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LOCATING OF THE ORE BEARING ZEBRA DOLOMITES BY USING LANDSAT 7 ETM+ AND QUICKBIRD SATELLITE DATA IN HINZIR MOUNTAIN, KAYSERİ, TURKEY

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The aim of this paper is determining the location of the ore bearing zebra textured dolomites by using various satellite data. The necessarry image inhancement and filtering techniques were applied to the sub-images and thematic evaluations were made concerning the studied rock units. Especially PCA 432 and DC 741 composites in Landsat data and Gradient-Sobel filtering technique were found to be very helpful for discriminating zebra dolomites. Nevertheless, the most effective discrimination was made by digitizing the circled karstic hollows and striped lines, which clearly appear in limestones and dolomites respectively. Hydrothermal zebra dolomites were differentiated from the limestones very easily because of their alteration differences. Many circled karstic hollows were seen in limestones, whilst zebra dolomites do not show any circled karstic hollows but parallel lines because of their black and white parallel stripes. The results were checked by ground truth and were supported by obviously different drainage patterns of the studied rocks. The ore bearing dolomite rock is developed in Triassic Hınzır mountain limestones through dolomitization of limestones and recrystalization of primary or early diagenetic dolomites. Zebra-textured dolomite is characterized by alternating layers of fine grained gray-black and coarse grained white dolomite. Worldwide, hydrothermal zebra dolomite (HZD) occurs in carbonate-platform margins in settings with elevated heat flow and extensional faulting. The secondary target of this paper is postulating the origin-source of the mineral enrichments in the study area. Two types of sources were suggested; primarily the brine migration most probably was channeled along extensional SW-NE strike-slip faults and permeable fabric elements in carbonate aquifers in the study area. The ore minerals were emplaced by mineralizing solution circulating in lithified dolomites, so the ores are definitely epigenetic in relation to dolomites. Carbon, oxygen and sulphur isotope studies of the gang carbonates and ore minerals in Hınzır mountain deposits were used to show models of the ore formation. Carbon isotope values of HZD reflect the composition of the seawater when the host rocks were formed. The values of $\delta^{13}C$ (PDB) ranges from +2.4 to +2.7, whilst the $\delta^{18}O$(SMOW) HZD values change just little from 29.4 to 29.5. Additionally, ^{34}S(CDT) isotope values of the analysed sulphure elements change from 8.0 to 18.7. The results of ^{34}S analysis of the sulphide minerals, such as sphalerite, fahlerz and arsenopirite minerals show ocean water originated hydrothermal solution's values as well. On the other hand, the occurences of some chalcopyrite and gold enrichments in ore bulk point out that the ores originated by hydrothermal fluids present in the study area. Therefore two different types of sources were figured out and modelled for the detected ore enrichments.

INTRODUCTION

Hınzır mountain is located in almost central Turkey, just northeast of Kayseri city and covers about 200 sq km (Fig. 1a and 1b). Limestones and dolomites are the main lithologies, whilst some outcrops of calcsilicatic hornfelses located along the main SW-NE fault which cuts the mountains mainly into two parts. Some transported blocks of metamorphic rocks were seen in Boyunbağı region. Additionally, ophiolithic rocks were seen located under the carbonate rock and cropout in very lower levels of the mountain, such as in Manavus and Çukuryurt dere region. Zebra textured dolomites are mainly seen in Aşıçıkan Tepe, Karcaömer Düzlüğü,Tipitutan Tepe, Çukuryurt dere and surroundings. All of these places are closely located to the main SW-NE fault. Hınzır zebra dolomites should have been formed in these tectonically fault system, which created channelways for descending meteoric waters and ascending hydrotermal solutions.

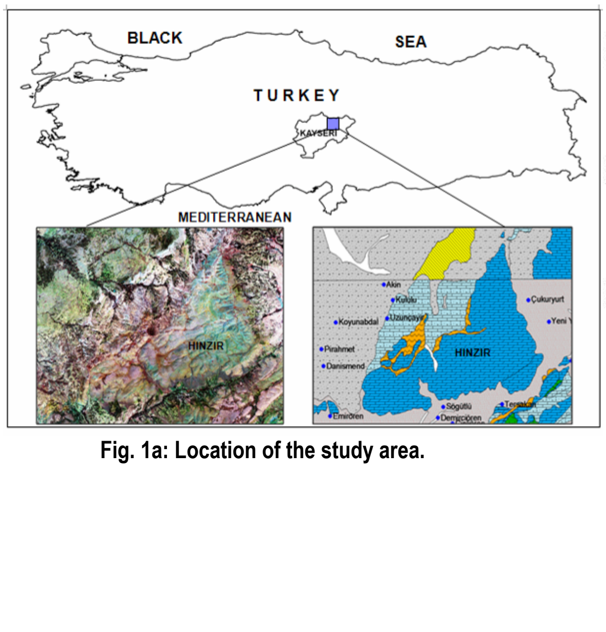

Fig. 1a: Location of the study area.

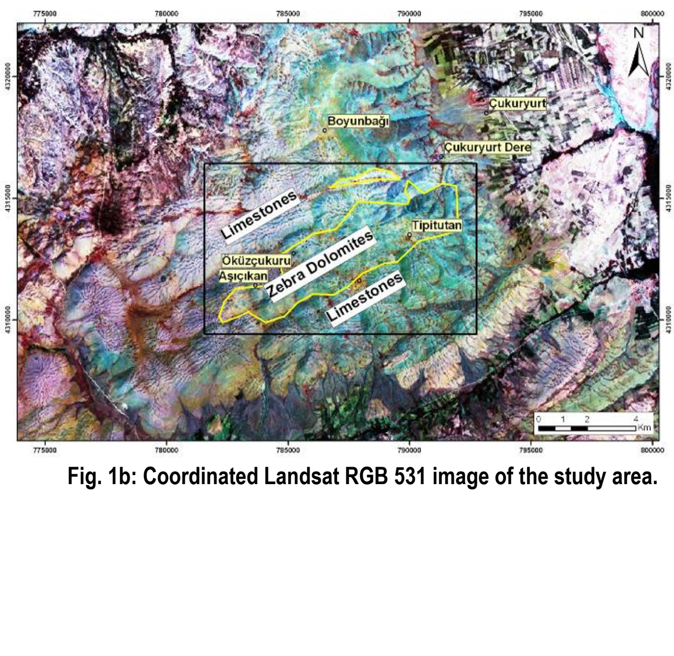

Fig. 1b: Coordinated Landsat RGB 531 image of the study area.

GEOLOGY OF THE HINZIR NAPPE

Hınzır mountain is considered as a Nappe emplaced in post Early Cretaceous (Özer et al.,1984). Crystalized limestones and dolomites are the main lithologies of the mountains during Carboniferous (?) - Early Cretaceous time interval. Permian sediments are represented by dark grey coloured medium-thick layered rarely dolomitized crystalized limestones on the lower levels, and white-gray coloured dolomitized limestone in the middle and Brachiopoda shell, worm traces and Mizzia containing medium-thick layered dark colured crystalize limestones on the top of the serie. The Permian rocks are concordantly covered by 400 meter thick Triassic crystalized limestones in the study area. These units are overlaid by the Jurassic-Cretaceous grey-black coloured, medium-thick layered, folded and crystalized limestones, which contains some red colored lamellibraches in the top part. Ophiolithic rocks outcrop in Manavus and Çukuryurt dere, which are the lowest levels in the study area, whilsts some randomly distributed metamorphic blocks are located in Boyunbağı region. The metamorphic rocks were most probably transported and carried by the Hınzır mountain limestones during the nappe movement. One of the important output of this study is that the Zebra dolomite outcrops, which have never been previously mentioned in previous works. These rocks were seen in many places as having direct contact with many hydrothermal veins.

What is Zebra Dolomites?

Banded carbonate textures formed by rhytmic mm- to cm-scale alternations of dark and white coloured laminae are known as zebra rocks or textures (Engel et al., 1958; Beales and Hardy, 1980). The suggested origin of these banded fabrics ranges from syngenetic and early diagenetic with a strong sedimentary facies control (Fontbote and Amstutz, 1983; Pohl, 1990) to epigenetic (Nielsen et al., 1998; Boni et al., 2000a; Lugli et al., 2000). Zebra banding of magnesite replacing dolomite in the Eugui magnesite deposite (Western Pyrenees, Spain) is described by Lugli et al. (2000) who demonstrate that repetitive replacement textural variations are related to a change in fluid chemistry. Thus, no consensus exists about the origin of these features and it is possible that similar banded textures can be formed under a range of conditions (Wallace et al., 1994; Boni et al., 2000b).

Opinions and interpretations also differ with respect to the exact timing of zebra dolomite development relative to the tectonic evolution. Krebs and Macqueen (1984) suggested that the Pine Point zebra dolomites were formed in the tectonically active McDonald fault system, which created channel ways for descending meteoric waters and ascending hydrothermal solutions. The dispute over this subject has followed the development of ideas on the genesis of similar ores all over the world and has centered on two principal questions: hydrothermal as opposed to non hydrothermal emplacement and syngenetic as contrasted with epigenetic development of sulfides.

There are about 20 sq km area of zebra dolomitized area were detected in the study area, despite of their interfingered appearance with the crystalized limestones. Alteration and texture differences of these two main rocks help for locating these two types of rocks. Many circled karstic hollows were seen in limestones, whilst zebra dolomites did not show any circled karstic hollows but parallel lines because of their black and white parallel stripes (Fig. 2). Zebra dolomites showing not only black and white parallel stripes in the study area but were seen as showing some peculiar textures (Fig. 3).

Fig. 2: Parallel stripes of the Zebra dolomites.

Importance of Zebra Dolomites

Zebra dolomites are often spatially associated with Pb-Zn ore deposits and/or potential hydrocarbon reservoirs in foreland fold and thrust belts (Macqueen and Leckie, 1992). Most of these types of deposits are called as Mississippi Valley-type (MVT) deposits.

Fig. 3: Peculiar shaped Zebra dolomites.

Numerous fluid-inclusion studies have shown that Mississippi Valley-type (MVT) deposits form from saline Na-Ca-Cl fluids at temperatures that generally range between 70 and 150°C (Roedder, 1968; Leach et al., 1975). Most deposits are found in shallow buried rocks at the edges of sedimentary basins (Anderson and Macqueen, 1982). A decade ago, these observations led many economic geologists to conclude that Mississippi Valley-type deposits formed as a result of the expulsion of pore fluids from basinal strata during compaction (Cathles and Smith, 1983).

Beales and Hardy (1980) suggested that the zebra textures in host rocks dolomites from the Gayna river Zn-Pb deposit may have developed by replacement of evaporite minerals. Sass-Gustkiewicz et al. (1982) proposed a replacement model involving metasomatic alteration for the ribbon type Upper Silesian Polish Mississippi Valley Type (MVT) Zn-Pb deposits (Northwest Territories, Canada) as pre-ore saddle dolomite filling dissolution structures after undolomitized remnants of limestone between earlier formed fine-grained dolomite. The stratigraphic equivalents of these rocks are important host rocks for large-scale Pb-Zn and polymetallic deposits in South China (Shen et al., 1987; Wu et al., 1987; Chen et al., 1998).

More recently, migration of fluids due to thrusting and tectonic compression and gravity-driven flow (Bethke and Marshak, 1990) are considered to play a major role in ore genesis. However, the volume of water expelled during thrusting and compression is probably only a small fraction of the total brine volume needed to have formed the large Mississippi Valley-type ore deposits (Ge and Garven, 1992; Garven et al., 1993).

REMOTE SENSING AND GEOGRAPHICAL INFORMATION SYSTEM (RS-GIS) DATA AND METHOD

In the present study, a Landsat 7 ETM+ image taken on 13 June 2000 was used. This image covers about an area of ~ 180*180 km² through UTM-WGS 84, zone 36 and 37 and numbered "175-34" by Landsat. Additionally, 19.06.2006 and 24.06.2006 dated Quickbird data were used and rectified with the 100.000 scaled J36 and K36 numbered topographical maps and GPS points, which were taken during field work. All data were evaluated in TNT Mips 6.9 and Arc GIS 9.1 (Arc Map and Arc Scene) environment. The study area was prepared and discussed from the standpoint of RS-GIS, and some 3D views were prepared as SRTM data in order to understand more clearly the tectonic features of the study area.

All kinds of image processing techniques, such as band combination, band ratios, clay anaysis, iron analysis, crosta, decorrelation streching and principal components analysis were applied in order to discriminate mineralized zebra textured dolomites from the other type of carbonate rocks. Besides some different type of filtering techniques were performed. Furthermore, all visible lines and circle shaped figures on the carbonate rocks were digitized (Figs. 4a,b,c,d). PCA 432 (Fig. 5) and DC 741 composites (Fig. 6) in Landsat data were found to be the best composites, whilst Gradient – sobel type of filtering (Fig. 7) gives the reasonable better image in differentiating zebra dolomites and the other carbonate rocks. Nevertheless, the most effective discrimination were made by digitizing of the circled karstic hollows and stripped lines, which clearly appears in limestones and dolomites respectively. Hydrothermal zebra dolomites were differentiated from the limestones very easily because of their alteration differences.

Many circled karstic hollows were seen in limestones, whilst zebra dolomites didn't show any circled karstic hollows but parallel lines because of their black and white parallel stripes. The results were checked by ground truth and were supported obviously by different drainage patterns of the studied rocks. Some 3D views were prepared in SRTM environment in order to understand the study area and the location of the deposits more clearly (Fig. 8).

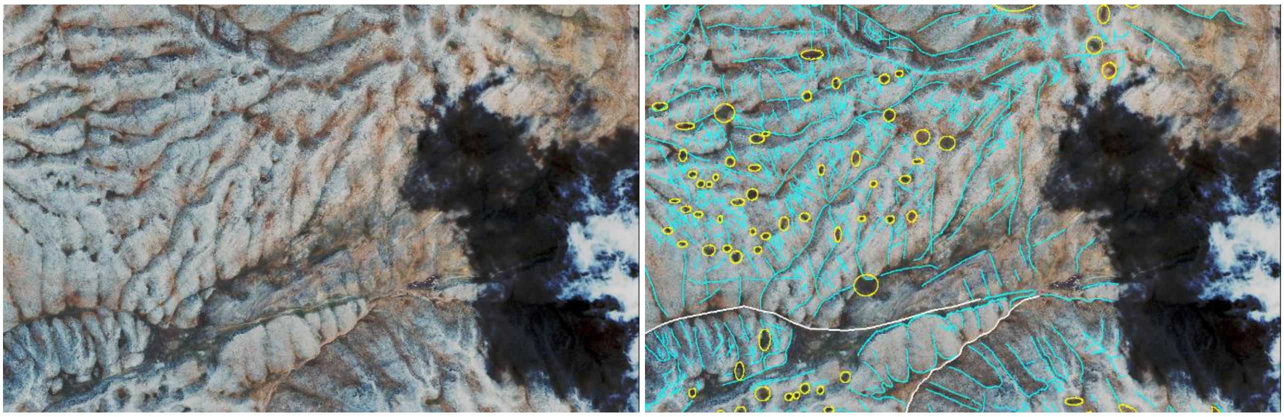

Fig. 4a: Digitization of limestones with typical karstic hollows on Quickbird image.

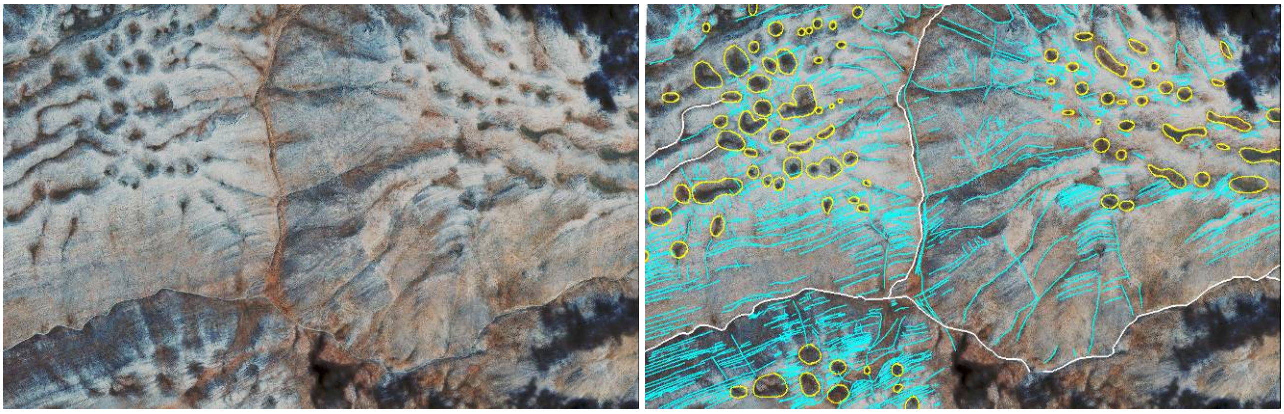

Fig. 4b: Digitization of limestones and interfingered parallel striped zebra dolomites on Quickbird image.

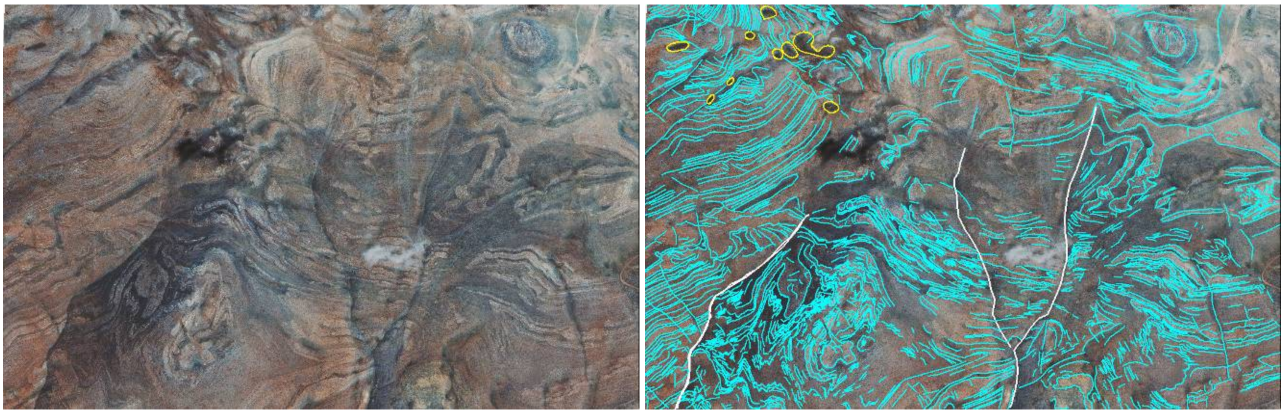

Fig. 4c: Digitization of parallel striped zebra dolomites on Quickbird image.

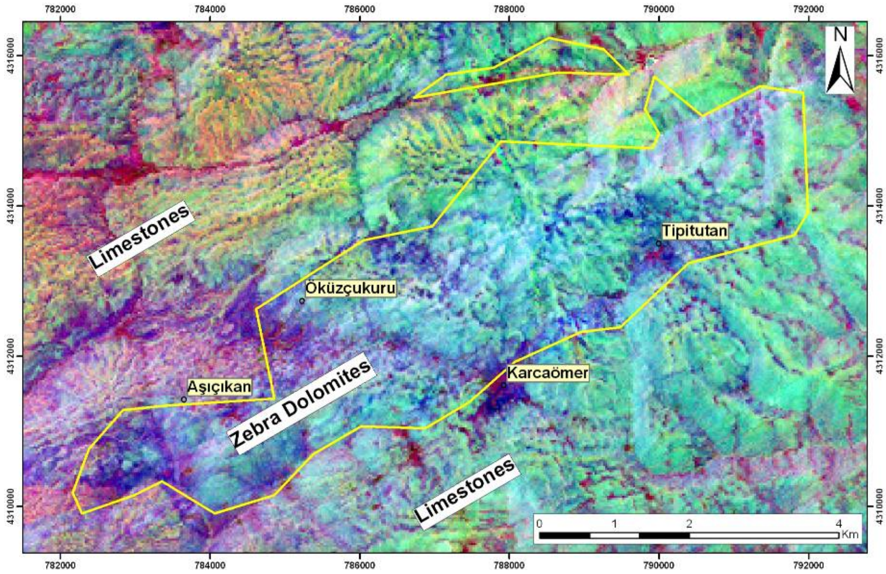

Fig. 5: Landsat PCA 432 image of the stuy area. The contoured line are showing the location of the zebra dolomites.

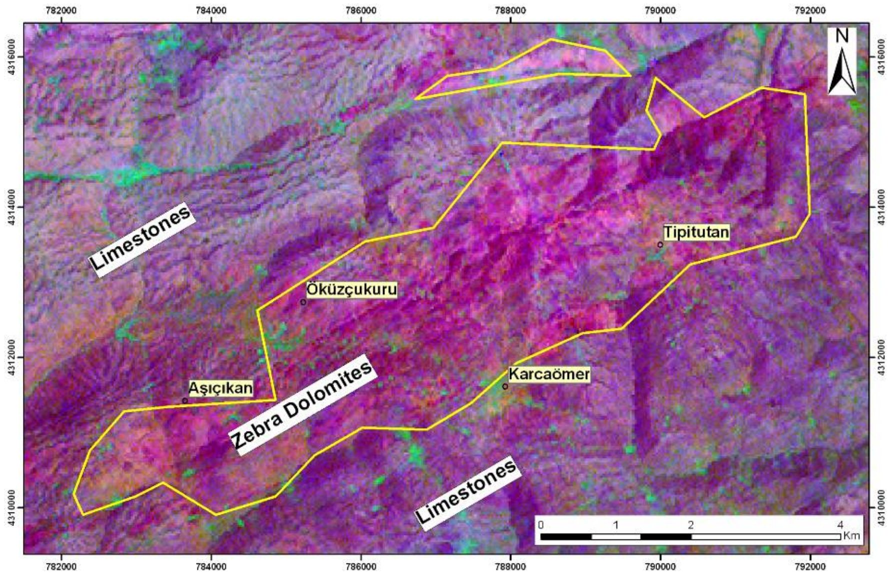

Fig. 6: Landsat DC 741 image of the stuy area. The contoured line are showing the location of the zebra dolomites.

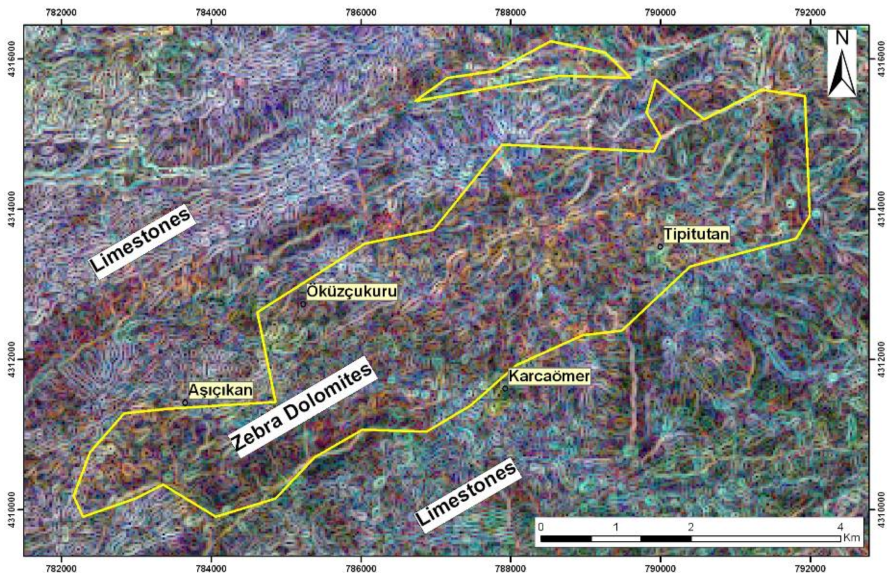

Fig. 7:Landsat Gradient Sobel filter image of the study area.

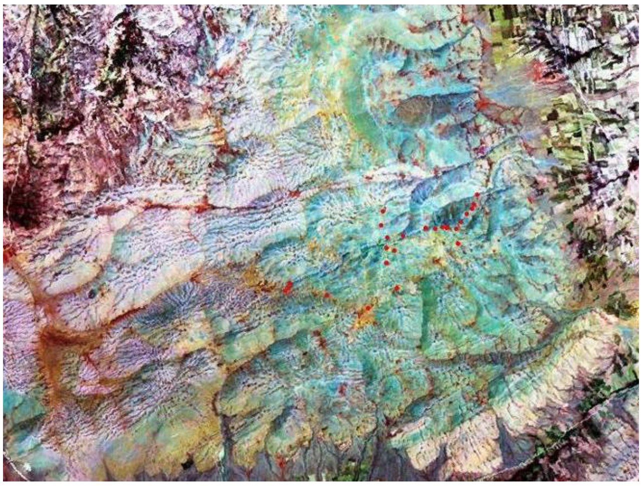

Fig. 8: Landsat RGB 531 image draped SRTM 3D view. Red dots are the location of the collected zebra dolomies samples.

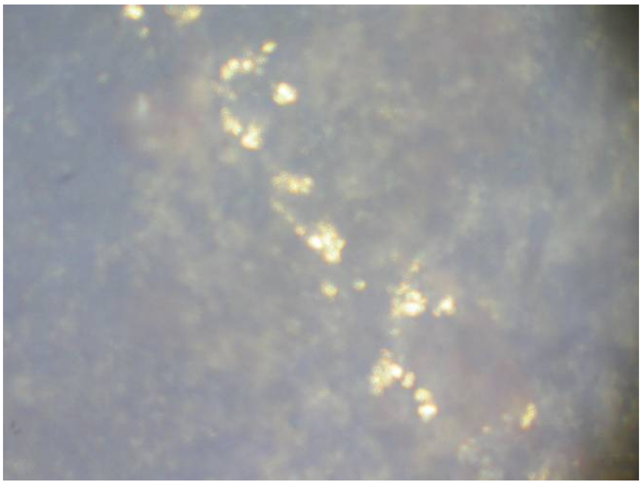

Fig. 9: Gold minerals in rhodochrosite.

LABORATORY STUDIES

Laboratory studies were performed in petrography, geochemistry and isotope studies. Thin section and polished section studies were naturally performed for all of the collected rock samples. The main topic of these study is not presenting the details of the petrographic investigation, therefore, the results of the studies will not be presented in detail in this paper. Nevertheless, summary of these studies is as follows; according to the petrographical investigation; iron ores in Tipitutan and Karcaömer areas are hematite. Sphalerite, fahlerz, galenite, pyrite, phyhotite, arsenopyrite, millerite, linneite, rhodochrosite and chromite (!) are the detected minerals in the hydrothermal bodies, while some chalcopyrite and gold are present in some locations, especially in Çukuryurtdere and Cehennemdere(Fig. 9). Kuvars, Kalsit and dolomites (especially zebra textured) are the main gang minerals. Presence of chromite minearals in hydrotermal deposits is not normally expected at all. This presence of chromite grains is evaluated and attributed as extraction of chromite minerals during leaching process of the ophiolithic units by granite originated by hydrothermal solutions, during their upward movement to their present location.

^{34}S analyses were performed in some samples taken from the hydrothermal bodies located in Çukuryurtdere. All of the results suggest that the sulphur elements originated from surface and/or ocean fluid. Additionally, ^{12}C and ^{18}O isotope analyses made on white and black stripes of the zebra dolomites indicate that these elements originated from surface and/or ocean water as well. The carbon and oxygen isotope analyses were performed in Acme isotope laboratories-Canada, whilst sulphure isotope analyses were done in Hatch laboratories -Canada. Carbon element determination was made in Ankara University, Geological Engineering laboratories and determined as carbon pyrolitic by XRF confocal micro point analysis (Fig. 10). The values of δ^{13}C (PDB) range from +2.4 to +2.7, whilst the δ^{18}O(SMOW) HZD value changes just little from 29.4 to 29.5 (Table 1). Additionally, ^{34}S(CDT) isotope values of the analysed sulphure elements change from 8.0 to 18.7 (Table 2).

Sample Number	δ^{18}O	δ^{13}C	Explanation
	SMOW	PDB	
	per mill	per mill	
1	29.5	2.4	White band
2	29.4	2.7	White and black mixture
3	29.5	2.7	Black band

Table.1: Oxygen(δ^{18}O) and carbon(δ^{13}C) isotope analyses of the zebra dolomites.

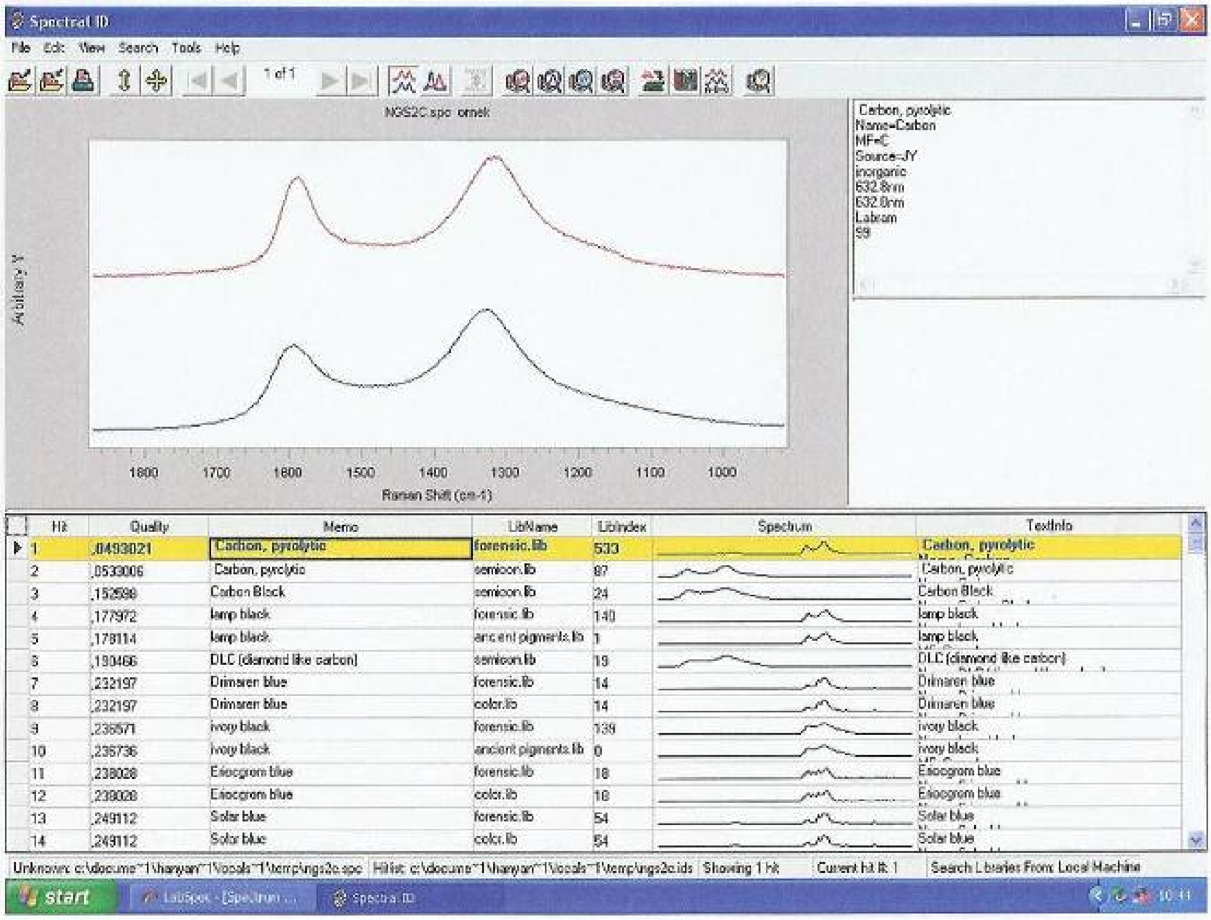

Fig. 10: Carbon element determination by confocal XRF.

Table. 2: ^{34}S(CDT) isotope values of the sulphide minerals.

OurLabID	Sample ID	Weight (ug)	Delta 34S cdt	%S	Comment	Hatch Lab ID
S-2371	D11346-YWPT142	10258	18.7	0.3	0	B0607-208-001
S-2372	D11349-YWPT147C	324154		0.03	very low concentration	B0607-208-002
S-2373	D11350-YWPT147A	5040	15.7	0.7	0	B0607-208-003
S-2374	D11358-YWPT147B	2500	17.2	0.3	0	B0607-208-004
S-2375	D11361-YWPT143	1480	16.9	7.1	0	B0607-208-005
S-2376	D11361-YWPT143 QCDuplicate	1482	16.7	7.1	0	B0607-208-006
S-2377	YWPT-147-Yeni	125414		0.01	very low concentration	B0607-208-007
S-2378	11714	13580	8.0	0.2	low concentration, use ca	B0607-208-008
S-2379	11716	10010	12.1	0.2	0	B0607-208-009
S-2380	11718	135477		0.01	very low concentration	B0607-208-010

ORIGINE OF THE MINERAL ENRICHMENTS/ORE DEPOSITS

According to the field and laboratory data, two main origine of the mineral sources are postulated. All isotope data suggest that the origin of the fluids, which causes ore enrichments/deposition in Zebra dolomites should have been originated from either surface and/or ocean water, whilst some others show granite originated hydrothermal fluid character according to their mineralogical content. The origin of ore minerals content in the zebra dolomites are stil under discussion, but the possibility of Zn and Mn absorbing algea-microbial mats seem to be the most possible source for these type of mineralization (Judith et al,1993). This possibility is still under research in the study area, therefore the details will not be given here.

The presence of chalcopyrite in the deposits needs higher crystalization temperature than the other determined ore minerals. Additionally, some unexpected chromite grains presence in the samples suggests that granite originated fluids should have extract some chromite as grains from the ophiolithic units which underlies the carbonate rocks. Thus, these hydrothermal fluids deposited chromite minerals with the other hydrothermal minerals to their present location in the study area (Aydal et al, 2008). Therefore, it is believed that at least some of the occurences caused by unexposed granite originated hydrothermal solutions instead of surface and/or ocean originated hydrothermal enrichments. As very well known that surface or ocean waters originated hydrothermal solutions never reaches enough tempeature which could cause chalcopyrite enrichments. Additionally, the presence of gold grains in some deposits may probably suggest the granite originated hydrothermal fluid. The postulated cross section showing the two different type of ore deposition in the study area (Fig. 11).

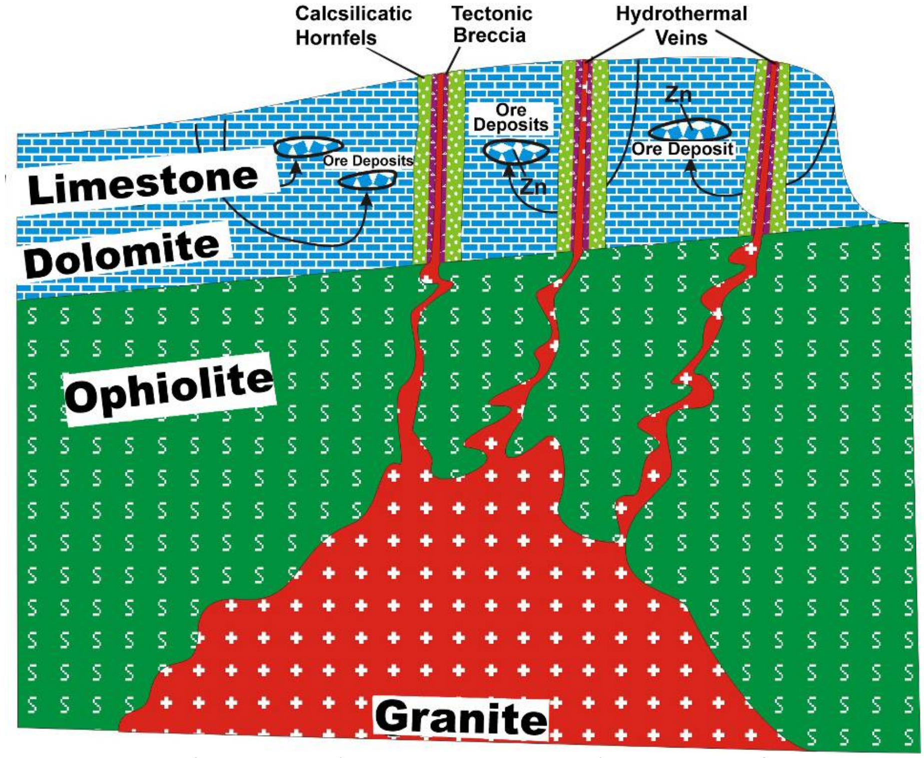

Fig. 11: Cross section of the the postulated origin of the ore deposits/enrichments.

CONCLUSIONS

Differentiation of zebra dolomites from the other carbonatic rocks by using satellite data is perfectly managed. Especially PCA 432 and DC 741 composites in Landsat data and Gradient-Sobel filtering technique were found to be very helpful for discriminating zebra dolomites from the other rocks in close enviroment. Nevertheless, the most effective discrimination was made by digitizing of the circled karstic hollows and stripped lines, which clearly appear in limestones and dolomites respectively. Hydrothermal zebra dolomites were easily differentiated from the limestones because of their alteration differences. Many circled karstic hollows were seen in limestones, whilst zebra dolomites didn't show any circled karstic hollows but parallel lines, because of their black and white parallel stripes. The results were checked by ground truth and were obviously supported by different drainage patterns of the studied rocks. Additionally, the petrographic, chemical and isotopic data suggested two different origins for the hydrothermal deposits located in the zebra dolomites in the study area.

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