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Term 112

Term Paper

Mineral Exploration Using GIS

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Table of Contents

Code	Content	Page No.
	Table of Contents	2
	List of Figures	3
	Abstract	4
1	Introduction	5
2	Objective	7
3	Motivation	7
4	Methodologies	7
5	Literature Review	8
5.1	Mapping the subsurface using GIS	8
5.2	GIS for mineral exploration	9
5.3	Benefits of GIS in mineral exploration	10
6	Case Studies	11
6.1	Utilizing GIS in mineral exploration: Case study	11
6.1.1	Introduction to study area	11
6.1.2	Exploration in Tara mines using GIS	12
6.1.3	Results	14
6.2	GIS modeling technique for gold exploration: Case Study	17
6.2.1	Introduction to Bulghah area	17
6.2.2	Geologic setting and mineralization	18
6.2.3	Methodologies	20
6.2.4	Results	24
7	Discussion and Analysis	25
8	Conclusions	26
	Acknowledgment	26
	Bibliography	28

List of Figures

Code	Description	Page No.
Fig. 1.1	GIS is the best platform for integration a wide range of data	5
Fig. 1.2	The work flow from acquisition to output	6
Fig. 6.1	Geological map of Ireland showing the mines locations	12
Fig. 6.2	Navan Orebody Footprint	12
Fig. 6.3	Various GIS software used to combine data	14
Fig. 6.4	From drill holes data to dynamic model	15
Fig. 6.5	Exploration Drillhole positions for Navan Orebody	15
Fig. 6.6	Combined Zinc and Lead distribution throughout the Navan Orebody	16
Fig. 6.7	Zinc Haloes in the Upper Dark Limestone Lithology Unit at Navan	16
Fig. 6.8	Modelling of Geochemical Haloes of Lead and Zinc	17
Fig. 6.9	Locations of Bulghah gold mine	18
Fig. 6.10	Geological map of the Bulghah area	19
Fig. 6.11	SPOT image covering Bulghah area	19
Fig. 6.12	GIS procedures to produce the favorability map	21
Fig. 6.13	Lithology layer and the major classes displayed in pseudo-colors	22
Fig. 6.14	Major structure layer "Faults"	23
Fig. 6.15	Lineaments distribution	23
Fig. 6.16	Favorable contacts between tonalite–diorite intrusions and Hulaifah volcanics	24
Fig. 6.17	Favorability map for gold exploration over Bulghah gold mine area	25

Abstract

Geographic Information System or GIS can be utilized in different fields in Geology such as; mineral and petroleum exploration, environmental studies, geological mapping and hydrogeological modeling, and others. In mineral exploration GIS can be used to a set of characteristics of specific minerals deposition that might be used as a guide to similar deposits in the region. Loss of organized way and procedure for collecting, displaying, managing and combining various geologic spatial data and from different sources and scales which in turn make the operation of mineral exploration encountered with some difficulties. The datasets include bedrock and superficial geological maps, geophysical survey data, geochemistry of samples, and mineral occurrence data. Also, a number of line features such as; structural features, fold axes and formation contacts, should be present. The GIS is the best management tool for collecting and integrating all these spatial data. So, the aim of this paper is to showing how the GIS serve mineral exploration companies by creating maps (2D and 3D) showing areas favorable for mineral to deposit, based on the distribution of known minerals occurrences, and how GIS can save time and money.

1. Introduction:

The Geographic Information System (GIS) now is used in many fields among such as agriculture and land use, forestry and wildlife management, monitoring of desertification, archaeology, city planning, municipal applications and geology. The applications of GIS in geology are very broad and diverse, but here we'll focus in GIS application to serve mineral exploration.

The process of mineral exploration composed of several stages which starts with small scale and develops into larger scale. In every stage, geological, topographical, geophysical, geochemical data are collected, processed and integrated. Then, after finishing every stage produced mineral potential map and the study area becomes smaller.

Mineral exploration companies deal with various types of data sources to explore for minerals deposits. The types of data vary from geological maps, multispectral satellite images, and geophysical images to databases in different formats. The best platform to bring all these data together and get a precious result is GIS (Fig. 1.1).

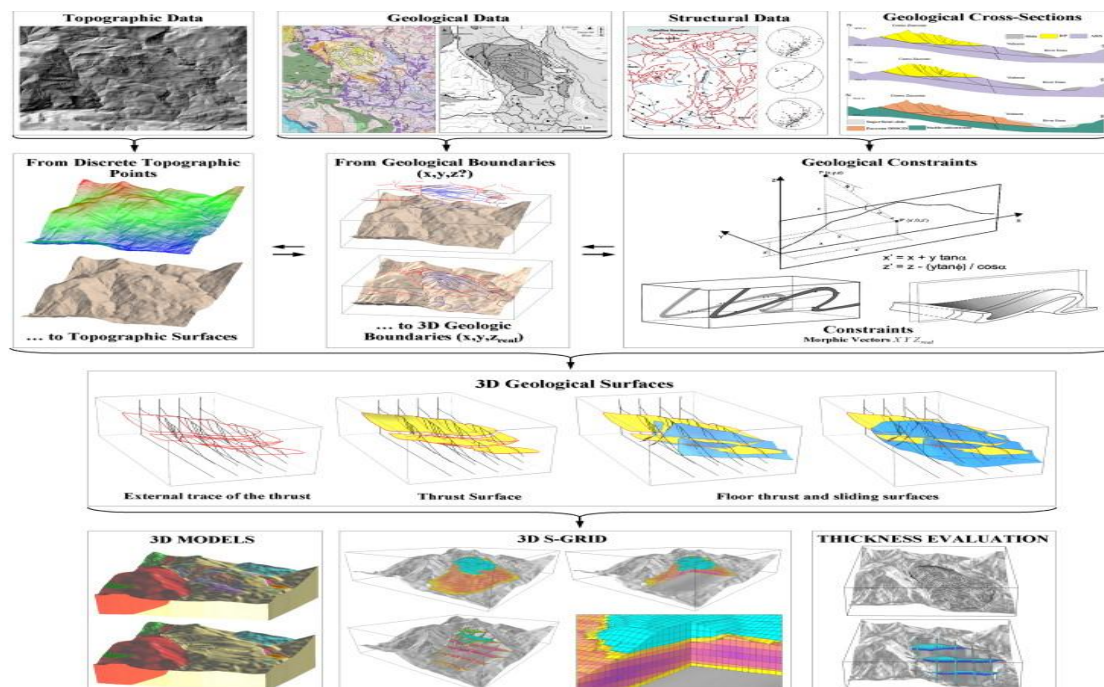


Fig. 1.1: GIS is the best platform for integration a wide range of data.
(<http://www.directionsmag.com>)

GIS also can be used to generate a mineral potential map, in the absence of comprehensive systematic mineral exploration programs, it is important to develop alternative methodologies of mineral potential classification.

Then, it's possible to use spatial data that are relevant to mineral potential such as; lithology and topography, which are available for most areas. The importance of such data can be realized by their incorporation in GIS (Bonham-Carter, 1994). Then it is important to add exploration criteria. Those criteria provided by conceptual mineral deposit models are invaluable bases for the generation of mineral potential information.

GIS can be useful in many stages of mineral exploration processes: data acquisition, storage, manipulate, and reporting. Its possible now to the geologists gain the field data electronically that by using Global Positioning System (GPS) receivers. The Internet also can be act as a source of data sets which can be downloaded directly from it. All these data types can be combined, integrated, and analyzed using GIS.

GIS can easily integrate with other specific programs for image and geophysical data processing. So, Raster images such as satellite imagery or geophysical images can be displayed in GIS and overlaid with vector data such as geology, faults, and geochemical samples. The Figure 1.2 shows the workflow from acquisition to the final result using GIS for mineral exploration.

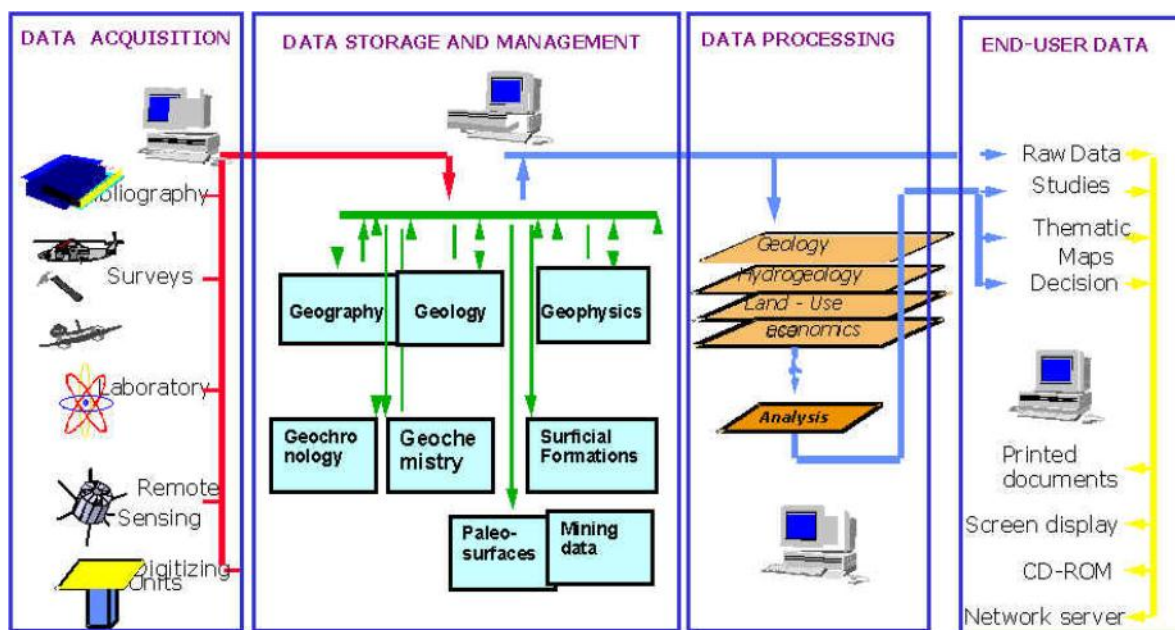


Fig. 1.2: The workflow from acquisition to output (Carranza, 2009).

2. Objective:

The main objective of this paper is to give an idea and workflow of the applications of the GIS technology in mineral exploration and mention how the GIS technology can assist in evaluating the potentiality of mineral in prospected locations and taking the appropriate decisions. Basically the advantages of GIS technology in mineral exploration are:

- GIS provides the companies by the geographic and spatial advantage to target mineral potential.
- GIS combines and displays the data together in easy to use software applications and tools.
- Improving and increasing the spatial context of the data available to mining planners and giving them a more thorough understanding of the geography of prospective sites.

3. Motivation:

The business of exploring and extracting for minerals is completely spatial, which help to make it easier for GIS. Because most of the mines cover wide areas of land, geologists require access to volumes of location-based data to lead the operation.

The using of GIS technology had these advantages:

- Minimize Exploration costs.
- Select targets with confidence.
- Effective field work.
- Quality maps and presentations.

4. Methodologies:

Due to the nature of the process of mineral exploration, geologists deal with a variety of data from different sources to explore for mineral deposits. They need to display and interpret this information quickly and easily. So, the study divided into several stages:

- Design the geodatabase according to the information that will go to be needed.

- Collect different datasets from a variety of sources and select the datasets which related to the study.
- Define the geological features based on the geological background and concepts that indicate to an area of mineralization.
- Bring all the datasets within the geodatabase along with all available and previous maps, charts and studies.
- Defining regions of interest from maps and graphs and it'll be created using a shape file from ArcGIS.

5. Literature Review:

5.1 Mapping the subsurface using GIS:

The mapping or modeling of the subsurface of earth is difficult to understanding our abilities and limitations regarding to oil and gas resources, mineral exploration, and environmental management.

The geologic modeling of the subsurface is a complex task for GIS technology. But, the spatial nature of the geologic objects always makes GIS to be an important part of the modeling and mapping systems.

The conventional activities in which GIS involved in geosciences are data display, data administration, area analysis, and support making decision. But, now the evolution allows the GIS capabilities on just a desktop computer with full possibility to integrate the industry-standard Relational Database Management System, 3D visualization, geostatistical functionality, 3D geoprocessing capabilities, and Web-based mapping. All these advantages make GIS the most useful and attractive tool for comprehensive and essential geoscientist's needs.

The latest GIS software's made on an open standard technology ensure that GIS can be easily integrated with advanced solid 3D geosciences software's to gain a solution for complex geologic problems. But until recently, although it's become easier, visualizing the subsurface of the earth within GIS has been a complex technical challenge.

These challenges are:

- Multiple data sets and maps.
- Efficiency of data combination and integration along various formats.

Nowadays, GIS subsurface modeling tools allow the geologists to present normally visualized on separate maps in an integrated form as well as deal and process surface data.

In addition to that, the possibility to display wells (drillholes and borehole), and other data from subsurface in 2D and 3D. Users can manipulate a large volume of surface and subsurface geological, geochemical and geophysical data in 3D within a single or transparently-linked interactive environment. They can enhance the drilling results and the environment that data was collected from. Also, they can display geochemical surface data and query geological mapping regions.

Geologists and geoscientists with these tools can integrate and manipulate all available data at each stage of the exploration program to gain a better understanding of the underlying subsurface geology, check their assumptions, and share their ideas with others on their exploration teams.

5.2 GIS for mineral exploration:

Geologists can apply GIS in mining and mineral exploration to present data in an integrated platform by using traditional cross-sections and graphical strip logs in conjunction with planning map views.

In mineral exploration geologists deal with various types and sources of data to explore for new economical mineral deposits. The data sources vary from geological maps, multispectral satellite images, and hyper-spectral airborne and geophysical images to data in many formats. GIS is the best platform to bring all these data together in a geologist's computer and deliver fruitful outcomes.

GIS is now able to assist geologists in many fields related to their activities such as; data acquisition, administration, manipulate, and evaluating the whole operation. Now, the geologists are able to collect field data electronically by

using Global Positioning System (GPS) receivers and ArcPad. Also, we can download other data from the Internet.

All types of geological datasets such as; geological maps, geochemical logs, geophysical images, boreholes, radius measurements, and mineral accumulations, can be shown, revealed, and interpreted immediately using GIS.

On the other hand, Roads, pipelines, ramps, electric lines, and other mining requirements change usually. The operators and engineer's crew can use GIS for the applications of production plans. For example, they keep tracking the available basement and combining it with the mining plan and pure modeling can be done using GIS.

Fortunately, GIS may used to combine survey data with complete models or mining planning information which result from various mine software groups such as GeolSoft, Surpac Range, Mine Sight, Vulcan, and Mining Visualization System (MVS).

Many of mine data comprising money and evaluate information has some source of spatial feature that may easily displayed in maps forms. Managers and economist are using GIS in their evaluation of corporate and competitor assets. Mining companies also use GIS to actively monitor the environmental impacts that may be caused by their activities and conduct reclamation.

5.3 Benefits of GIS in mineral exploration:

GIS in mineral exploration can be time effective in order to the following factors:

- Combine data and datasets from different sources with ease.
- Link directly from modeling software such as; MapInfo and Leapfrog to database of results ensuring the most recent assay information from analytical testing are included.
- Model quickly and easily in 3D the resource you are exploring from both historical and modern drillhole data stored in your database.

- This method of modeling saves digitizing many different features to be included in the model as it can be interpolated from the drillhole data by the system.

On the other hand, GIS can save money and decrease the regular cost to explore for minerals and this due to these reasons:

- Fewer hours spent digitizing to incorporate data into models.

- Variety of GIS analysis methods on quantitative and raster data to look for anomalous areas.

- The ability to capture old data of different types and view/analyze as compatible layers. Some of this data would only previously have been examined in paper formats.

- Ability to utilize free historical and modern data in current projects - there is a wealth of mineral exploration resources available on the web for free which can be utilized in the search for ore bodies: historical geological maps, satellite imagery, geophysical data and geochemical assay results data for the exploration target area in question are published freely on the internet.

- Using GIS in mineral exploration encourages a more efficient use of already existing data which is cost effective. Exploration costs are rising –exploration drilling can be expensive and the rate of discovery of large world-class ore bodies is decreasing. However, re-analysis of existing data – both modern and historical, through GIS modeling e.g. through 3D modeling, allows for more targeted, cost effective exploration drilling.

6. Case Studies:

6.1 Utilizing GIS in mineral exploration: Case study

6.1.1 Introduction to study area:

This case study is done by Boliden Tara Mines Company, which is located besides Navan, 55 Km NW of Dublin, Ireland (Fig. 6.1) which is Europe's largest Zinc producer (Fig. 6.2).

They produce zinc and lead concentrates and started production in 1977 and resources remain to support mining until the year 2018, and beyond. Up to 2009 over 73 million tons have been mined.

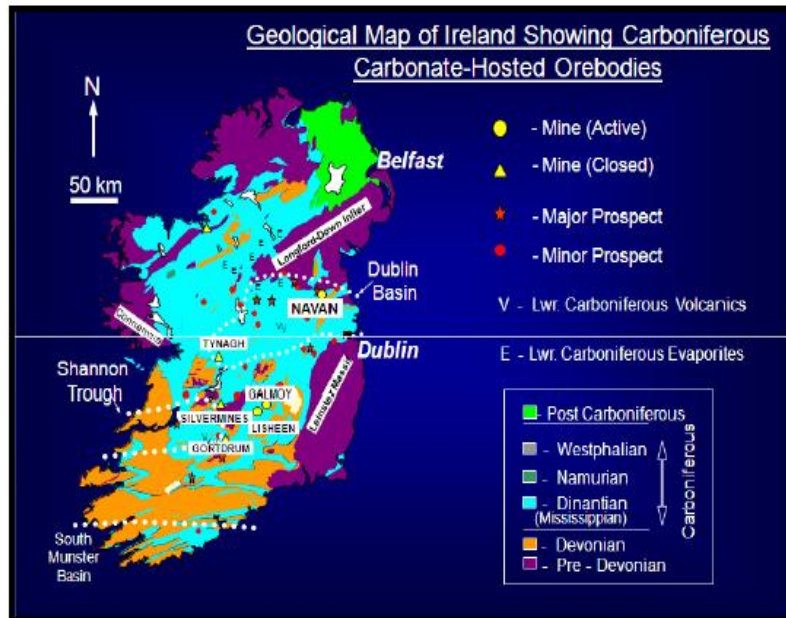


Fig. 6.1: Geological map of Ireland showing the mines locations (Tara mines, 2010).

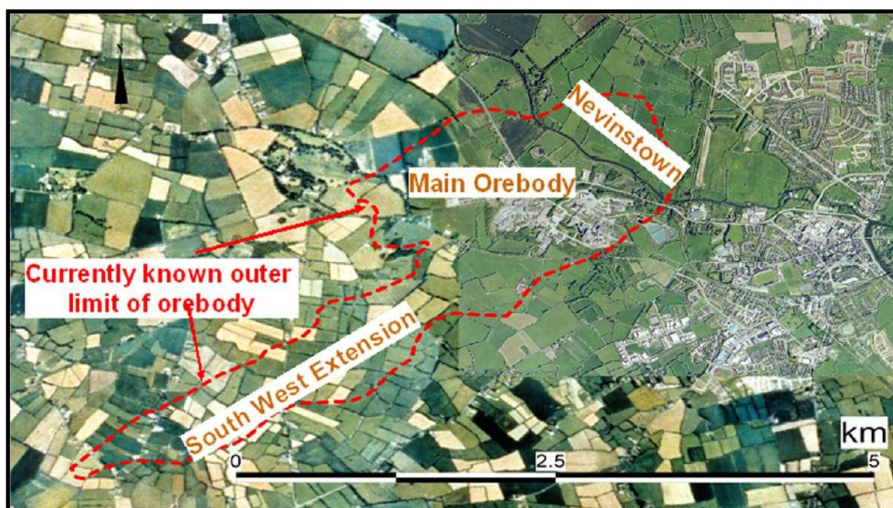


Fig. 6.2; Navan Orebody Footprint (Tara mines, 2010).

6.1.2 Exploration in Tara mines using GIS:

* Exploration Methods:

They used different exploration methods which are combined easily using their GIS systems. Those methods are:

-Aeromagnetic Surveys.

- Airborne and Borehole Electromagnetic Surveys.
- Electrical Resistivity.
- FTG (Full-tensor gravity Gradiometer).
- Geochemical Surveys.
- Gravity Surveys.
- Historical Data.
- IP Surveys (Induced Polarization).
- Remote Sensing.
- Seismic Surveys.

*** Exploration Database:**

In a study of the Boliden Tara Mines Limited Database by Walker (2010) it was determined that there are 3 types of lithochemical data stored within the central database – The Acquire© (Geoscientific Information Management System) System:

- 1- Mine Drilling Results: Analysis of drill-core for Zinc, Lead and Iron from Mine Drilling.
- 2- Exploration Drilling Results: Samples may have been assayed as in point 1 for Zinc, Lead and Iron and/or also sampled for a range of other elements. The exact method of analysis, range of elements assayed for and digestion is variable. This variance has arisen over a number of years due to technological advances and changes in methodology.
- 3- External Data; Assay data similar to points 1 and 2, however it has been acquired over a number of years from ‘open file’ data. Open file data is typically data from prospecting licenses previously held by other prospecting companies, usually detailed in a submission/release form of the prospecting license. Data also produced by the Geological Survey of Ireland (GSI) may become commercially available e.g. regional soil geochemical data.

***Combining Databases:**

The databases as seen previously gather a variety of different methods, also a lot of different sources.

GIS used with various 2D and 3D software programs to amalgamate and view results (Fig. 6.3). Such as;

- MapInfo®.
- Leapfrog3D©.
- Oasis Montaj.

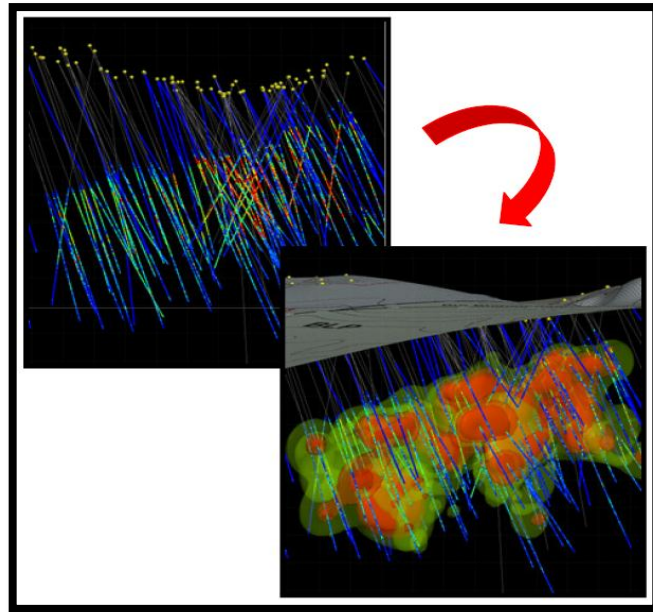


Fig. 6.4: From drill holes data to dynamic model (Tara mines, 2010).

Using a 3D GIS Modeling package like Leapfrog3D in Mineral Exploration you can quickly go from what shown in Fig. 6.5:

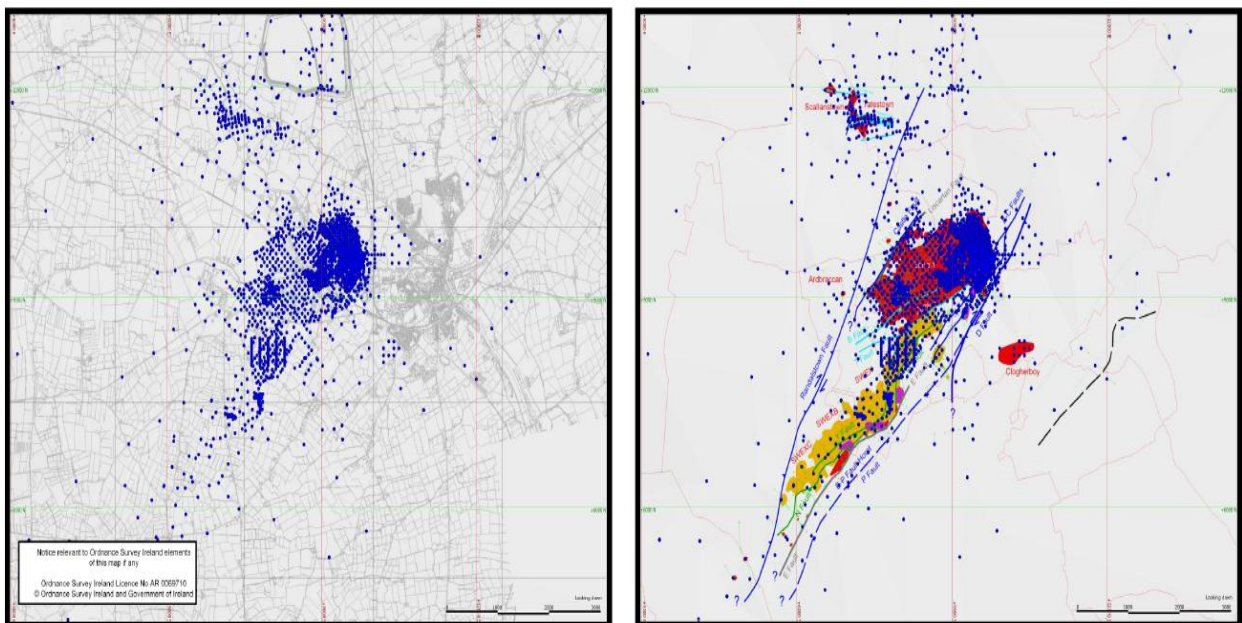


Fig. 6.5: Exploration Drillhole positions for Navan Orebody, on left overlying OS Map of Navan and surrounding area, on right over simplified Geological Orebody Projection (Tara mines, 2010).

To this shown in Fig 6.6:

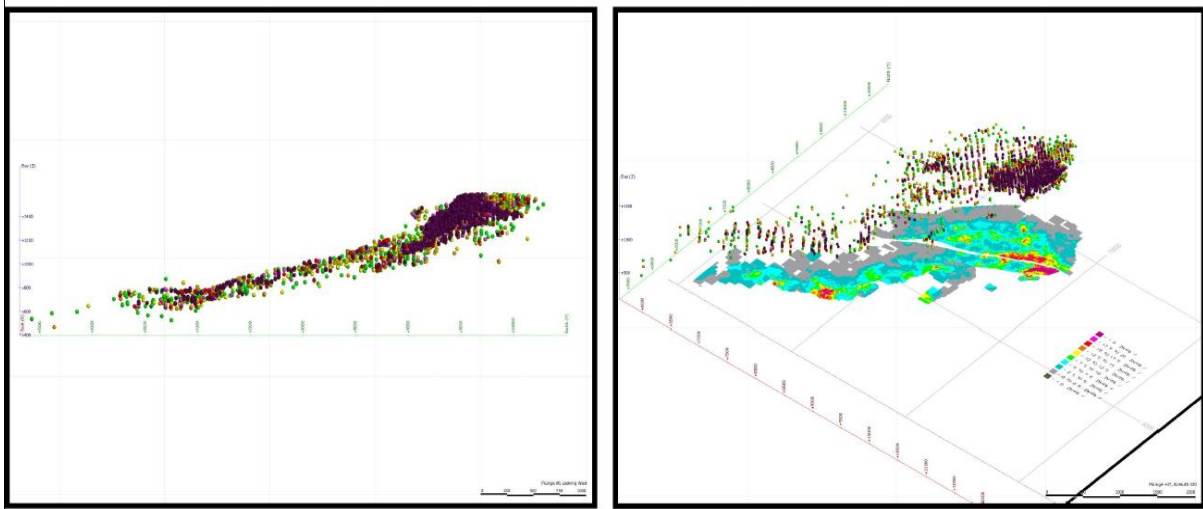


Fig. 6.6: Combined Zinc and Lead distribution throughout the Navan Orebody. In the image on the right, the lithochemical data is colour-ramped to match the gridded mine image (Tara mines, 2010).

And then quickly to this shown in Fig. 6.7:

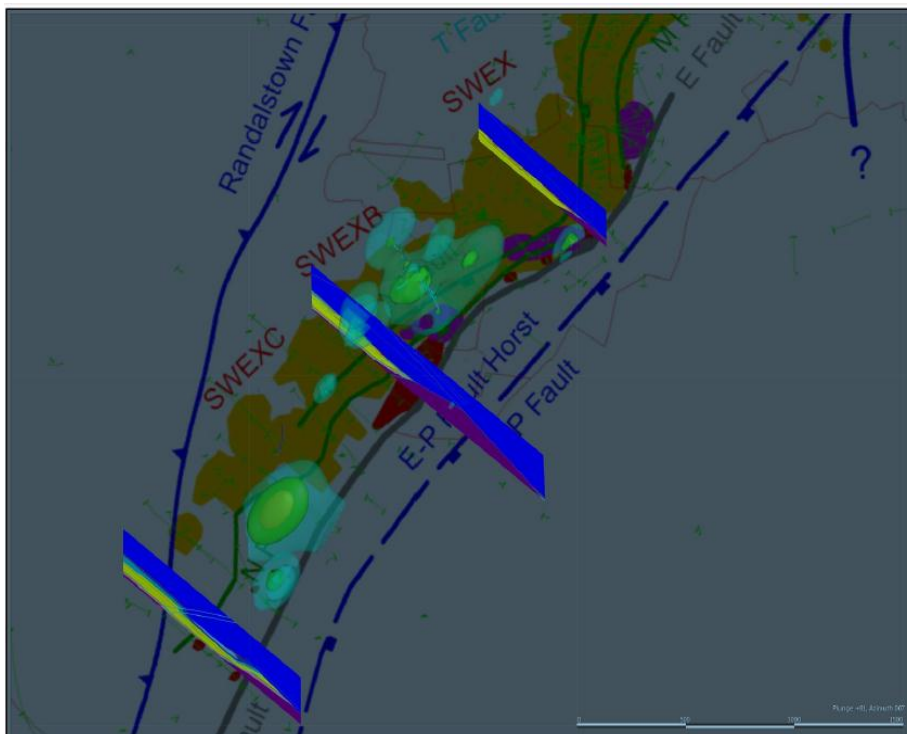


Fig. 6.7: Zinc Haloes in the Upper Dark Limestone Lithology Unit at Navan (Tara mines, 2010).

They also used the software to delineate the geochemical holes for serving the exploration process (Fig. 6.8).

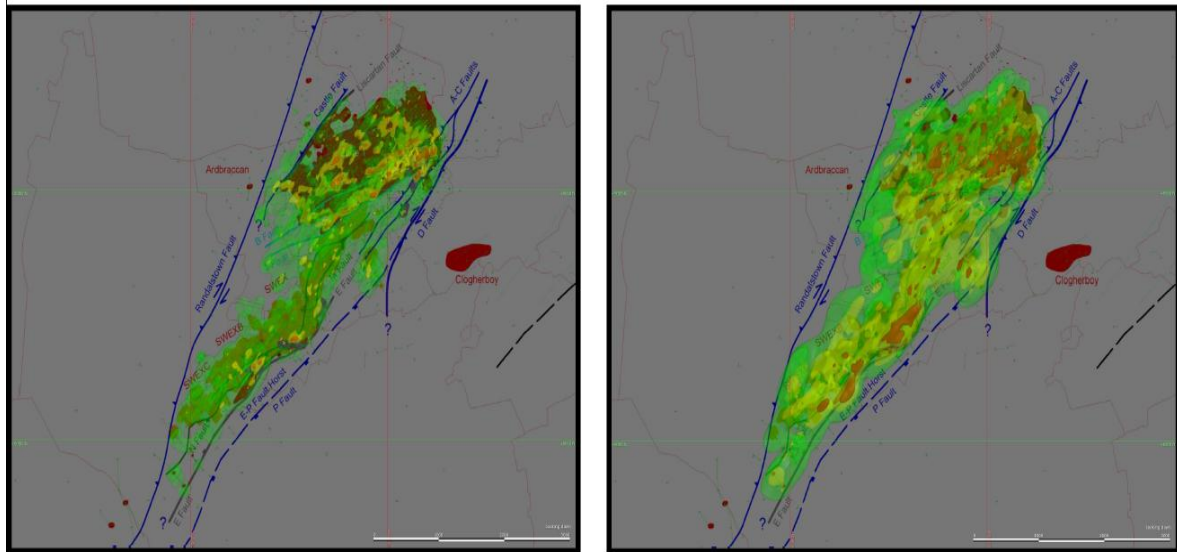


Fig. 6.8: Modeling of Geochemical Haloes of Lead (on the left) and Zinc (on the right) around the Navan Orebody which are useful in Exploration purposes (Tara mines, 2010).

6.2 GIS modeling technique for gold exploration, Bulghah mines area, Saudi Arabia.

6.2.1 Introduction:

Bulghah gold mine is extended from west of Afif terrane to east of the Nabitah suture zone (Fig. 6.9), approximately 520 km west–northwest of Riyadh city, the capital of Saudi Arabia.

Geographic information system (GIS) is an effective tool for generating favorability maps for mineral exploration by integrating, analyzing and weighting several exploration datasets.

The present study aims to locate new extensions for tonalite–diorite intrusions hosting gold deposits using integration of geo-datasets with the aid of weighting approach.

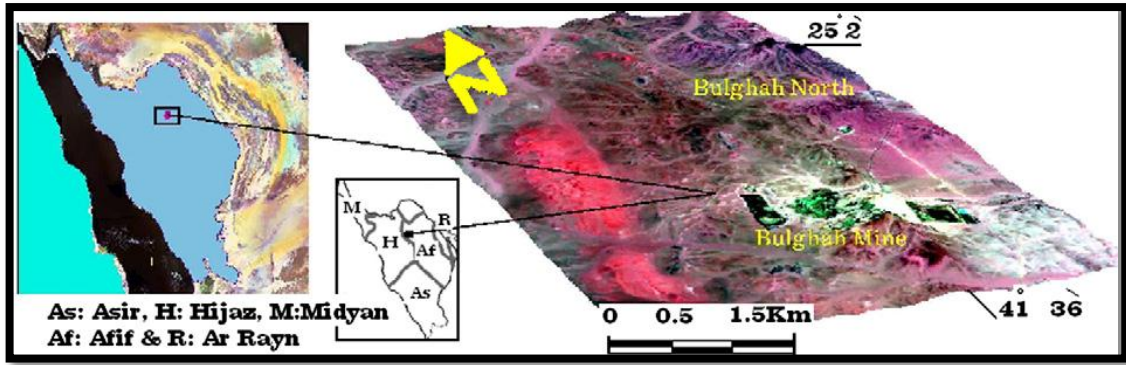


Fig. 6.9: Locations of Bulghah mines (3D view) (Madani, 2011).

Gold production at the Bulghah mine reached 1.735 t tonnage with 0.7 g/t Au in 2007 (SRC, 2007).

The mineralization of gold in Bulghah area is mainly formed during syn to late tectonic intrusions of tonalite–diorite rocks and is associated with quartz (\pm carbonate) veins, cataclastic zones and micro-fractures.

6.2.2 Geologic setting and mineralization:

The country rocks at the Bulghah area are represented by Hulaifah volcanics which are made up of the older Formation (Afna) and the younger Formation (Nuqrah) (Fig. 6.10). Volcanic rocks and volcanoclastic derivatives also found in the eastern and western parts of the Bulghah area and may represent the Afna Formation.

The present field study with the aid of multispectral SPOT data reveals the presence of three main deformation events affecting the study area. The oldest deformational event in the study area is represented by the major N–S strike-slip fault that lies to the west of Bulghah gold mine (Nabitah belt). The second phase of deformational events is represented by NW-SE left-lateral strike-slip faults that obey the Najd fault system, which is observed to dissect the major N–S strike-slip fault and the bend basin especially in its southern part (Fig. 6.11). Najd faulting event is characterized by elastic deformation of a brittle craton resulting in an extensive left-lateral wrench-fault system. The last deformational event affecting the study area is represented by extensional deformation as indicated by the NW-SE andesitic dykes cut the intrusions of tonalite and diorite observed in the northern part of Bulghah mines.

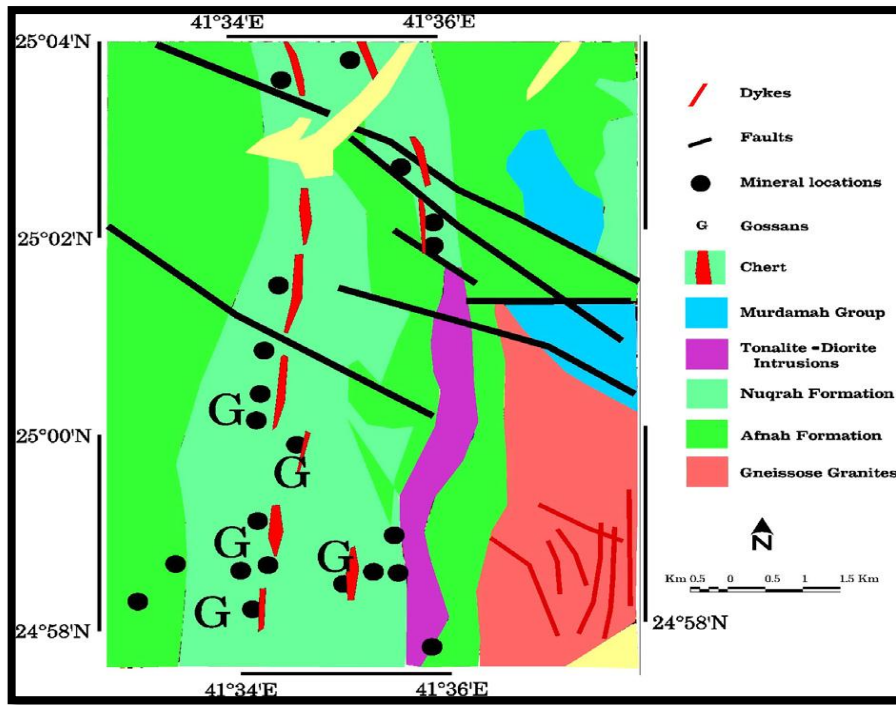


Fig. 6.10: Geological map of Bulghah area and distribution of the units cover area, modified after Delfour (1977).

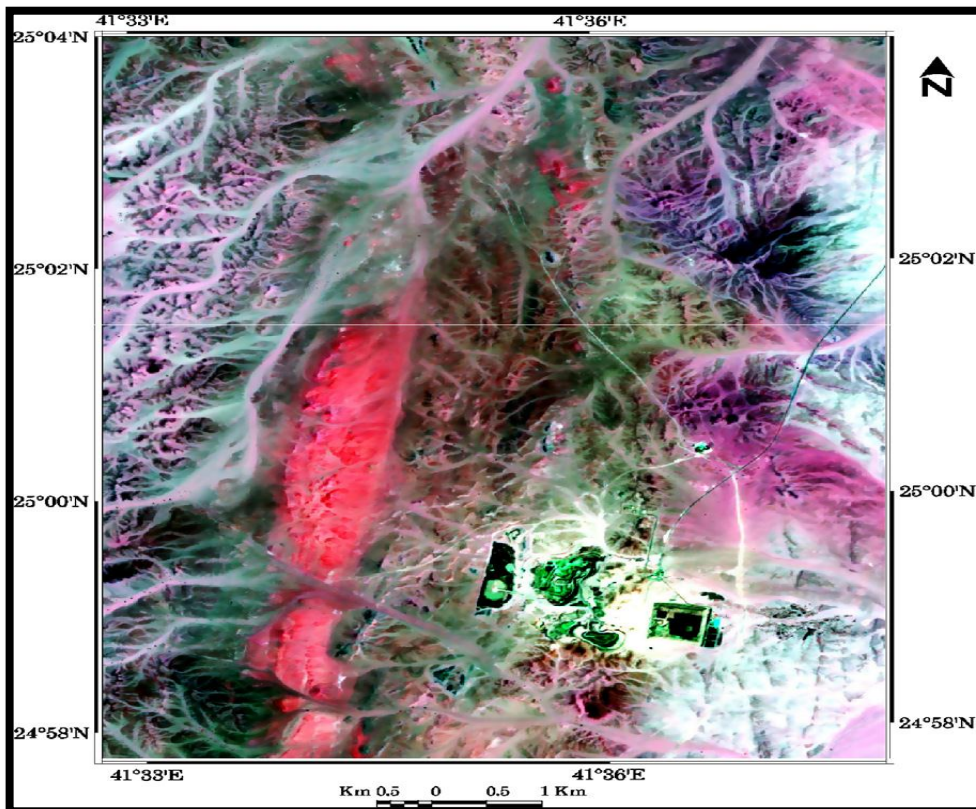


Fig. 6.11: SPOT image covering the study area (Madani, 2011).

The mineralization in Bulghah mines was a result of structurally focused hydrothermal fluid that formed during regionally extensive crustal extensional deformation and associated cataclastic fault development.

Bulghah gold deposits are classified as mesothermal vein-type mineralization formed in association with interplate settings and hosted in Najd fault system structures mostly in intrusions of granite either structurally and/or magmatically controlled (Agar, 1992). Barnicoat et al. (1998) attributed the formation of gold deposits in Bulghah mines to structurally focused hydrothermal fluids that occurred during strongly and regionally extensional deformation.

Two steps of gold mineralization are associated with the Nabitah and Najd phases of deformation. Enrichments for gold may occur during the second stage of deformation (Najd system) and play a valuable role in the grade of the gold. Areas in vicinity of Najd faults are supposed to be highly enriched in gold.

6.2.3 Methodologies:

This study depend on the integration between various data layers (Fig. 6.12), each class within each layer has a specific weight according to its important in mineral exploration.

Assignment of weight on different layers is done using knowledge-driven approach. After the score had been defined for layers using knowledge-driven approach, the average score is then defined by this equation:

$$S = \frac{\sum_{i=1}^n S_{ij} W_i}{\sum_{i=1}^n W_i}$$

Where S is the assigned score to the cell, W_i is the weight for the input layer, and S_{ij} is the score for the j -th class of the i -th layer, the value of j depends on the class actually occurring at the current location.

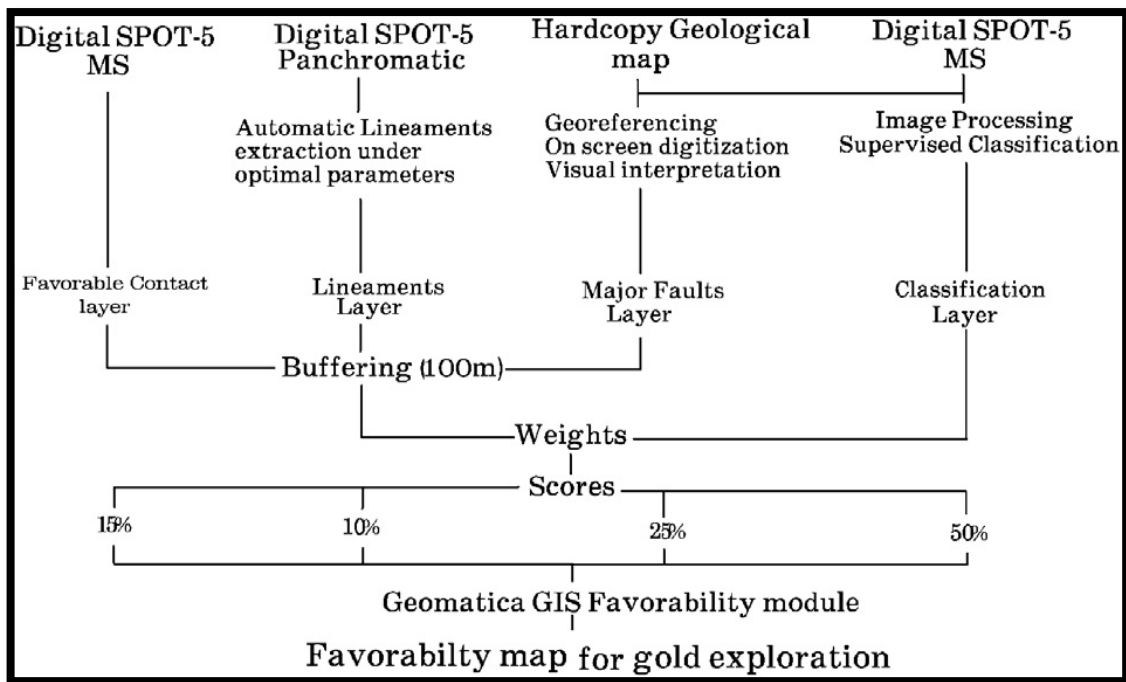


Fig. 6.12: GIS procedures to produce the favorability map.

Four main layers are prepared for GIS modeling. These layers are lithology (classified image), major faults, lineaments and favorable contacts layers. The favorability map is generated by summing up the various layers. Internal weights for each layer are assigned based on favorability for gold deposits. Scoring with the following percentages (50%, 25%, 10% and 15%) is assigned to lithology, major faults, lineaments and favorable contact layers, respectively.

- **Spatial data analyses:**

There are some criteria such as; Lithology and structure are assessed to be the most important for gold deposits exploration in the Bulghah area. These criteria are recognized on the basis of understanding the geological setting and the controls of gold mineralization. The layers used in the model are:

1- Lithology Layer:

From lithological point of view any areas characterized by tonalite–diorite intrusions have high potential for gold mineralization. Digital SPOT 5 multispectral images covering the study area are utilized to perform supervised classification method using maximum likelihood classifier. Four main classes (tonalite–diorite intrusions, Hulayfah volcanics, gossans and other units) are defined using training areas gathered during the field visits.

From this classification a thematic map that contains four main classes is the result and each class has a unique gray level which can be displayed with pseudo-colors (Fig. 6.13). The class bias is used to resolve the overlap between classes, and weights one class in favor of another.

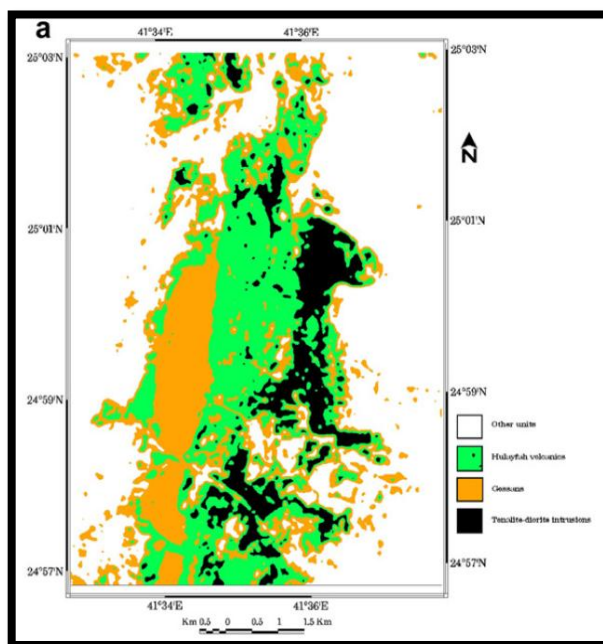


Fig. 6.13: Lithology layer and the major classes displayed in pseudo-colors (Madani, 2011).

2- Major structure layer:

This layer generated by combination between SPOT panchromatic imagery with field observations (Fig. 6.14). It shows the three fault systems in Bulghah area and their trends. Generally, the faults trending NE–SW and NW–SE, and are about 20 cm width. The faults also marked by the occurrence of brown hematite clay material appear on the fault plane.

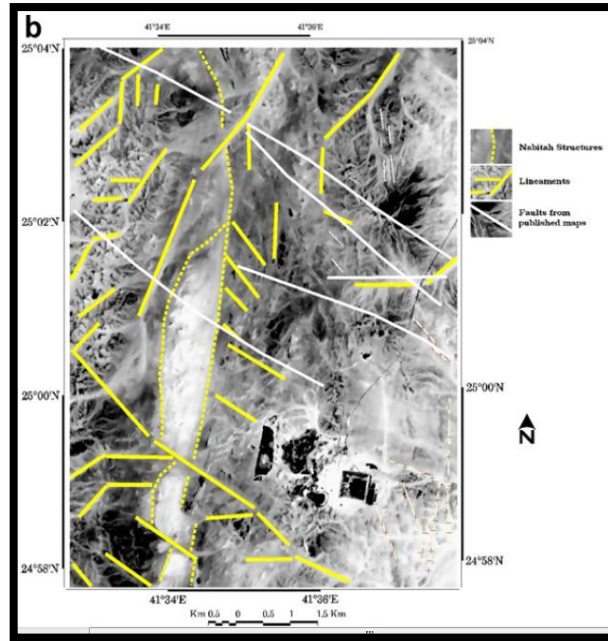


Fig. 6.14: Major structure layer "Faults" (Madani, 2011).

3- Lineaments layer:

In this study they used SPOT panchromatic band is used for lineament extraction. The result (Fig. 6.15) shows that NE–SW and NW–SE are two main trends whereas E–W and N–S are subordinate trends.

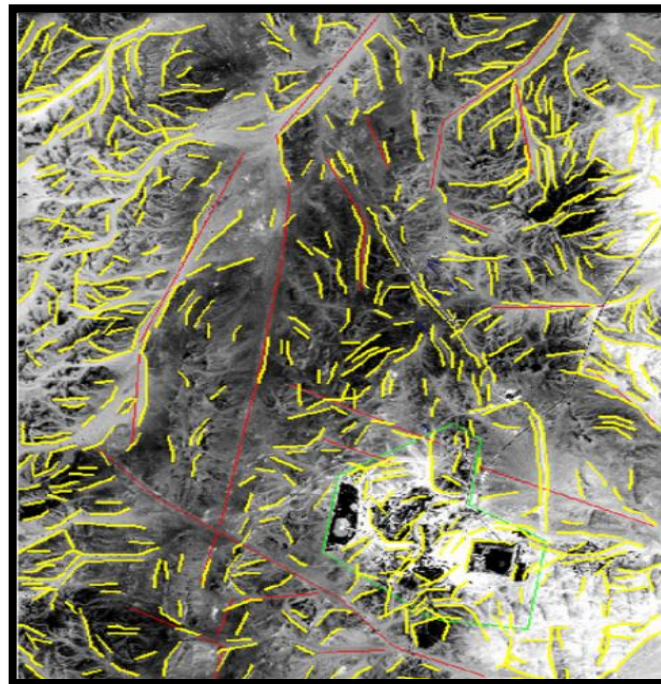


Fig. 6.15: Lineaments distribution (Madani, 2011).

4- Favorable contacts layer:

Lithological boundaries between the intrusions of tonalite and diorite and the volcanics of Hulayfah are high potential for gold concentrations especially along the fault contacts (Fig. 6.16).

Several trenches been studied along the western margin of the intrusions of tonalite and diorite. They discovered that there is a presence of a tight high grade mineralization area almost 2 g/t along the contact that can be traced for several hundreds of meters.

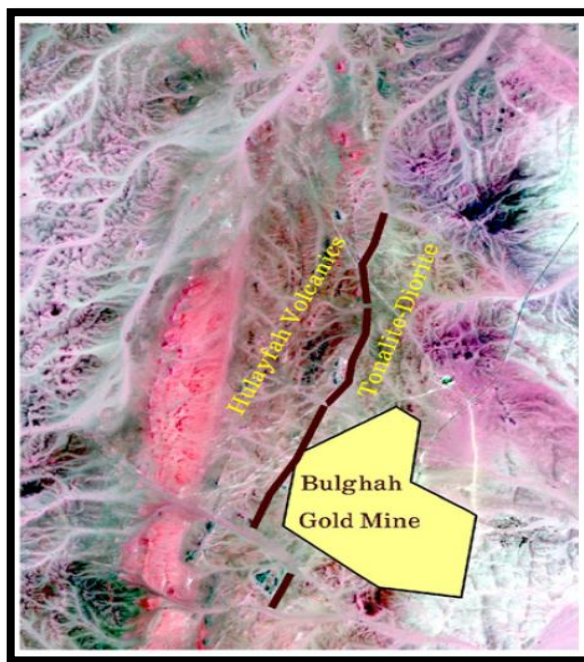


Fig. 6.16: Favorable contacts (black line) between tonalite–diorite intrusions and Hulayfah volcanics (Madani, 2011).

6.2.4 Results:

Spatial data analyses and integration based on knowledge-driven and weighting model are performed with pixel size of SPOT imagery. The methodology involves the generation of four binary predictor maps (lithology, lineaments, major faults and favorable contacts) indicating the presence or absence of gold mineralization. These binary maps are used as predictors for generating a favorability map. Three binary predictor maps (lineaments, faults and favorable contacts) are buffered to 100 m and weighting internally, in which the highest favorable sites for gold mineralization are assigned to 7 whereas the lowest favorable sites have 0. Fig. 6.17 shows the result of the favorability map for gold exploration at the Bulghah area derived using knowledge-driven and weighting method. On the favorability map the unfavorable sites have the black color. The

favorability increases till reaching white color which represents the highest favorable sites.

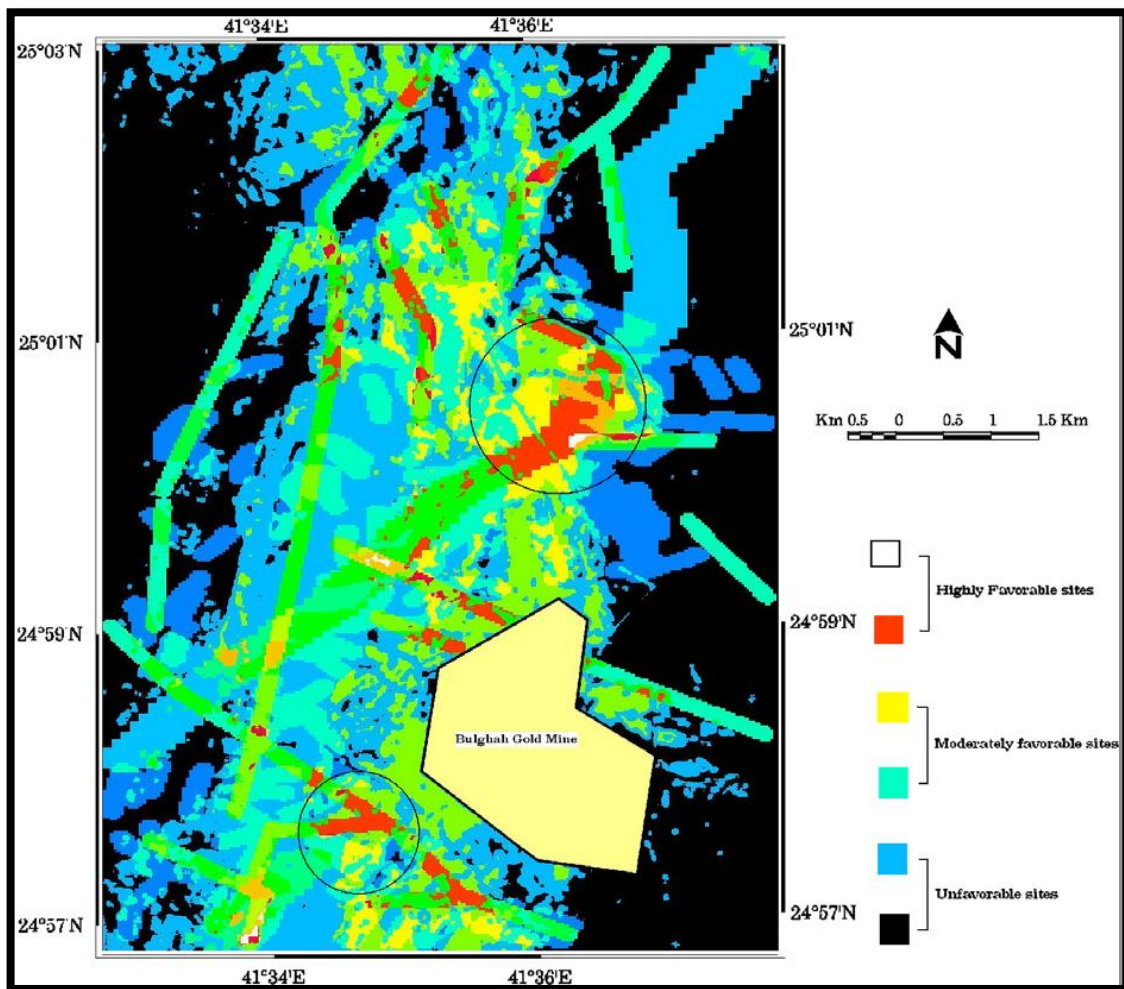


Fig. 6.17: Favorability map for gold exploration over Bulghah gold mine area. Circles defined the new favorable sites for gold exploration.

7. Discussion and Analysis:

Successful and valuable management of a country's mineral resources requires collection and integration of a wide range of geological, geophysical, topographical and other related information. GIS form the perfect area to gain this success.

However, the advantages of using GIS in mineral exploration are:

- Displaying a wide range of data with various types in one place.

- Relative ease of importing diverse map inputs, graphics and creating fruitful database.
- Ability to move and combine between GIS and other DOS –compatible software packages.
- Interactive graphics capability, with windowing, map overlays, and vector overlays permitting experimentation not previously practical.
- Integration of various data, unique conditions mapping, area analysis, and modeling.
- The browse character which is very useful for keeping track of both the development and final stages in a data integration project.

8. Conclusions:

Most of the data related to the operations of mineral exploration have a spatial nature. So, GIS has the capability for storage, updating, revising, displaying, retrieving, processing, manipulating and integrating of different geo-spatial data.

Recently, GIS technology able to help geoscientists and geologists in mapping and modeling the subsurface by a modern tools and softwares packages and can be integrated with other specialized 3D programs to get a precious results. All this just act as additional properties to its traditional functionality.

Now it is important to finish polishing the tool so it can be used to advance the mineral exploration process while saving time and money and increasing profitability and efficacy.

Acknowledgement:

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