

USING 2D GIS TO ASSIST 3D MODELLING OF THE ZARSHURAN GOLD DEPOSIT, IRAN

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ABSTRACT

The Zarshuran gold deposit in NW Iran is an area of historic mining for gold and arsenic with considerable potential for discovery of economic gold mineralisation. Geological, geochemical and geophysical data, collected by the Ministry of Mines and Metals were compiled and analysed in a 2-dimensional (2D) GIS. This resulted in the definition of major structural features, and lithological units, that control the gold mineralisation. Spatial modelling and interpretation of the geochemical and geophysical data showed that the mineralization is mainly controlled by chemically-reactive Precambrian carbonates and black shales, extending in a NW-SE direction, and also by NE-SW high angle faults and their intersections with NW-SE structures. The results obtained, from the 2D GIS analysis, were used in the initial phase of the construction and validation of the 3-dimensional (3D) models used for resource estimation. Comparison of the statistical analyses of geochemical data in soils and in drillcore indicated enhanced concentrations of gold in soils at surface, due to residual enrichment. An enrichment relationship was established based on interpretation of the cumulative frequency plots for gold in soil and drillcore samples. Based on this relationship the gold anomalies interpreted from the soil geochemical data were used to infer a resource potential, to a depth of 200m below surface, of 10Mt at an average grade of 0.2 g/t gold. The combined interpretation of results from the geochemical and geophysical data highlight several features which warrant follow-up with further drilling.

1 INTRODUCTION

The Zarshuran gold deposit is located north of Takab town in northwestern Iran (Figure 1). It is a well-known area of ancient arsenic and gold mining. In modern times orpiment and realgar have been mined for several decades on a small scale. In 1989, the Ministry of Mines and Metals of Iran undertook a gold exploration project to define and locate gold mineralisation in the Zarshuran mining district. This project resulted in identifying the district as having the highest mineral potential in Iran particularly for the occurrence of deposits of Au, Ag, Sb, Hg and As. An area of about 0.65km² around an arsenic mine has been the target for gold exploration during the last ten years. Results obtained from geological mapping, geophysics, soil geochemistry and drilling have been used to define a possible resource tonnage of 2.5 million tonnes of ore with an average grade of 10g/t of gold (Samimi, 1992).

The study presented here shows how an analysis of deposit scale surface geo-information, in a 2-dimensional (2D) GIS, can be used to provide valuable information for use in the initial phases of construction and validation of the 3-dimensional (3D) models used for resource estimation. The development of a 2D spatial model, which highlights features characteristically associated with gold mineralisation, is illustrated. The use of 3-dimensional sub-surface geological structures, inferred from an interpretation of this 2D spatial model, in the evaluation of the location, size and morphology of the potential orebody is also discussed.

2 GEOLOGY AND MINERALIZATION

The Zarshuran area is underlain mainly by rocks of Precambrian age. The oldest unit, the Iman Khan unit, forms the core of the Iman Khan anticline, symmetrically-plunging NW-SE over some 7 km. The Iman Khan unit mainly consists of chlorite-amphibole-schist and locally serpentinite. The Iman Khan schist is followed upwards by the Chaldagh limestone, the Zarshuran black shale with silica and carbonate intercalations and the Qaradash shale, tuff and sandstone. An Oligo-Miocene granitoid, intruded into the mineralised Precambrian formations, is highly altered, mylonitised and

weakly mineralized (Figure 1). The main faults present trend northeast-southwest and northwest-southeast in the Precambrian formation. Gold occurs mainly as disseminations in carbonaceous, siliceous, and calcareous beds within the Zarshuran black shale. Gold is also found in hydrothermal veins of massive quartz (jasperoid) and quartz veinlets formed by carbonate replacement along high-angle faults in Chaldagh limestone. The Chaldagh limestone is also mineralized at its contacts with the Iman Khan schist and with the overlying Zarshuran unit.

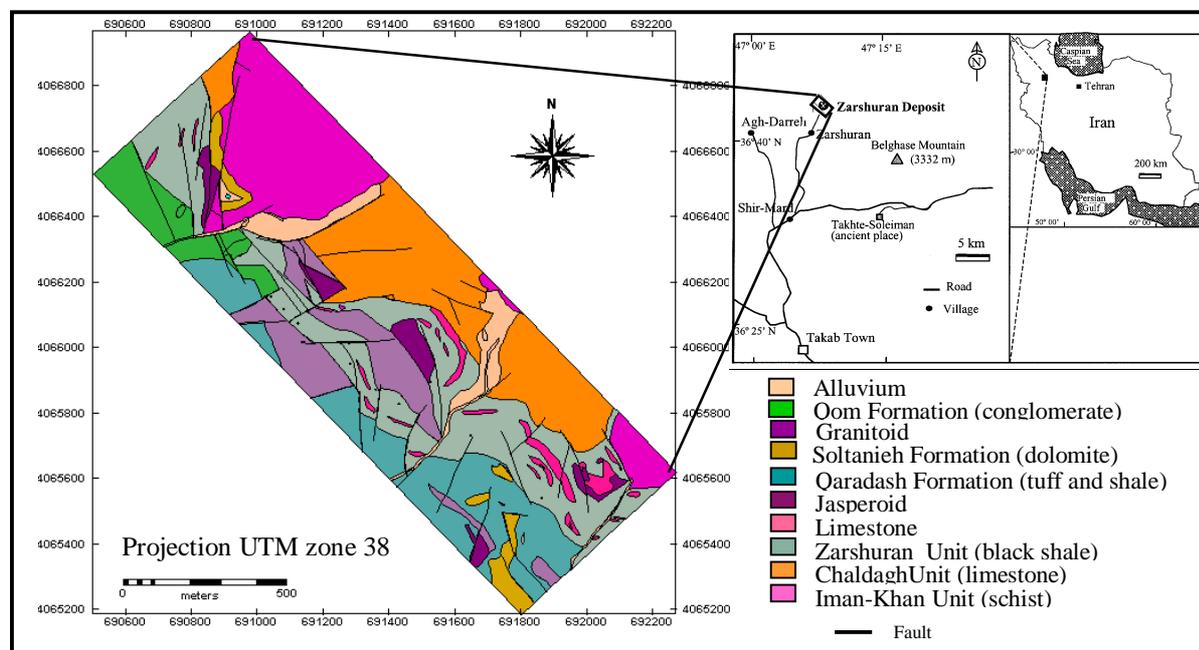


Figure 1. Location and detailed geology of the Zarshuran gold deposit, NW Iran.

Quartz, calcite, dolomite and clays are the principal minerals of the host rocks. Decalcification, silicification, and argillization characterize mineralized rocks. Decalcification increased the porosity and permeability of the host rocks and thus provided favorable sites for hydrothermal mineralization. The ore consists mainly of orpiment and pyrite, and to a lesser extent sphalerite, galena, realgar and stibnite, with subordinate cinnabar, HgS, lorandite, TlAsS₂, christite, TlHgAsS₃, coloradoite, HgTe, getchellite, AsSbS₃, aktashite, Cu₆Hg₃As₄S₁₂, baumhuerite, Pb₃As₄S₉, boulangerite, Pb₅Sb₄S₁₁, geochronite, Pb₁₄(Sb, As)₆S₂₃, plagiogonite, Pb₅Sb₈S₁₇ and twinnite, Pb(Sb, As)₂S₄. Sulfide oxidation is mainly confined to veins, veinlets, and fracture zones. Quartz, calcite, fluorite, hematite and barite are the main gangue minerals. Accessory minerals include apatite, Ca₅(PO₄)₃ (OH, F, Cl), rutile, TiO₂, zircon, ZrSiO₂, and xenotime, YPO₄ (Asadi et al., 2000). Gold is rarely visible but occurs invisibly in arsenian pyrite and sphalerite (Asadi et al, 1999).

The petrography, mineralogy and trace element geochemistry of the Zarshuran gold deposit show that it is a Carlin-like sediment-hosted disseminated gold deposit. The association of mineralisation at Zarshuran with a magmatic intrusion, and the presence of tellurium in concentrations sufficient to precipitate telluride, suggest a greater magmatic component in the mineralising hydrothermal solution than is typical for most Carlin-type deposits, best known in the western United States (Asadi et al., 1999 and 2000).

3 GIS DATA INPUTS

The geological maps on a district scale (1:10 000) and deposit scale (1:2000), 19 geological cross sections on a deposit scale (1:2000), a topographic map at a scale of 1: 2000 and bore hole locations were digitized using the Integrated Land and Water Information System (ILWIS) GIS.

The geochemical data available were derived from samples taken on a surface grid with a 100m by 20m sampling interval which covered an area of about 9km² (larger than the area shown in Figure 1). A total of 4500 surface-soil samples were collected from the grid and were analysed for Au, As, Sb, Ag, Tl, Hg, Cu, Pb, and Zn; these elements having been selected as direct and pathfinders indicators for gold mineralisation in an epithermal setting. The analyses were performed using atomic absorption spectrophotometry (AAS) at the Karaj Geochemical Laboratory in Tehran, Iran. The results were obtained in the form of hardcopy data listings, which included the sample numbers, coordinates

in a local grid, and the analytical results. These data were captured in digital form using scanning and an optical character recognition (OCR) program. The resultant data were saved in a spreadsheet file after careful validation of the data entry against the original data sheets. The soil samples had been collected on two separate rectangular grids, orientated at 46° (lines 280W-90E) and 63° (lines 100E-320E) to the North. In order to facilitate subsequent processing the UTM coordinates of all sample points were determined using a coordinate transformation option after the data had been transferred into a GIS.

Geophysical data were available in the form of a contoured ground magnetic intensity hardcopy map at a scale of 1:2000. The information contained on this map was converted into a digital format through digitising, a process that involved capturing the UTM coordinates (X and Y values) and ground magnetic total field intensity contour values (Z values) down the samples lines, which provided the closest approximation to the original data. The results were stored in an ASCII XYZ file format that allowed direct input for gridding and contouring processes.

4 2-D GIS ANALYSIS

4.1 Geophysical data

Epithermal gold deposits are highly variable in form, ranging from thin quartz veins to large bodies of disseminated mineralisation, and occur in a variety of geological environments. Consequently, they exhibit a wide range of geophysical signatures. The hydrothermal alteration that accompanies these deposits causes pronounced changes in the physical properties of the rocks. Asadi and Hale (1999) attributed the high analytical signals of total magnetic intensities of aeromagnetic data in the Takab area to intermediate composition magmatic rocks both at surface and at depth. They demonstrated that the highest magnetic anomalies are located in the Zarshuran mining area, where a number of carbonate-hosted epithermal gold-arsenic and antimony deposits are present. In this study processing and interpretation of ground magnetic data over the Zarshuran gold deposit are used to identify magnetic signatures associated with surface and subsurface geological features controlling mineralisation.

4.1.1 Qualitative analysis

Paterson and Reeves (1985) point out that analytical signal analysis of total magnetic field is often used for mineral exploration. It displays magnetic information in a more interpretable manner than total magnetic intensity: anomalies correlate directly with causative bodies and are positioned symmetrically over them. The analytical technique assumes constant directions of both geomagnetic field and the crustal magnetization over a certain region. On the other hand the analytical signal is independent of the inclination of the magnetic field (Qin, 1994).

An analytical signal image of total magnetic intensity was created for mapping surface and subsurface igneous rocks at Zarshuran (Figure 2a). The resulting analytical signal map with overlaid geology shows that the zone, which appears to have the highest amplitude signals (purple shade) is located in the marginal part of the Imam Khan schist. The strength of the magnetic intensity over the Imam Khan schist is very high in the order of 10,000nT. Such high large anomalies are seldom encountered (Reeves, personal communication) and are very typical of banded ironstones. From petrographic studies, in this case they can only be attributed to the serpentized ophiolitic rocks. Such rocks have been recently mapped at the core of Imam-Khan anticline as metamorphosed ophiolites in the 1:100,000 scale geological map of Takab area, published by Geological Survey of Iran. The low magnetic analytical signals (blue shade) are associated with Qaradash acidic volcanics and a highly altered Oligo-Miocene granitoid, which are both located in the SW of the area.

Processing of the geophysical image also involved the use of a combination of various filtering techniques that assisted in the interpretation by highlighting various aspects of the magnetic data. In many cases such processing revealed information that is not recognisable in conventional contour maps. Three directional filters (edge enhancement filters in the X, Y and 45° directions), were applied to the gridded total magnetic field data of Zarshuran. The horizontal and diagonally filtered maps highlight several linear trends in a NW-SE direction, whereas the vertical gradient filter reveals the presence of several NE-SW striking linear features. The processed images assisted identification of several NW-SE lineaments which are locally crosscut by NE-SW structures (Figure 4). The interpreted lineaments which lie within the Imam Khan unit are not present on the available geological map. These are therefore interpreted as being an expression of fracturing and faulting within the greenschists, which may be related to the adjacent granitoid intrusion.

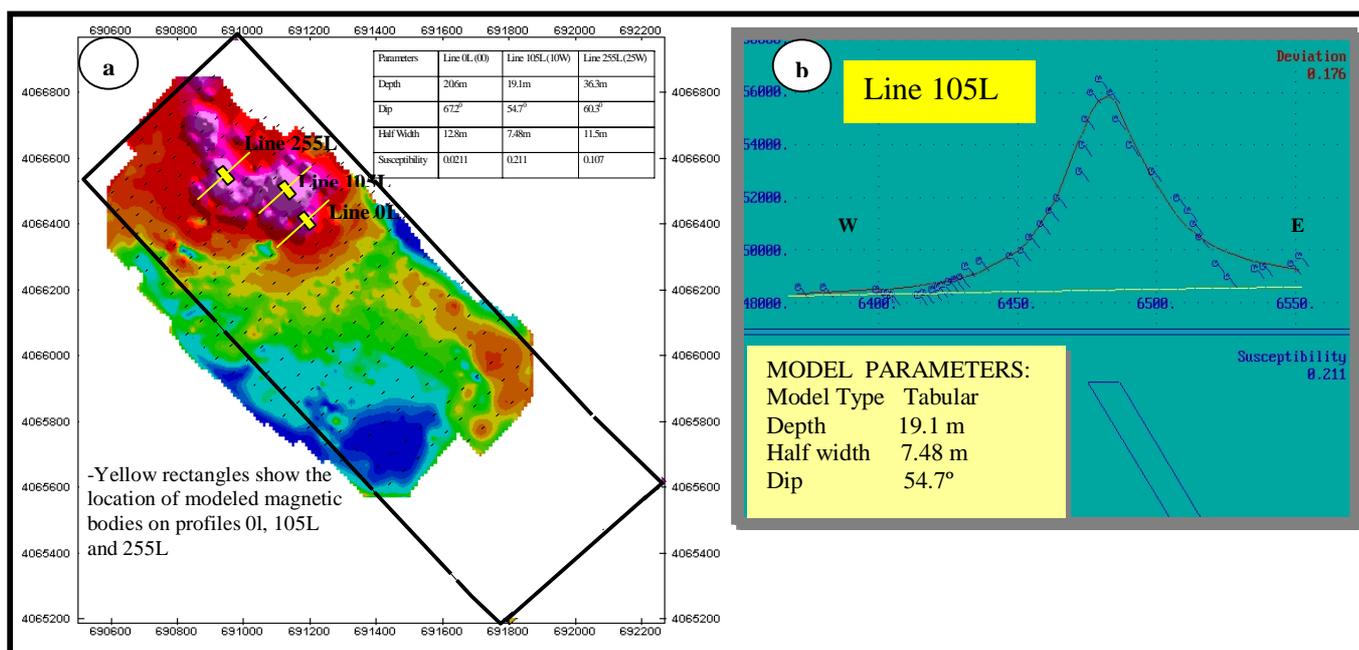


Figure 2. Analytical signal map of total ground magnetic intensity data at the Zarshuran deposit (a); and results obtained for quantitative modeling of the data for survey line 105L (b).

4.1.2 Quantitative analysis

Based on the qualitative analysis of the magnetic data, some elongated and circular strong magnetic anomalies over the Iman-Khan schist are interpreted as dykes or veins about 25-50m wide. The dimensions could probably be a bit larger but were affected by the smoothness of the data.

An interactive magnetic anomaly modelling and inversion program (MAGMOD3) was used to quantify the morphology of the subsurface magnetic bodies. The process of obtaining the "best fit" is carried out by adjusting the magnetisation and geometric parameters such as depth, dip, thickness, magnetic susceptibility, main position, and model type (tabular) that are applicable to a chosen geometrical model for a magnetised body. Three profiles, from the high magnetic anomaly area, were modelled using a TABULAR model. The location of these profiles is shown on Figure 2a.

The results obtained suggest that the anomalies present on all three profiles may reflect the presence tabular, highly-magnetic, bodies located at an average depth of 25 m, and dipping in a NE direction towards the core of Iman-Khan anticline. These magnetic bodies may be dykes or stock with intermediate-basic composition intruded into the basement schist. Details of the results obtained for survey line 105L are shown in Figure 2b, and results for all three profiles are summarised in Table 1.

Parameters	Line 0L (00)	Line 105L (10W)	Line 255L (25W)
Depth	20.6m	19.1m	36.3m
Dip	67.2°	54.7°	60.3°
Half Width	12.8m	7.48m	11.5m
Susceptibility	0.211	0.211	0.107

Table 1. Results obtained from the three modeled magnetic profiles

4.2 Geochemical data

Exploratory data analysis, using statistical and spatial mapping methods, was first carried out for the analytical results of all 4500 samples analysed from the total grid covering both the Zarshuran district and its surroundings (Kiiza, 2000). For the purposes of the study described here, a subset of the data covering the area immediately surrounding the Zarshuran deposit was subsequently created. This subset covers an area of around 3km², corresponding with the geographic limits of Figure 1, and contains 1214 samples.

4.2.1 Qualitative analysis

Exploratory analysis, aimed at the delineation of mineralised zones, was carried out using statistical and graphical methods. Only the results obtained for gold are discussed in this paper, since the main objective is to try to obtain a direct indication of the quality and quantity of gold mineralisation present. The procedures used to analyse and interpret the soil geochemistry results for gold are summarised briefly below:

- Statistical summaries were used to identify data ranges, presence of any outliers, and number of valid analyses. The results obtained highlighted a few data entry errors that were corrected prior to subsequent analysis. Gold values showed a high skewness (10.25), and large differences between the arithmetic mean (842 ppb) and the median (33 ppb), indicating the presence of a log normal distribution.
- Plotting of frequency histograms and cumulative probability plots. These confirmed the log normal nature of the distribution and indicated the presence of multiple populations. The cumulative frequency curve for gold (Figure 3, left hand graph) clearly indicates the presence of at least two distinct log-normal populations. The inflexion point at 300 ppb was taken as a possible threshold value for separating the two populations.

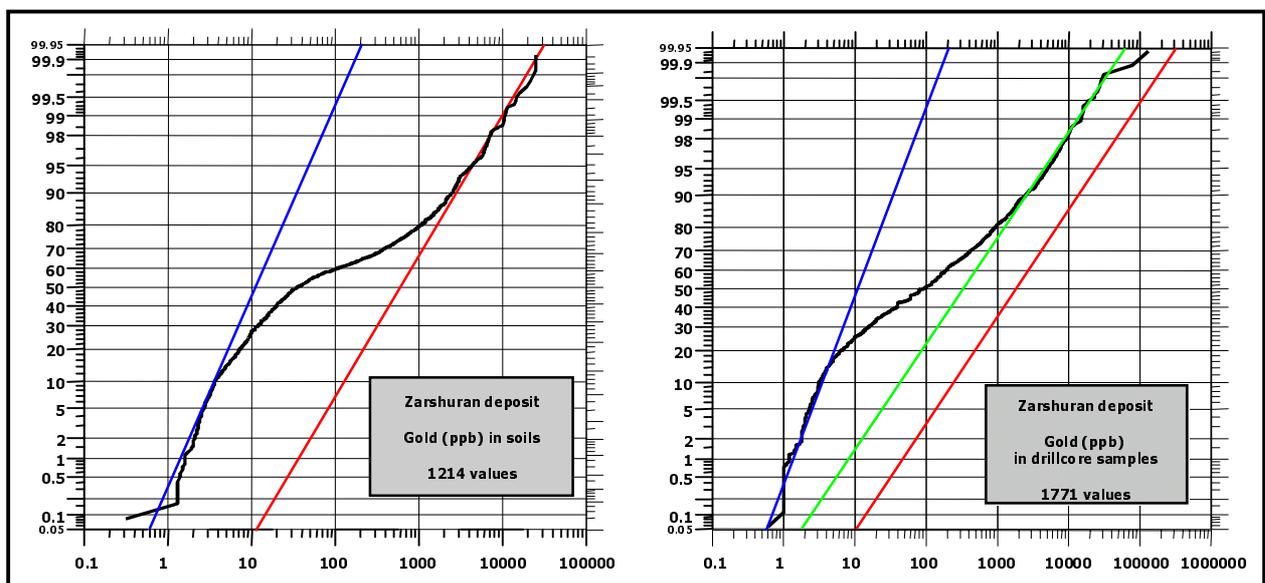


Figure 3. Log-scaled cumulative probability plots for the gold distribution in soil (left), and in drillcore (right), samples. Inferred populations present are indicated by the diagonal lines (blue - low grade population common to both sample types; red - high grade population in soils; green - high grade population in drillcore samples)

- Classed symbol plots of the gold values. These were used to indicate the spatial distribution of the two populations identified on the cumulative frequency curve. A simple two class plot, based on the 300 ppb threshold value, indicated that the majority of the high grade population samples fell in a single area corresponding with the outcrop area of the Chaldagh and Zarshuran units at the Zarshuran deposit (see Figures 1 and 4). Additional symbol plots with a larger number of classes were used to confirm trends identified on the contour plots of gridded data.
- Gridding of data. Data was gridded using a quadrant search control, with an anisotropic search ellipse, in order to ensure that the unequal spacing, along and between sample lines, did not result in distortions of the results. Several different gridding methods were tested, in order to select the optimal approach for interpretation of geological related features in the data. Given the strongly skewed distribution of gold values, and the log-normal character of the two inferred populations, gridding of the natural logarithms of the gold values was eventually selected as giving the most readily interpreted results. Anisotropic inverse distance squared weighting was applied in order to take account of a preferred continuity parallel to the strike (NW-SE) of the units present.
- Contouring and imaging of results. Various displays were used to create the maps which formed the basis for interpretation of the geochemical data. Due to the log normal distribution, it was found preferable to contour data at regular intervals according to the log values. The colour shaded example shown in Figure 4 was used to interpret "ridges" and "troughs" that are inferred to reflect the influence of geological variations on the soil results. Black and white contour plots with more closely spaced contours were also used to highlight sharp discontinuities that may

reflect cross-cutting faults, or geological contacts across which there are abrupt changes in gold content. Features interpreted from these plots are summarised in Figure 4.

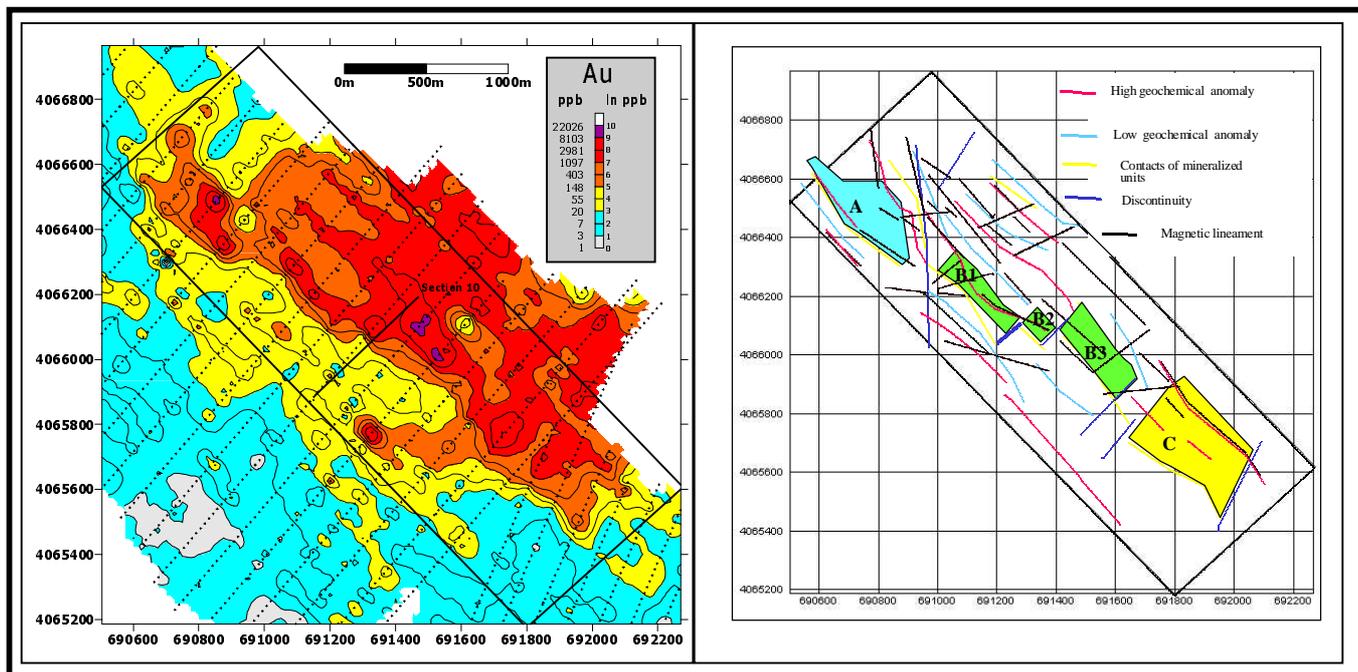


Figure 4. Colour shaded contour plot for gold in soils at the Zarshuran deposit (left); contours shown are at regular \log_e ppb intervals. Features interpreted from the gold soil geochemical maps, and processed ground magnetic data, are summarised in the map shown on the right.

4.2.2 Quantitative analysis

Results from follow-up drilling done in the Zarshuran area in 1994 and 1995 were available from 13 drillholes. A comparison of these results with those obtained from the soil geochemistry in the same area was used in order to allow quantitative predictions of resource potential to be made using the soil geochemical results.

Log probability plots of the drillhole data again indicates the presence of two distinct populations (Figure 3). Comparison of the populations inferred from the soil and drillcore samples suggest that whilst more or less identical low grade populations can be inferred, there is a strong difference between the high grade populations (Figure 3). The high grade population in the soils shows a significantly higher average gold grade than that for the drillcore samples, although similar variances are indicated. This is interpreted as reflecting strong residual enrichment of gold in the soils. The relationship indicated in Figure 3 was used to predict in situ gold grades from the average present in the defined soil anomalies (Figure 4), as discussed below.

4.3 Three-dimensional interpretation

Based on the results obtained from the interpretation of the available spatial data sets, several important features of direct relevance to 3-d geological interpretation for resource estimation have been identified. The main features of relevance are summarised briefly below:

- The main NW-SE stratigraphic trend is confirmed by linear anomalies identified in both the geophysical and geochemical data (Figure 4).
- Several NE-SW linear features, which terminate or displace the stratigraphic trends, are inferred to represent faults (Figure 4).
- Quantitative interpretation of the peak magnetic anomalies indicates the presence of one or more tabular magnetic bodies, within or on the contact of the Iman-Khan schists, which dip NE at around 60 degrees (Figure 2).

- d) The N-S magnetic anomaly, which has been modelled on line 255L, coincides with an inferred N-S structure identified from the geochemical data (Figures 2 and 4). This feature may represent an important, previously unmapped, fault forming the western boundary of the Iman-Khan unit in this area. From the results of the quantitative geophysical modelling it is inferred to dip E at about 60 degrees.
- e) Results for several drillholes were compared with the corresponding geochemical results obtained in soils (Figure 5). This comparison highlights the considerable enrichment of gold in soils compared with corresponding grades in drillcore. The soil anomaly shown here correlates well with the mapped contact between the Zarshuran limestones and the granitoid. This profile then shows a 200m section with soil values in excess of 1000ppb gold, whereas in the drillhole which cuts the same units there are only 4 samples with grades greater than 1000ppb, representing a single 3m intersection. In addition the soil geochemistry results suggest the presence of significant mineralisation within the Chaldagh limestones, which is not confirmed in the drillhole. This is interpreted as "smearing" of the anomaly over units which were previously overlain by mineralised material, with gold having been concentrated in soils after erosion of their host rocks. This would account for the scarp-like topography of the main geochemical anomaly shown in Figure 4 (ie sharp gradient on the SW flank compared with a gently sloping plateau to the NE). Comparison of the results of geophysical modelling with drillhole data was not possible since all the available drillholes are situated to the south of the main magnetic anomaly.

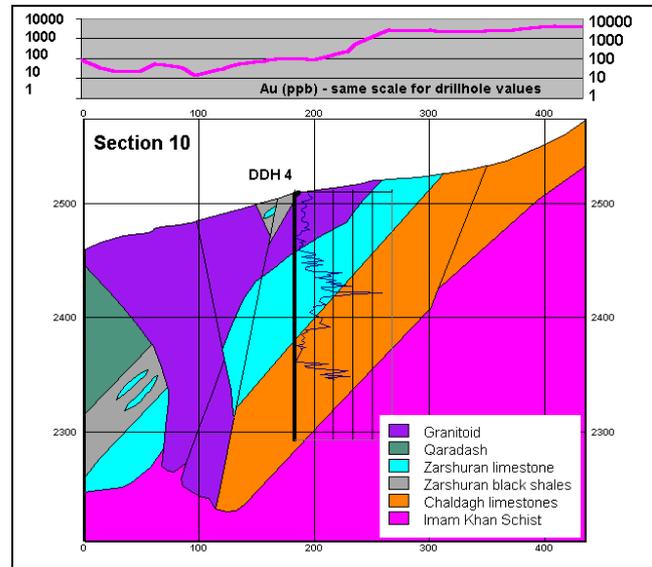


Figure 5. Interpreted geology on drillhole cross-section number 10 (see Figure 4 for location), showing downhole histogram of gold values in drillhole 4 for comparison with profile showing gold values in soils (both profiles are log scaled starting at 1ppb gold)

- f) Calculated areas, and average values of gold in soils, for the main geochemical anomalies (Figure 4), were used to predict the potential volume and grade of the in-situ resource. In this case the inferred in-situ grades were determined using the log-probability graphs presented in Figure 3. These results are summarised in Table 2.

Anomaly	Area m ²	Soils Au In ppb	Soils Au ppb	Rock Au Ppb	Vol_100m Mm ³	Vol_200m Mm ³	Mass_100m Mt	Mass_200m Mt
A	53125	6.26	523	90	0.53	1.06	1.33	2.66
B1	24375	7.12	1236	250	0.24	0.49	0.61	1.22
B2	6250	7.98	2922	500	0.06	0.13	0.16	0.31
B3	32500	7.88	2644	400	0.33	0.65	0.81	1.63
C	94375	6.87	963	175	0.94	1.89	2.36	4.72
TOTAL	210625	6.93	1201	207	2.11	4.21	5.27	10.53

Table 2. Resource potential inferred from geochemical anomalies for gold in soils. Anomaly areas (column 2) are used to infer volume and mass to 100m and 200m depth (columns 6-9). The average grade of the soil anomalies (columns 3-4) are used to infer in situ grade (column 5) using the sample populations identified on the cumulative frequency plots (Figure 3).

5 CONCLUSIONS

The results presented here indicate that the Zarshuran deposit occurs in an area with exceptionally anomalous values of gold in soils and very high intensity magnetic anomalies. Careful analysis and modelling of these features in a 2D GIS

allows the extraction of several important geological structures that are believed to play an important role in determining the morphology of sub-surface gold mineralised zones. In particular the quantification of the degree of residual enrichment of gold in soils was possible by comparison of the soil results with analyses from drillholes made in the same area. Based on this relationship, it has been demonstrated that it is possible to use the size and magnitude of soil gold anomalies to infer the quantity and grade of in-situ gold mineralisation present.

REFERENCES

- Asadi H.H., J. H. L. Voncken and M. Hale (1999). Invisible gold at Zarshuran, Iran. *Economic Geology*, vol. 94: pp.1367-1374.
- Asadi H.H. and Hale, M. (1999). Integrated Analysis of Aeromagnetic, Landsat TM and Mineral Occurrence Data for Epithermal Gold Exploration in Northwest Iran. Presented at the 13th International Conference on Applied Geologic Remote Sensing, Vancouver, British Columbia, Canada, 1-3 March 1999.
- Asadi H.H., J. H. L. Voncken, R. A. Kuhnel and M. Hale (2000). Petrography, mineralogy and geochemistry of the Zarshuran gold deposit and implications for ore genesis. *Mineralium Deposit* (in Press).
- Ngonzi K. (2000). Spatial Modeling of mineral exploration data from the Zarshuran gold deposit, Iran: using 2D approaches to guide 3D resource modeling. International Institute for Aerospace Survey and Earth Sciences (ITC), The Netherlands, MSc thesis, 150 pp.
- Paterson N.R. and Reeves C.V. (1985). Applications of Gravity and Magnetic Surveys: The State-of-the-Art in 1985," *Geophysics*, 50: pp. 2558-2594.
- Qin S. (1994). An Analytical Signal Approach to the Interpretation of Total Field Magnetic Anomalies, *Geophysical Prospecting*, Vol. 42: pp.665-676.
- Samimi M (1992) Reconnaissance and preliminary exploration in the Zarshuran area. Kavoshgaran Engineering Consultant, Tehran, 47 pp (in Persian).