J Indian Soc Remote Sens (August 2016) 44(4):539–552
DOI 10.1007/s12524-015-0510-0

RESEARCH ARTICLE

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Prospecting of Au by Remote Sensing and Geochemical Data Processing Using Fractal Modelling in Shishe-Botagh, Area (NW Iran)

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Received: 2 October 2014 / Accepted: 30 September 2015 / Published online: 9 February 2016

Abstract The Shishe-botagh area is located in the western Azerbaijan Province, Iran. In this paper, geological map, ASTER satellite images were used and processed by ENVI software. Furthermore, lithogeochemical data were analyzed by fractal modeling. In this paper alternation zones distinguished by using band ratio, Minimum Noise Fraction (MNF) and Spectral Angle Mapper (SAM). Geochemical anomalies were separated by number – size (N-S) fractal model. The (N-S) fractal method was utilized for delineation of high intensive Au, As and Ag anomalies with silica veins in the west and South West of the the Shishe-botagh area.

Keywords Alteration zones · Aster · Geochemical data · Shishe-botagh · Number-size fractal model

Introduction

In this paper used to apply spectral angle mapper (SAM), Minimum Noise Fraction (MNF) and band ratio to map the iron zones on the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) data. Separation of anomalies and background is the most important aim of geochemical exploration especially for metallic deposits. Stream sediment and lithogeochemical data are essential for prospecting of different ore deposits (Hawkes and Webb 1979). Several methods are used for geochemical data interpretation and modelling such as classical statistics (e.g.,Tukey 1977; Hawkes and Webb 1979; Reimann et al. 2005), fractal/multifractal modelling (Cheng et al. 1994; Agterberg et al. 1996; Cheng 1999; Li et al. 2003; Zuo et al. 2009; Afzal et al. 2013; Heidari et al. 2013) and singularity modeling (Cheng 2007). Fractal theory has been established by Mandelbrot (1983) as a important non-Euclidean branch in geometry. Several methods have been proposed and developed based on fractal geometry for application in geosciences since the 1980s (Agterberg et al. 1993; Sanderson et al. 1994; Cheng 1999; Turcotte 1997, 2002; Goncalves et al. 2001; Monecke et al. 2005; Gumiel et al. 2010; Zuo 2011; Sadeghi et al. 2012). The present study is based on the integration of remote sensing techniques and geochemical data analysis (stream sediment and litho geochemical samples) and as well as geological field verification studies to identify Au, Ag and As prospects in the Shishe-botagh, NW Iran.

Regional and Geological Setting of the Study Area

Shishe-botagh area is located between longitudes 709,040–710,450 and latitudes 4,041,811–4,039,924 (UTM, WGS 84, zone 38 N) in the western Azerbaijan Proveince, NW Iran (Fig.1). The studied area is a small north part of 1:100, 000 Takab geological map (Fig.2). Based on this map, there are lots of silica and silicified units in the studied area, also there are some Schists, altered Schists, Serpentines and Asbestos in the studied area. As it is shown in Fig.2, there is a thrust fault with NW – SE trend from north to south in the east margin of the area. Also there is a fault with the same trend in the South West of the area.

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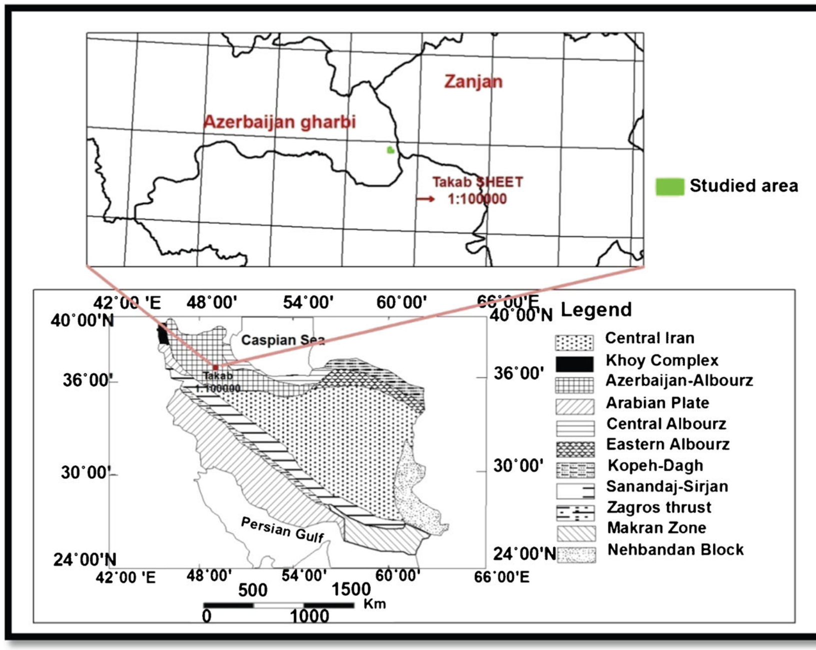


Fig. 1 The studied area in the map of Iran

Materials and Methods

The aims of the paper are to perform spectral angle mapper (SAM), Minimum Noise Fraction (MNF) and band ratio to map zones of hydrothermal alteration on the ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) satellite imagery data and delineation of high intensive Au, As and Ag anomalies using Number-Size (N-S) fractal method based on litho geochemical data for finding new prospects in Au mineralization in studied area. ENVI and ArcGIS software packages were used for multi-spectral image interpretation and fractal modeling of geochemical data, respectively.

Results

Remote Sensing Interpretation

The ASTER is an advanced optical sensor comprised of 14 spectral channels that will provide scientific and also practical data regarding various field related to the study of the earth (Rowan and Mars 2003; Moghtaderi et al. 2007; Yousefifar et al. 2011; Feizi and Mansouri 2012; Feizi and Mansouri 2013a, b). Numerous factors affect the signal measured at the sensor, such as drift of the sensor radiometric calibration, atmospheric and topographical effects. Therefore, Aster data set was used and radiance correlation such as wavelength, dark subtract and log

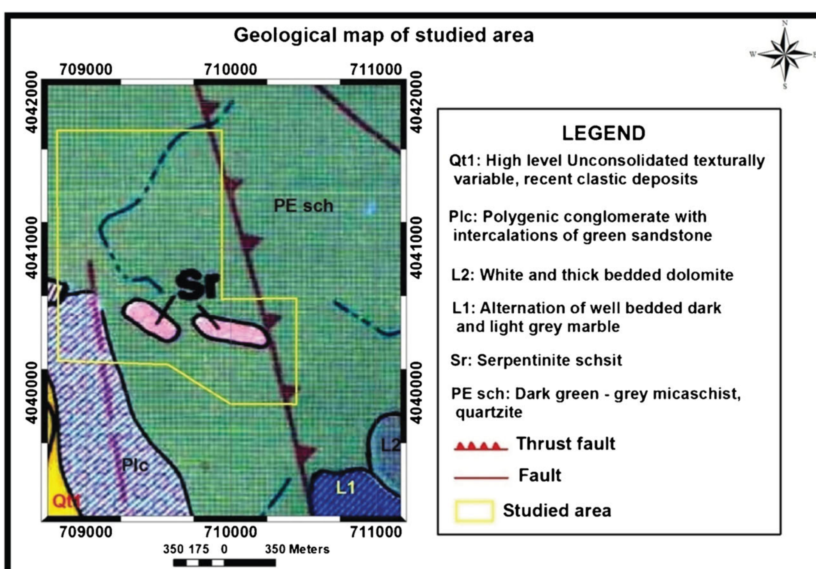


Fig. 2 The geological map of studied area

residual by ENVI4.4 software which is essential for multispectral images, were employed. Many image analysis and processing techniques can be used to interpret the remote sensing spectral data (Mars and Rowan 2006; Azizi et al. 2010; Poormirzaee and Oskouei 2010; Beiranvand Pour and Hashim 2012; Oskouei and Busch 2012). In this research, band ratio, spectral angle mapper (SAM) and Minimum Noise Fraction (MNF) methods were used on ASTER data for discrimination of alteration zones.

Band Ratio

Band ratio is a technique where the digital number (DN) value of one band is divided by the DN value of another band. BRs can be useful for highlighting certain features or materials that cannot be seen in the raw bands. Similarly, the choice of bands depends on their spectral reflectance and positions of the absorption bands of the mineral being mapped (Inzana et al. 2003; Kujjo 2010; Rajendran et al. 2012). For instance, to enhance a specific alteration mineral that hosts a distinct absorption feature, the most unique spectral ratio for that mineral is employed. In order to discrimination of iron oxide, phyllic, propylitic, silica and serpentinization (2/1), (5 + 7/6), (6 + 9/7 + 8), (14/12) and RGB: (4/7,3/4,2/1) were used (Fig. 3).

Minimum Noise Fraction

The Minimum Noise Fraction (MNF) analysis can identify the locations of spectral signature anomalies. This process is of interest to exploration geologist because spectral anomalies are often indicative of alterations due to hydrothermal

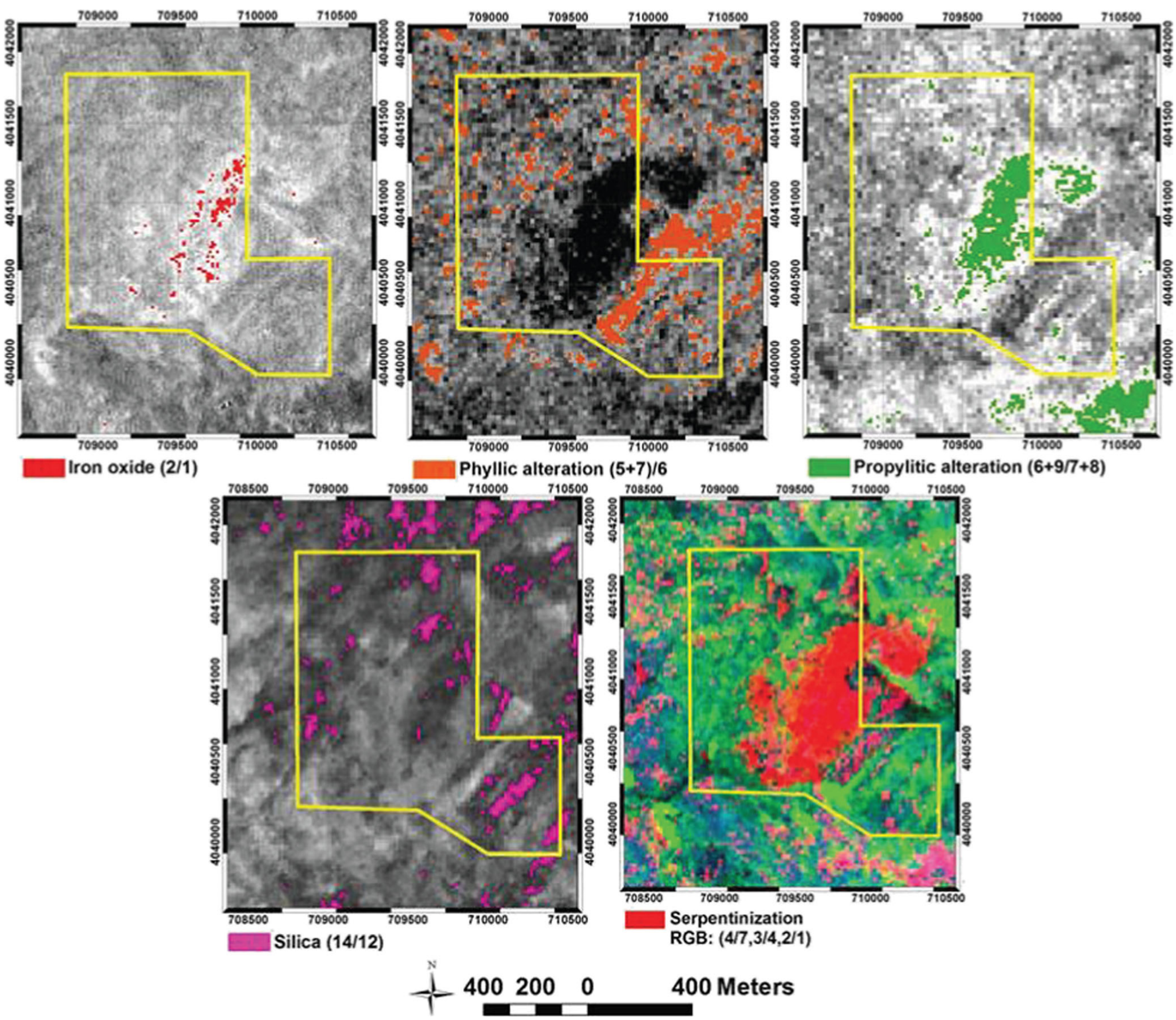


Fig. 3 The iron oxide, phyllic, propylitic, silica and serprntinization images prepared based on band ratio method

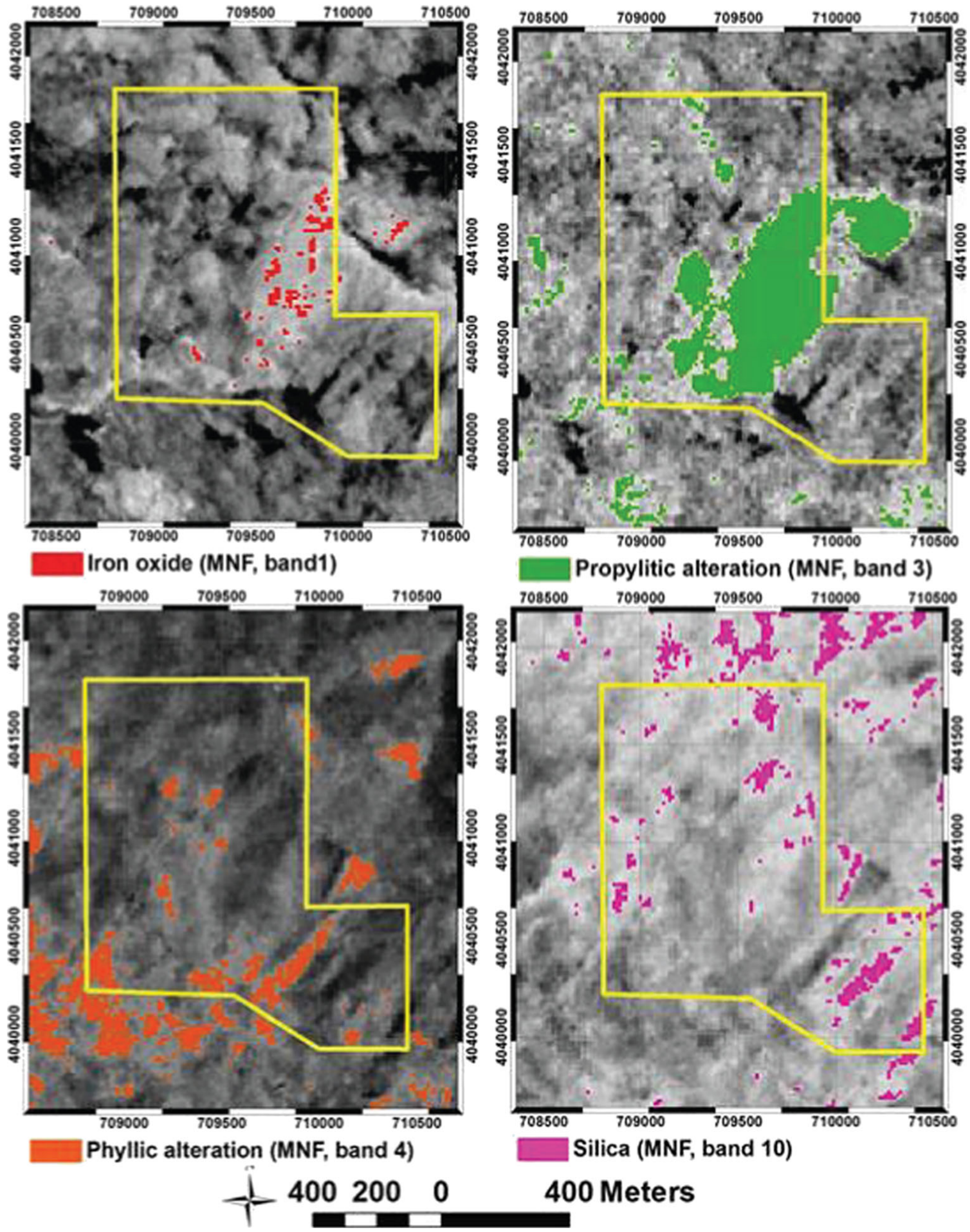


Fig. 4 The iron oxide, propylitic, phyllic and silica images prepared based on MNF method

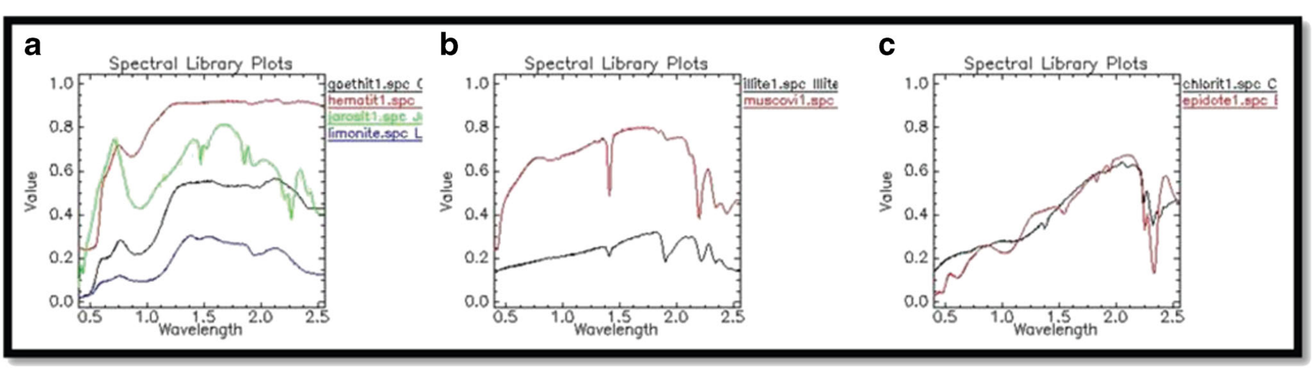


Fig. 5 The remarkable mineral reflection for: **a** iron oxide, **b** phyllic and **c** Propylitic zones

mineralization. MNF involves two steps; in first step a calculated output value. This predicted band is what that band should be according to the linear equation. The minerals which are sensitive to a specific band are then differentiated from the features which are reflective to the other bands as well; just by taking the difference between the predicted values and the original values (Yetkin et al. 2004). Distribution of iron oxide was created by using MNF method, band 1. Also, phyllic, propylitic and silica alterations were mapped by using residual band 4, residual band 3 and residual band 10. (Fig. 4).

Spectral Angle Mapper (SAM) Method

Spectral Angle Mapper (SAM) is a physically-based spectral classification that uses an n-D angle to match pixels to reference spectra. The algorithm determines the spectral similarity between two spectra by calculating the angle between the spectra and treating them as vectors in a space with dimensionality equal to the number of bands. This technique, when used on calibrated reflectance data, is relatively insensitive to illumination and albedo effects. End member spectra used by SAM can come from ASCII files, spectral libraries, or you can extract them directly from an image (as ROI average spectra). SAM compares the angle between the end member spectrum vector and each pixel vector in n-D space. Smaller angles represent closer matches to the reference spectrum. Pixels further away than the specified maximum angle threshold in radians are not classified.

SAM classification assumes reflectance data. However, if you use radiance data, the error is generally not significant because the origin is still near zero.

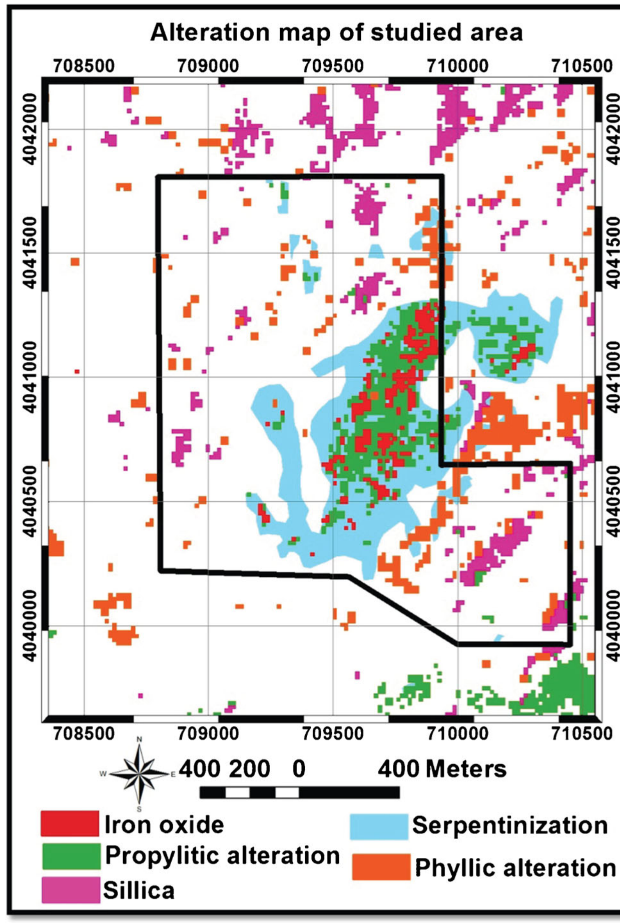


Fig. 7 Final map, prepared by GIS

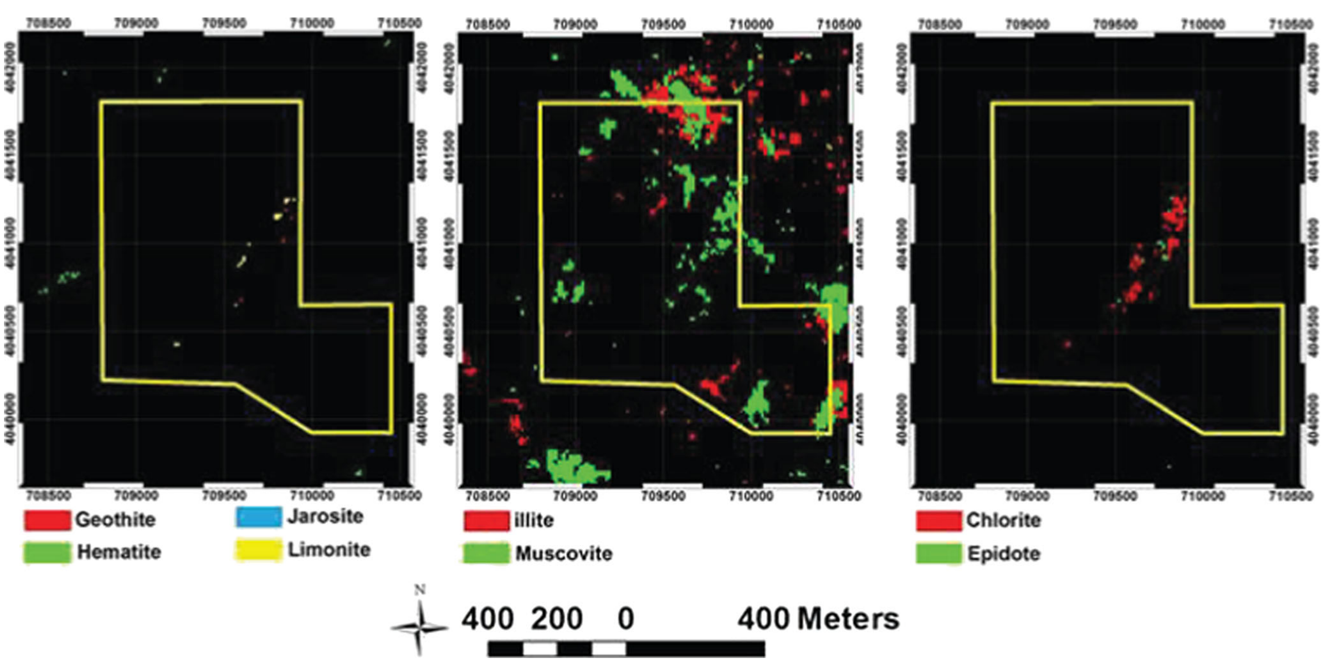


Fig. 6 The iron oxide, phyllic and propylitic images prepared based on SAM method

Iron oxide zones were determined on VNIR bands. Mineral spectral such as Hematite, Geothite, Jarosite and limonite by aid of USGS were investigated (Fig. 5a).

Propylitic and Phyllic alterations were determined by aid of SWIR bands. Minerals spectral such as Illite and Moscovite were used for phyllic alteration by aid of USGS library and alteration were determined (Fig.5b) and minerals spectral such as Chlorite and Epidote were used for Propylitic alteration (Fig. 5c).these minerals are important in identification of hydrothermal alterations related to porphyry systems. The iron oxide, phyllic and propylitic images prepared based on SAM method were shown in Fig. 6.

At last with Integration of the Silica, phyllic, propylitic and iron oxide maps, the Final alteration map of studied area was prepared (Fig. 7).

Field Observations and Check Fields

Finally field studies were done for confirming the results (Figs. 8, 9, 10 and 11). As it were shown in figures all the remote sensing results were confirmed by field studies. As it is shown in Fig. 8 Serpentinization zones were extracted with (RGB: 4/7,3/4,2/1) which were all confirmed by filed investigations.

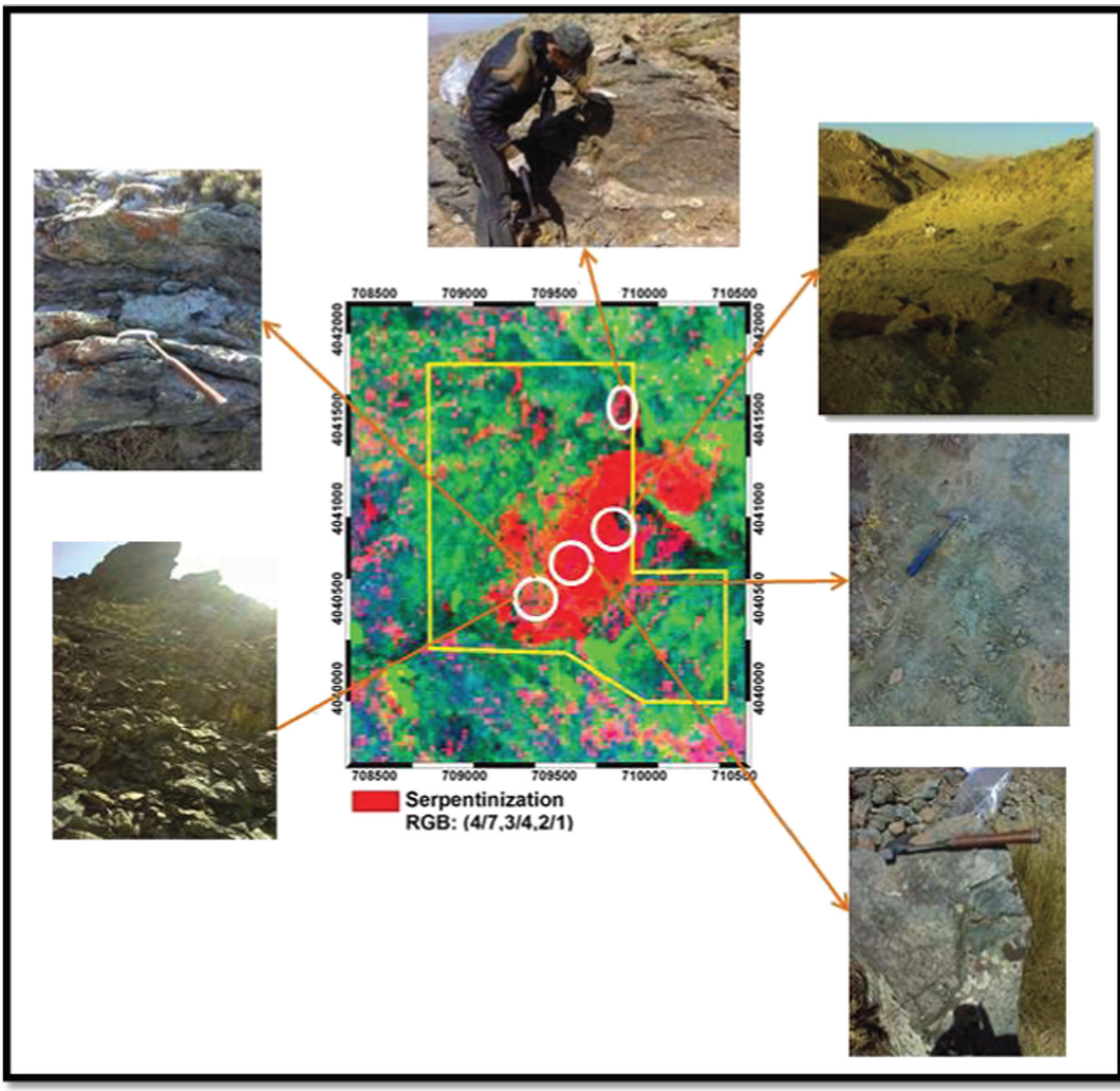


Fig. 8 Satellite image processing and check fields for Serpentinization zones

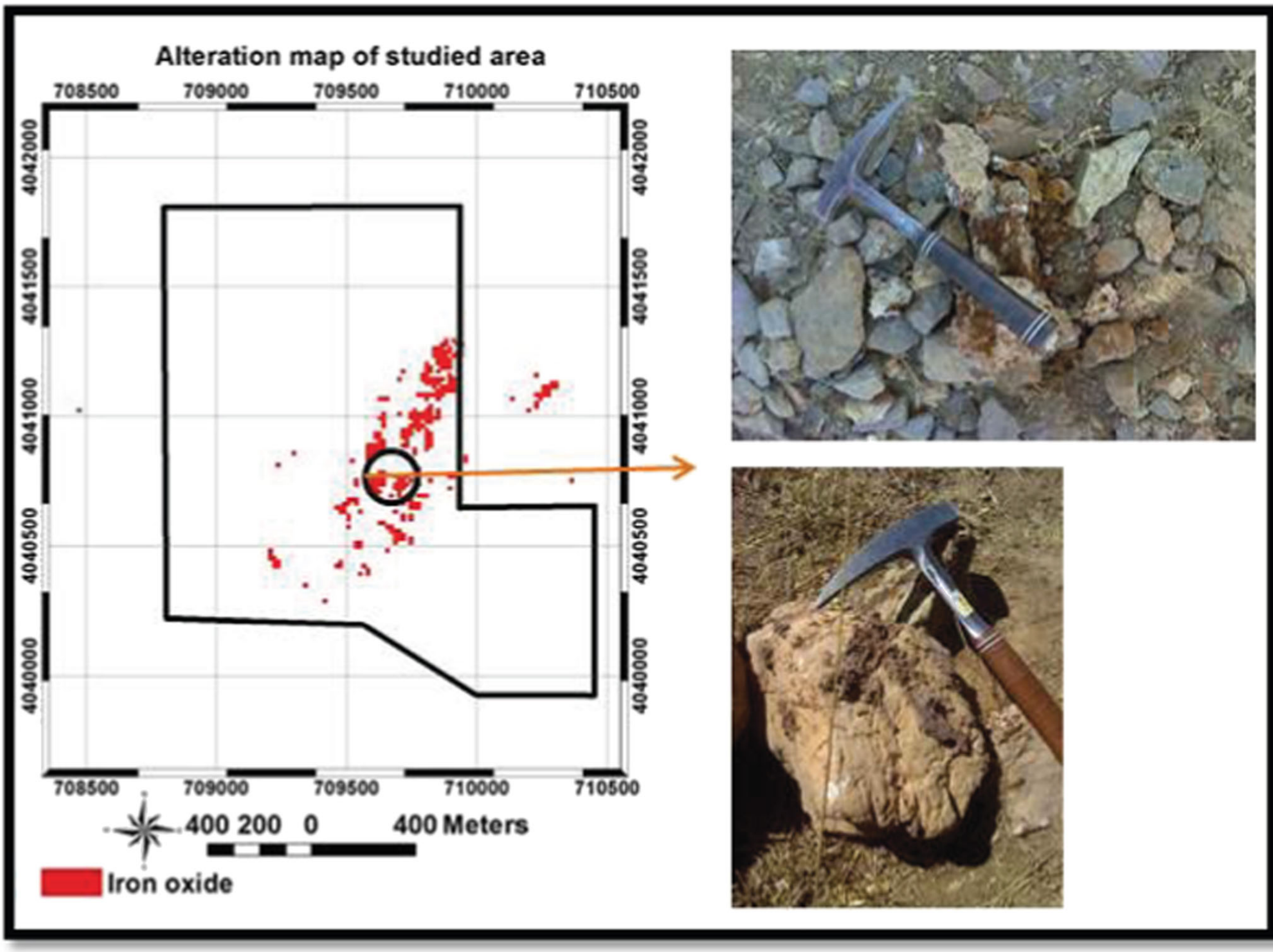


Fig. 9 Satellite image processing and check fields for Iron oxide zones

With notification to the presence of Fe minerals as Amphibols in PE sch و SR unites (Amphibol Talc Serpentin Schist) and the Oxidation of these minerals, these unites were extracted as Iron oxide zones by satellite image

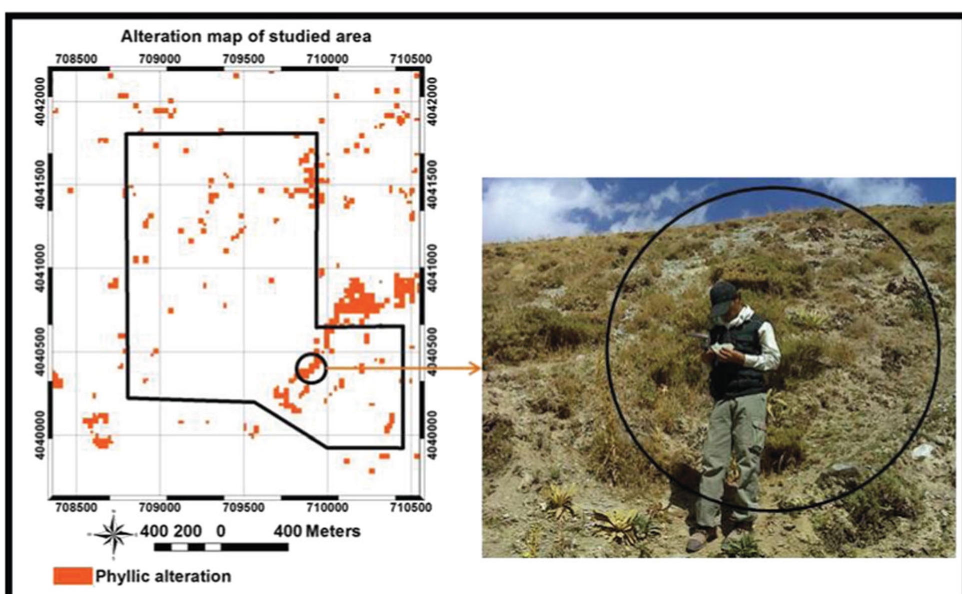


Fig. 10 Satellite image processing and check field for Phyillic zones

processing.Filed investigations were confirmed the results (Fig. 9).

Based on 1:100,000 geological map, PE sch unite was introduced as Mica schist and Quartzite.The index alteration for this unite is Phyillic which were extracted by image processing as Phyillic unite (Fig.10).

Because the vein type Quartz mineralization were seen widespread in the area and it was confirmed by remote sensing methods, It seems this unite could be a suitable host rock for poly metal hydrothermal mineralization. So filed investigation and sampling were suggested.The results were indicated, this silica is related to last phase of magmatic differentiation without any mineralization but it could be a suitable pathfinder for exploration (Fig.11).

Figure 12 is shown the silica vein which came upward with schist unite in the west of area was mineralized. The result of analyses were shown the Au assay was variated between 300 to 800 PPb in surface.

Geochemical Data Analysis Based on Number – Size (N-S) Fractal Model

Number-Size Fractal Model Theory

The Number–Size (N-S) method, which was originally proposed by Mandelbrot (1983), can be used to describe the distribution of geochemical populations without pre-processing of data. The method indicates that there is a relationship between desirable attributes (e.g., ore elements) and their cumulative numbers of samples. Based on the model, Agterberg (1995) proposed a multifractal model named size-grade for determination of the spatial distributions of giant and super-giant ore deposits. Monecke et al. (2005)used the N–S fractal model to characterize element enrichments associated with metasomatic processes during the formation of hydrothermal ores in the Waterloo massive sulfide deposit, Australia. A power-law frequency model has been proposed to describe the N–S relationship according to the frequency distribution of element concentrations and cumulative number of samples with those attributes (Li et al. 1994; Sanderson et al. 1994; Shi and Wang 1998; Turcotte 1996; Zuo et al. 2009). The model is expressed by the following equation (Mandelbrot 1983; Deng et al. 2010; Hassanpour and Afzal 2013; Hashemi and Afzal 2013):

$$N(\geq\rho) = F\rho{-}D \quad (1)$$

where ρ denotes element concentration, N(≥ρ) denotes cumulative number of samples with concentration values greater than or equal to ρ, F is a constant and D is the scaling exponent or fractal dimension of the distribution of element concentrations. According to Mandelbrot (1983) and Deng et al. (2010), log–log plots of N(≥ρ) versus ρ show straight line segments with different slopes −D corresponding to different concentration intervals.

Lithogeochemistry Data Analysis

Cause of special importance of sampling models, several factors has to considered during the sampling. The most important of them are: Litho logical units, Faults, Alteration zones,

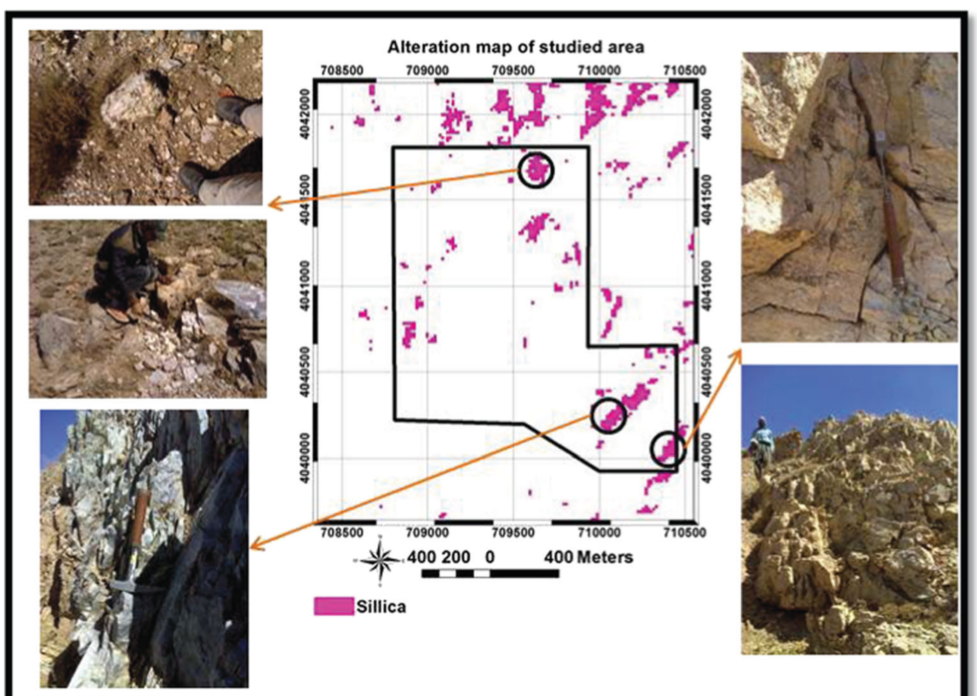


Fig. 11 Satellite image processing and check fields for Silica zones

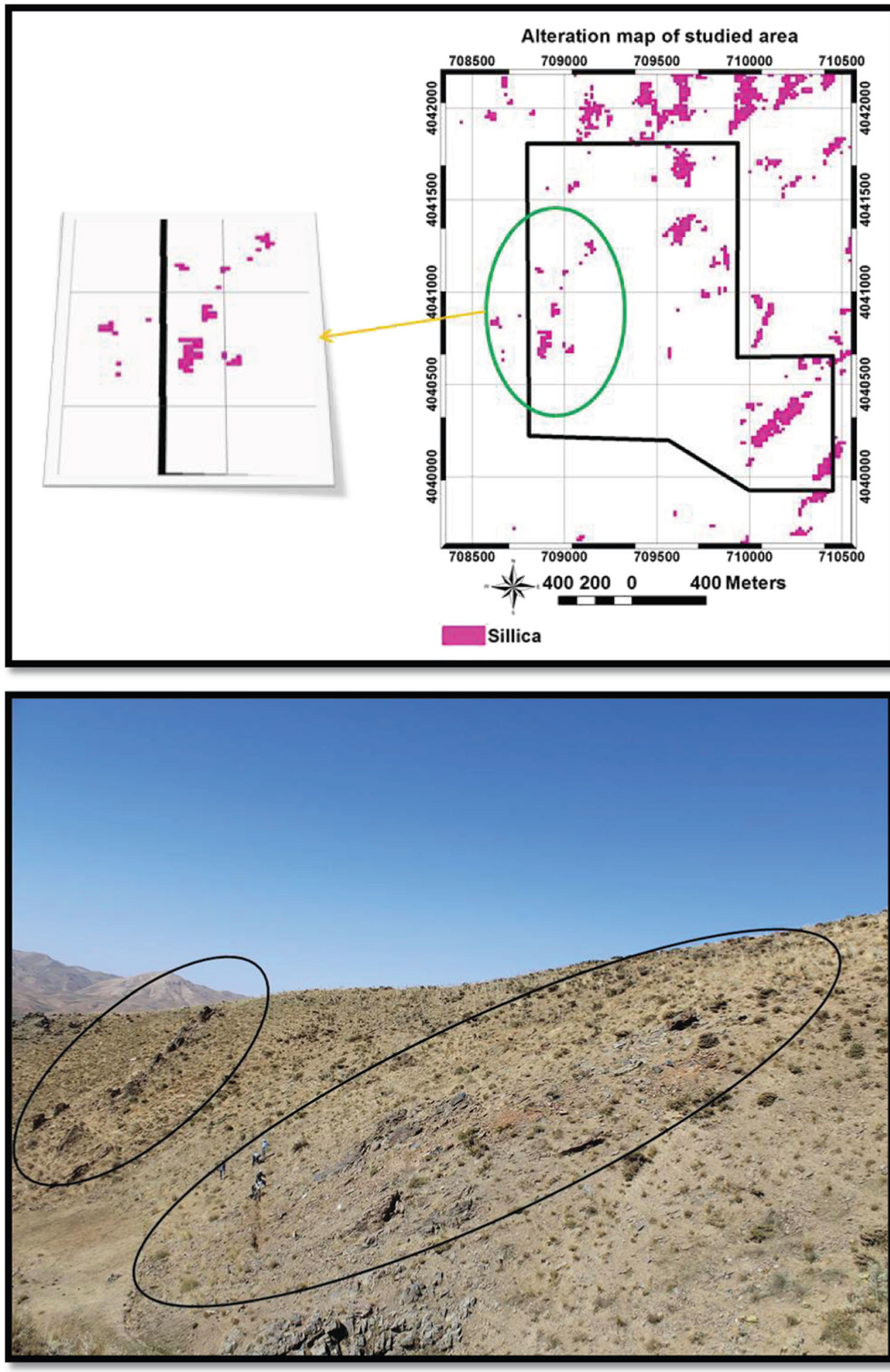


Fig. 12 The discoveries for Au mineralization.Satellite image processing (up) and checkfiled (down)

Mineralization zones, Topography, Dikes and Intrusive bodies.

In this project, sampling distances were chosen based on the above factors. These factors can change based on experience of researches and filed evidences.

In this project the 147 lithogeochemical samples were chemical analyzed by ICP-MS method for elements especially for copper and gold. In this study, Number-Size (N-S) fractal method was utilized for High intensive Au, Ag and As anomalies in the studied area. Some of the samples were chosen on the silica vein in west of the studied area (Fig. 13).

A total of 147 lithogeochemical samples were collected from the area and analyzed using the ICP-MS method for elements which are related to Au, As and Ag mineralization.

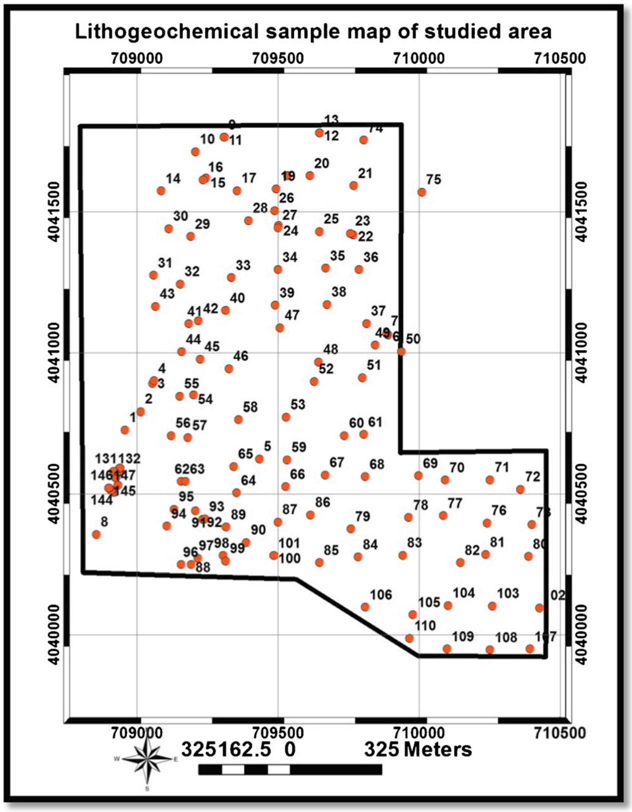


Fig. 13 Lithogeochemical samples location map of the studied area

(The N-S) fractal method was utilized for High intensive Au, As and Ag anomalies. These anomalies are related to silica veins which are recognized in west of the area. These anomalies are related together too. As it is shown in Fig. 14, Au anomalies were distinguished in west of the area where the silica veins are presents. Figure 15 is shown the anomaly of Ag, which is adapted on Au anomaly in the same place. As it is shown in Fig. 16 the As anomalies are adapted with Au anomalies exactly in the same two places, one in the South West corner and another in west of the area.

Results and Discussion

Correlation Between Geological Particulars, Remote Sensing and Geochemical Data

The vein type Quartz mineralization were seen widespread in the area and it was confirmed by remote sensing methods, it seems this unite could be a suitable host rock for poly metal hydrothermal mineralization. The results of filed investigation were indicated, this silica is related to last phase of magmatic differentiation without any mineralization but it could be a suitable pathfinder for exploration. There are just a few silica veins in the west and South West corner of the area which are

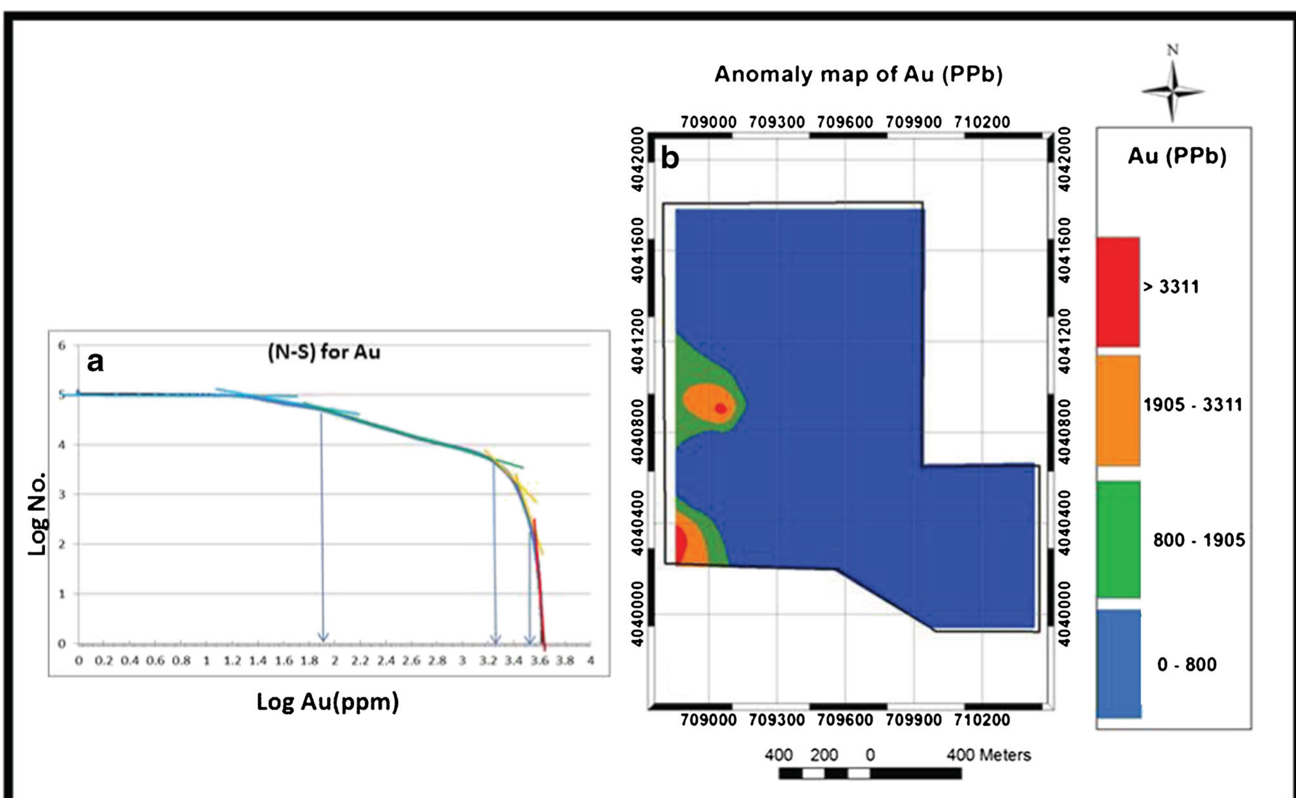


Fig. 14 **a** Log–log plots from C–N method for Au. **b** Au lithogeochemical population distribution map based on the C–N method

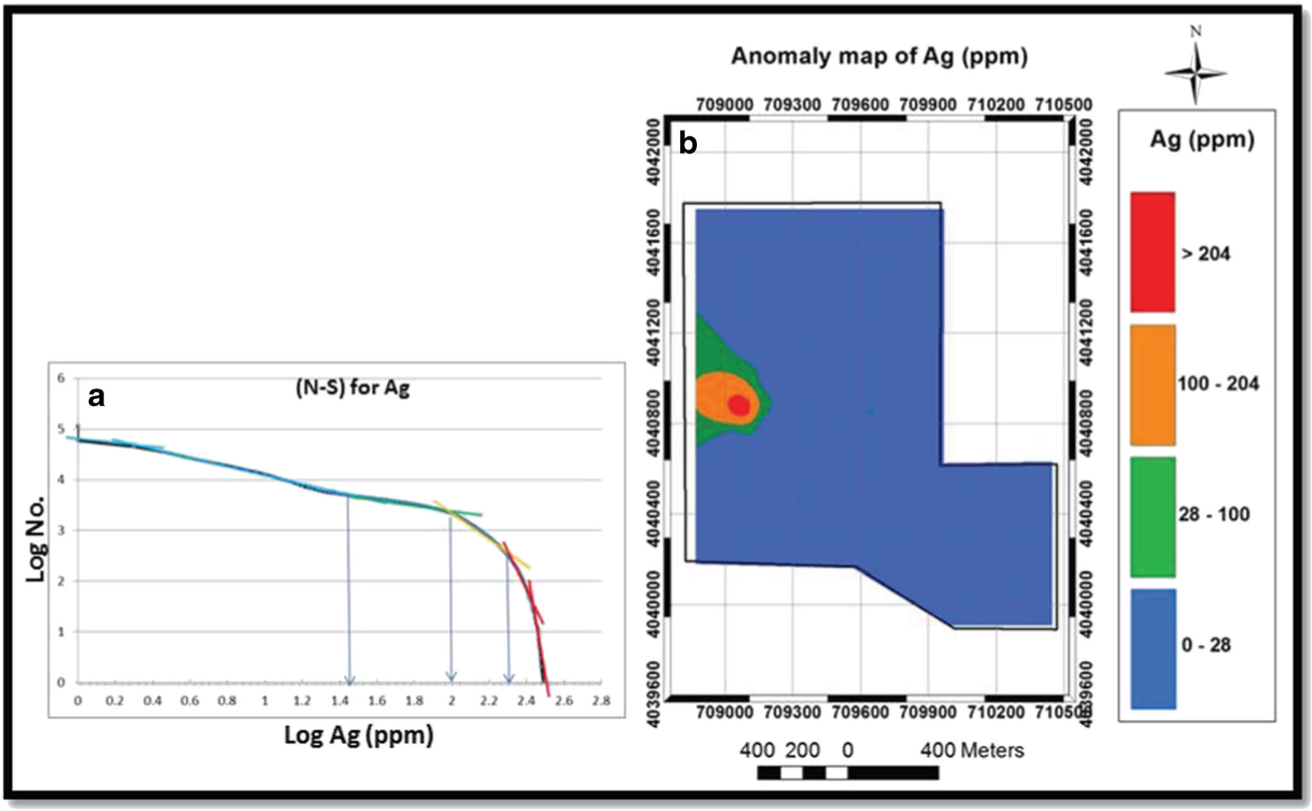


Fig. 15 **a** Log–log plots from C–N method for Ag. **b** Ag lithogeochemical population distribution map based on the C–N method

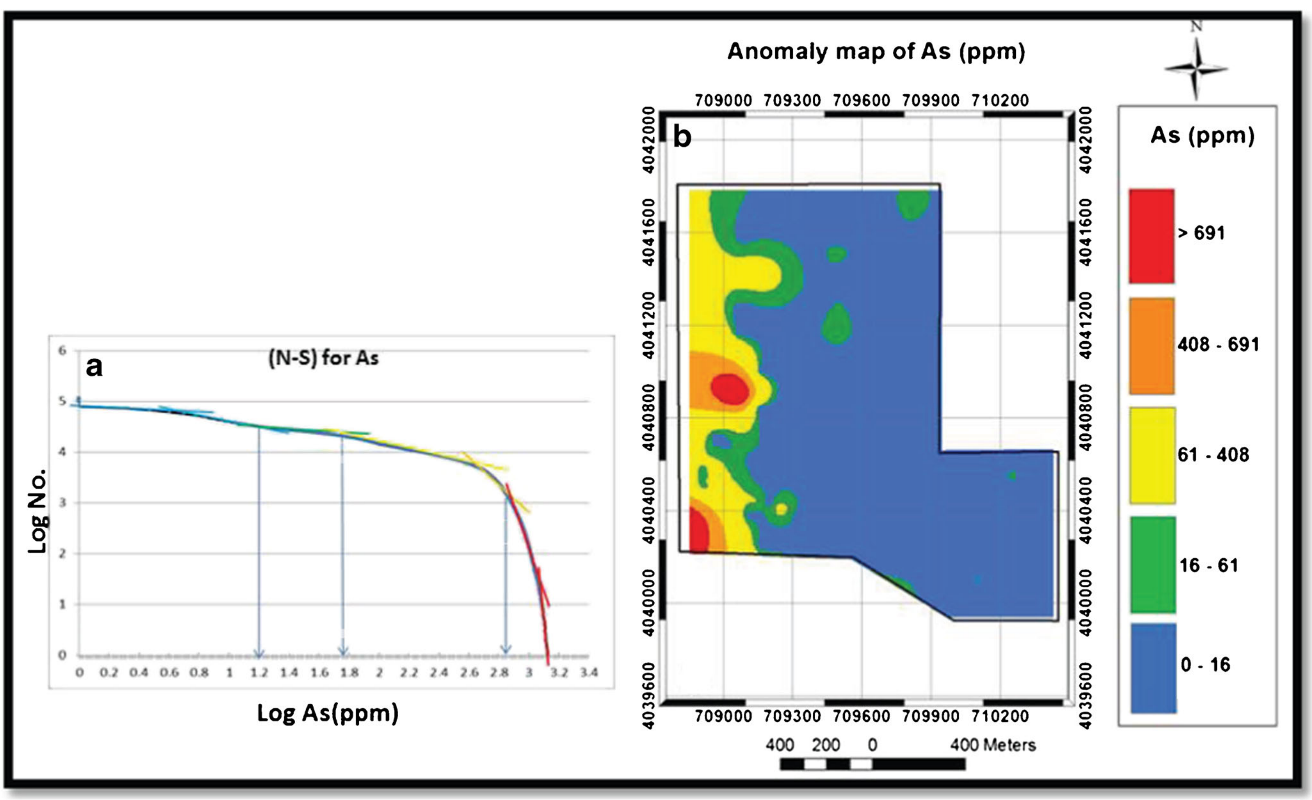


Fig. 16 **a** Log–log plots from C–N method for As. **b** As lithogeochemical population distribution map based on the C–N method

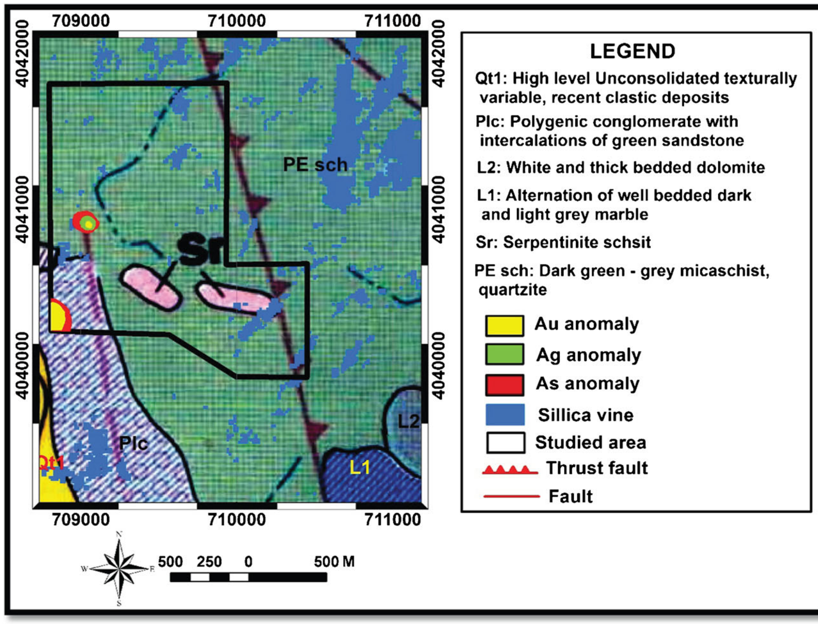
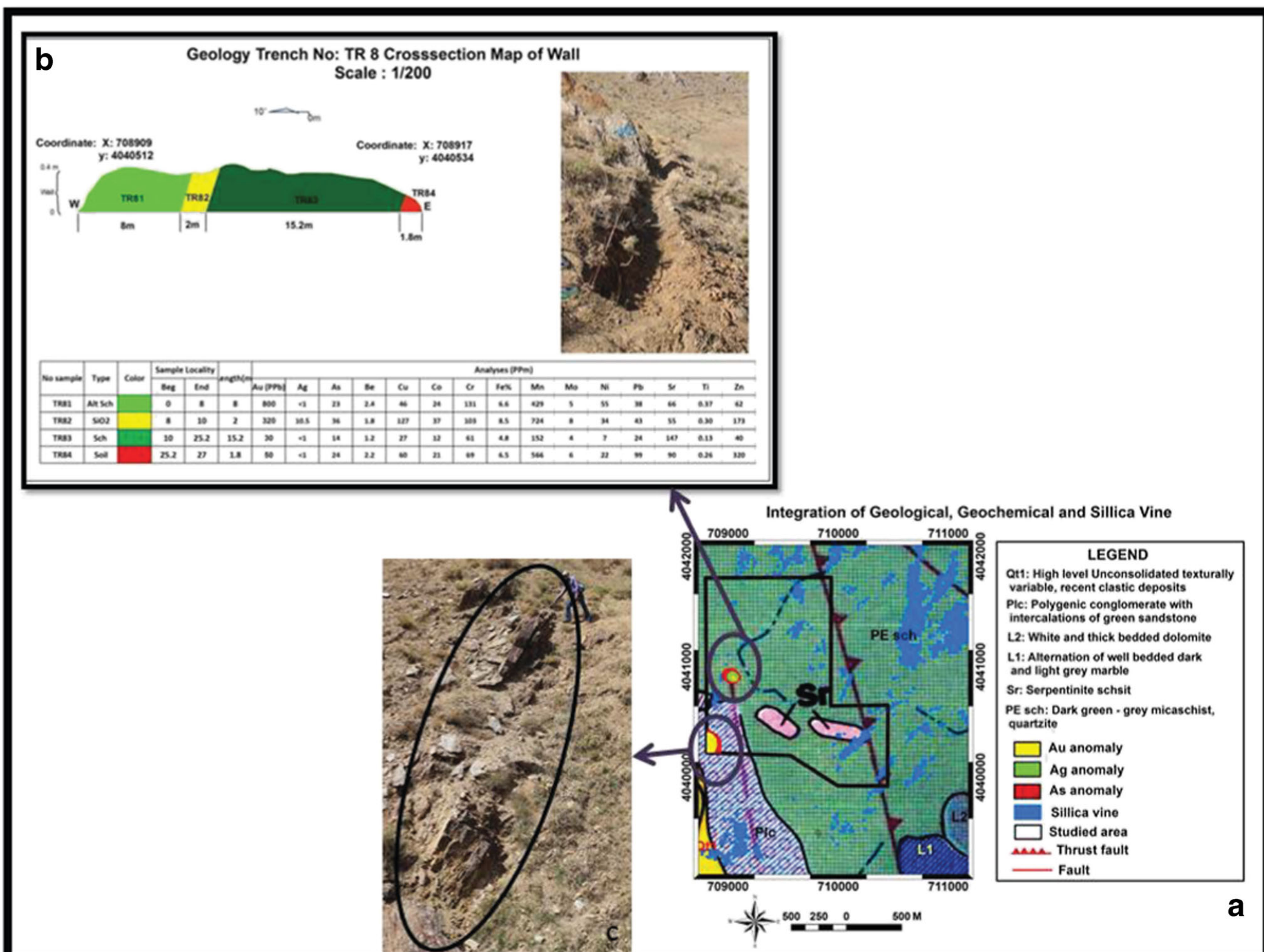


Fig. 17 Correlation among the geological, geochemical data and silica veins



No sample	Type	Color	Sample Locality		ength(m	Analyses (PPm)														
			Beg	End		Au (PPb)	Ag	As	Be	Cu	Co	Cr	Fe%	Mn	Mo	Ni	Pb	Sr	Ti	Zn
TR81	Alt Sch		0	8	8	800	<1	23	2.4	46	24	131	6.6	429	5	55	38	66	0.37	62
TR82	SiO2		8	10	2	320	10.5	36	1.8	127	37	103	8.5	724	8	34	43	55	0.30	173
TR83	Sch		10	25.2	15.2	30	<1	14	1.2	27	12	61	4.8	152	4	7	24	147	0.13	40
TR84	Soil		25.2	27	1.8	50	<1	24	2.2	60	21	69	6.5	566	6	22	99	90	0.26	320

Fig. 18 The discoveries (**a**) with field investigations (**b**) & (**c**)

included Au, Ag and As anomalies. Although there are many outcrops of mineralization such as Galena in this area but they are not confirmed by geochemistry analyses as high potential anomalies.

Finally the Geological map of the area, the results of the geochemistry analyses and silica veins were integrated in GIS environment (Fig. 17). At last two final discoveries are suggested which are shown in Fig. 18a by black circles. The check field results of these 2 areas are shown in Fig. 18b as a trench and sample analyses and Fig. 18c as a silica veins with Au anomalies.

Conclusions

As a result of the elaboration of geological domains, there is ambiguous knowledge on prospecting a favorable deposit type. So in this paper, target areas were distinguished by three geo-evidential layers. Integrated of Geological particulars, remote sensing and geochemical data introduced Au anomalies. Au anomalies dependent on vein type Quartz mineralization were seen widespread in the studied area. It seems that silica veins could be a suitable host rock for poly metal hydrothermal mineralization. The results of filed investigation were indicated, this silica is related to last phase of magmatic differentiation without any mineralization but it could be a suitable pathfinder for Au exploration in the studied area. Integrated of Geological particulars, remote sensing and geochemical data in GIS environment recognized two discoveries which are shown in Fig. 18a by black circles.

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