish coloured are medium grained and vary in thickness. The study area represents pyroclastic rocks represented by agglomerate, lapillistone, and tuff. The agglomerates are composed of bombs with a grain size of more than 64 mm, and a cement material welds the volcanic parts. The lapillistones have a basic and andesitic composition. The tuffs are fine grain. Ertürk et al. (2018) reported that the middle Eocene Maden magmatism developed in a post-collisional environment by asthenospheric upwelling owing to convective removal of the lithosphere during an extensional collapse. Yalçın et al. (2020) stated that Cu anomalies in Maden Complex are around Hasenekevleri (Maden-Elazığ) and said that Cu mineralization is in vein type within diabases.

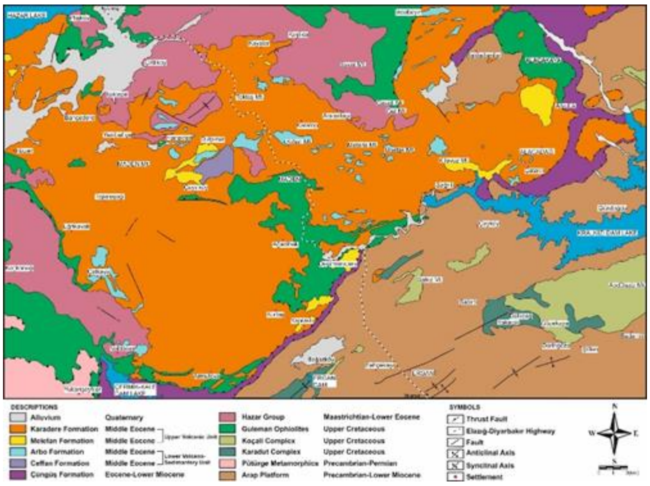

Figure 1. Geological map of the study area (modified from MTA, 2011).

3. Results

3.1. GIS application

Many samples were taken from the field in the petrographic and petrological study by Ertürk et al. (2018). Geochemical analyzes of these samples were carried out and used in many clarifications. In this study, a heat map was prepared in the QGIS program to compare and review the attribute information of the sample points. In Figure 2, it is seen that the major oxide values commonly show a similar distribution in many samples. SiO_2 is an essential component of minerals that make up many rocks. Other oxides (Fig 2) take place in the structure of silicate minerals together with SiO_2. The SiO_2 distribution also summarizes whether the rocks are acidic or basic. Higher values represent acidic rocks, while lower values represent basic and ultrabasic rocks. Except for the northeast of the study area, most basic and near-basic rock groups are observed (Fig 2).

The distribution of some trace elements is given in Figure 3. While Cr, Ga and V have a roughly similar distribution, Cu, W and Rb have different patterns. These differences are due to lithology, mineralogy and geochemical differences. With these studies, the existence of structures with different characteristics should be correlated with field data. Therefore, the information that will be a guide will lead to more meaningful interpretations. Moreover, it is exceedingly challenging to make lithological discrimination in the Maden Complex, where rocks of many different characters are observed closely. For this reason, it is significant to evaluate the data obtained in the field in the GIS environment.

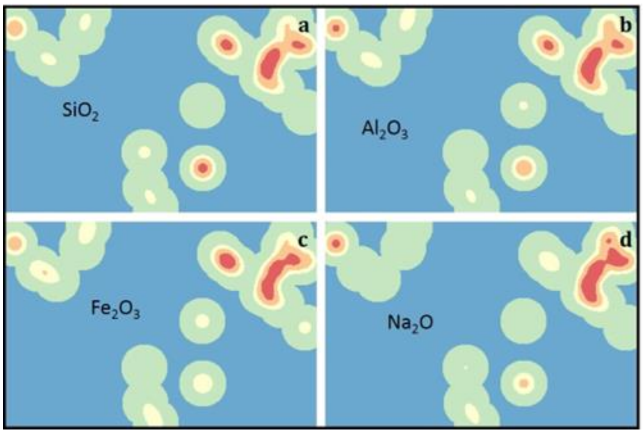

Figure 2. Heat map of the study area via major oxide contents

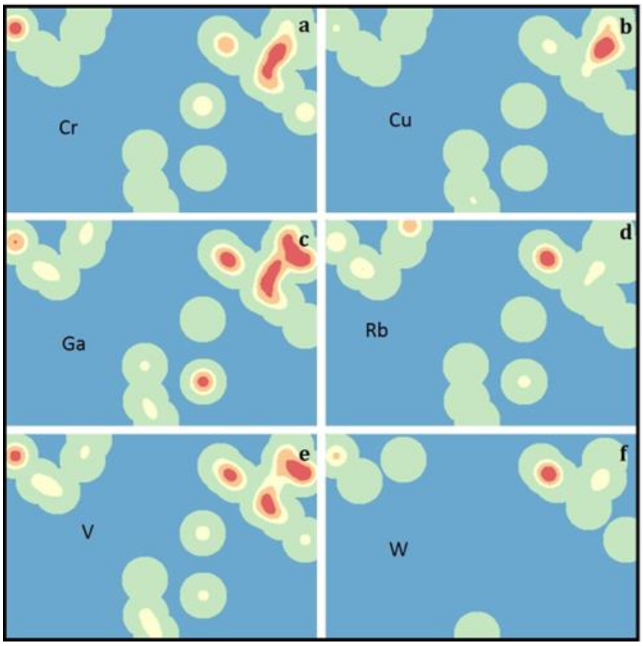

Figure 3. Heat map of the study area via trace element contents.

4. Discussion and Conclusion

GIS-based modelling has been proposed in addition to geology-geochemistry studies (Brown et al. 2003; Partington 2008). This modelling provides the geostatistical approach to the geological structures. For example, Atakoğlu and Yalçın (2021) explained the statistical properties of Sutlegen (Antalya) bauxite according to their geochemical content and set up thematic maps with the Krigging interpolation method.

Mapping minerals, elements or oxides based on multi-source geoscience data (geology, geochemistry, and remote sensing) and computer technology is an effective technique that merges information and data-driven production (Bonham-Carter 1994; Zhao 2002; Wang et al. 2016). For this reason, the data of the study conducted by Ertürk et al. (2018) in the Maden (Elazığ) district were re-evaluated in the QGIS environment. In the evaluations prepared, GIS-based thematic maps correctly exhibit the relationship of the geochemical contents of the study area correctly.

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