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Utilization of Lineaments Extraction from Satellite Imageries in Structural Mapping and Mineral Exploration of Central Wadi Araba, Southwest Jordan

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*A*bstract This study utilizes the extraction of lineaments from digital satellite imageries in structural mapping and minerals exploration along the eastern part of Central Wadi Araba in southwest Jordan. Lineaments have been automatically extracted from the digital data of panchromatic Landsat ETM and panchromatic SPOT imageries under the selective optimal parameters of PCI-Geomatica software Package. The total numbers of the extracted lineaments from Landsat and SPOT imageries were 342 and 784, respectively, so the lineaments map extracted from the SPOT imagery is selected to produce the structural lineaments map of study area. The structural lineaments map is corrected and verified by field investigation finally. The structural framework of the study area has been achieved, where most of the lineaments are related to the Dead Sea transform and transverse fault systems, while the Syrian Arc System is less dominant.

On the other hand, it was found that gold and copper mineralization are controlled by (NE, N-NS, for gold and NW, N-S & NE for copper). This is due to the low special resolution of both Landsat and SPOT images.

The image processing and field verifications reflect that the gold and copper mineralization in the study area are mainly associated to Ahaymir Volcanic Suite and Abu Khushayba Sandstone Formation respectively. The Gold and Copper mineralization are controlled by trends of structural lineaments in the NE and N-S directions and in the NW, N-S and NE directions respectively.

Introduction

In the present study, the remote sensing techniques were applied for lineaments extraction in the eastern part of central Wadi Araba. This area represents one of the most important areas in the world according to its structural and seismological points of view; "The Dead Sea Transform". Using of these new techniques will help to get more accurate and detailed results than the conventional methods in the fields of structural mapping, also to delineate more structural trends, and to detect the mineralization sites.

The study area lies along the eastern margin of the Central Wadi Araba, southwest Jordan, covering an area of about 1900 km² with 56 km in N-S trend and from 30 to 39 km along E-W direction. It is located between latitudes 30º 00´ - 30º 30´N and longitudes 35º 05´– 35º 30´E (Fig.1). The northern boundary of the study area is approximately 100 km south of the Dead Sea, whereas the southern boundary is located about 55 km North of Gulf of Aqaba. It`s elevation ranges between 40 m above sea level (a. s. l.) in the northwestern part to more than 1700 m (a. s. l.) in the eastern part. The area is situated within the Dead Sea Transform (DST), which extends about 1100 km in length from the southern tip of Sinai Peninsula in the south to Taurus Mountains in the north.

Few studies have been applied in remote sensing technique in geological studies in Jordan, among them, Kaufmann, (1988) and Abdelhamid and Rabb'a, (1994) used Thematic Mapper (TM) data in mineral exploration of Qurayiqra area, which is located to the north of the study area, while Zaineldeen (2000) used TM data in tectonic, mineralogical and lithological discrimination of Wadi Araba segment of the Dead Sea Transform. Zaineldeen concluded that the classification can only provide indications for discriminating lithologies on the image, but is certainly not accurate enough for direct geological mapping.

Many prospecting studies have been carried out on the copper ore in the Wadi Araba areas by Gold Otto (1964a and b), Nimry (1973), BRGM (1975), Bigot (1976), and Seltrust Engineering Ltd., (1985). The origin of copper ore has been discussed by Lillich (1963), Van Den Boom and Ibrahim (1965), Nimry (1967 and 1973), Bender (1974a), and Khoury (1986). Hagen, 1980 and Burgath *et al.* 1984 used geochemical and mineralogical investigation to locate a significant Cu-Pb-Zn anomaly in

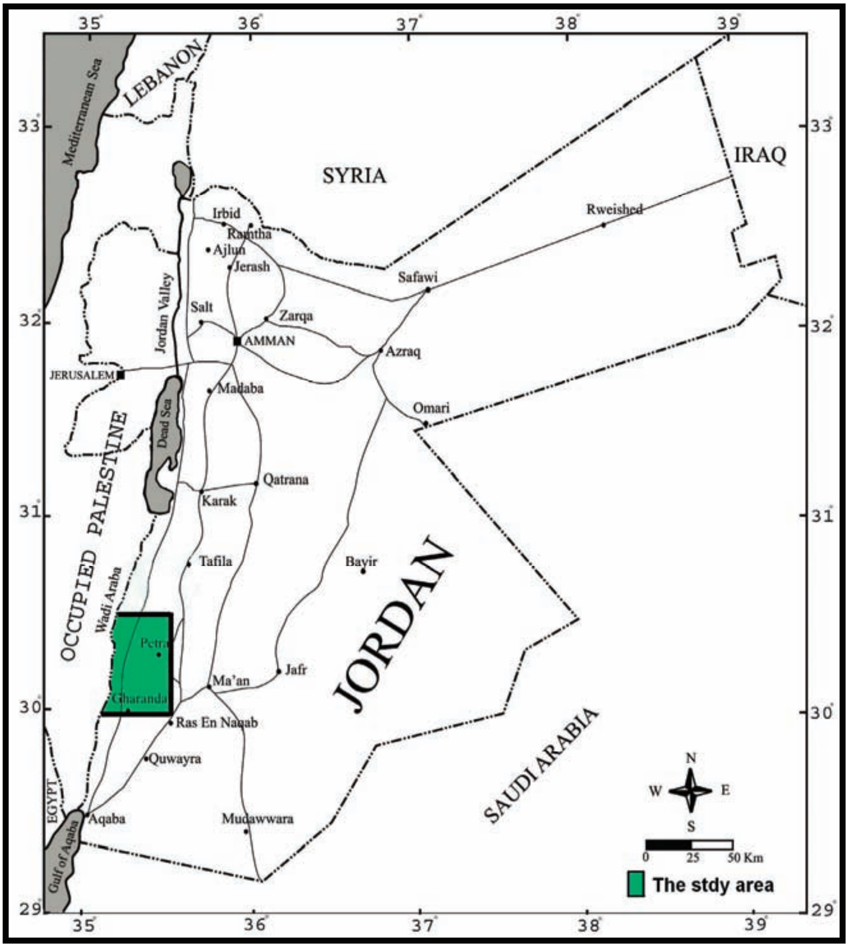

Fig. 1. Location map of the study area.

Wadi Abu Barqa area which is located within Wadi Araba area. Omari (1983) reported that the copper mineralization is present in the volcanic acidic rocks of the Ahaymir Suite (as crusts filling joints) unconformable overlying the basement Aqaba Complex units. Ibrahim (1993a) and Barjous (2003) concluded that copper mineralization in the southwestern and northern parts of the Araba area are mainly associated with the Ahaymir Volcanic Suite and the Middle Cambrian Abu Khushayba Sandstone Formation. The Jordanian Natural Resources Authority and BRGM carried several geochemical and mineral explorations on the Aqaba and Araba complexes (NRA and BRGM project staff, 1994), and indicated the presence of copper anomalies at the central part of the study area while gold was located in the wadi sediments in the central parts of the study area. Recently, the area of Wadi Abu Khushyba in the central part of the study area was the target for geochemical prospection project for gold (Nimry *et al.,* 1995, Bullen *et al.,* 1995 and 1996, and Al-Dalou and Abu Laila, 2000). Geological maps at scale of 1:10,000 and 1:25,000 were prepared for Wadi Abu Khushyba area by Rabb'a *et al.* (1999) and Barjous and Rabb'a (2000).

Detailed studies also have been carried out by the Jordanian Natural Resources Authority (Al Zoubi *et al.,* 1999; Dana *et al.,* 2001; Rabba and Qararaa, 2002 and Rabb'a *et al.,* 2005).

The main aims of the current article can be summarized in the following points:

- Applying the remote sensing techniques in lineaments extraction in order to determine the major structural framework affecting the area and the main trends characterizing the major rock units.

- Using the remote sensing techniques to determine the relationship between gold and copper mineralization and the geological structures in the study area.

Geologic Setting

A modifed geological map of the investigated area has been constructed by Natural Resources Authority of Jordan (1996) in a scale of 1 : 250,000 (Fig. 2a). This map shows that the study area is mainly covered by igneous and sedimentary rocks and the Pleistocene and Holocene sediments.

About 70% of the study area is previously mapped in two geological maps (Fig. 2b) namely; Wadi Gharandal map which covers the southwestern part of the study area, (Ibrahim and Rashdan, 1988) and Petra and Wadi Al Lahyana map, which covers the northern part of the study area (Barjous, 1995). These two maps are included in two geological bulletins (Ibrahim, 1993a, and Barjous, 2003). They are at a scale of 1:50,000 and are produced by "Jordan National Geological Mapping Project" (JNGMP) of the Jordanian Natural Resources Authority.

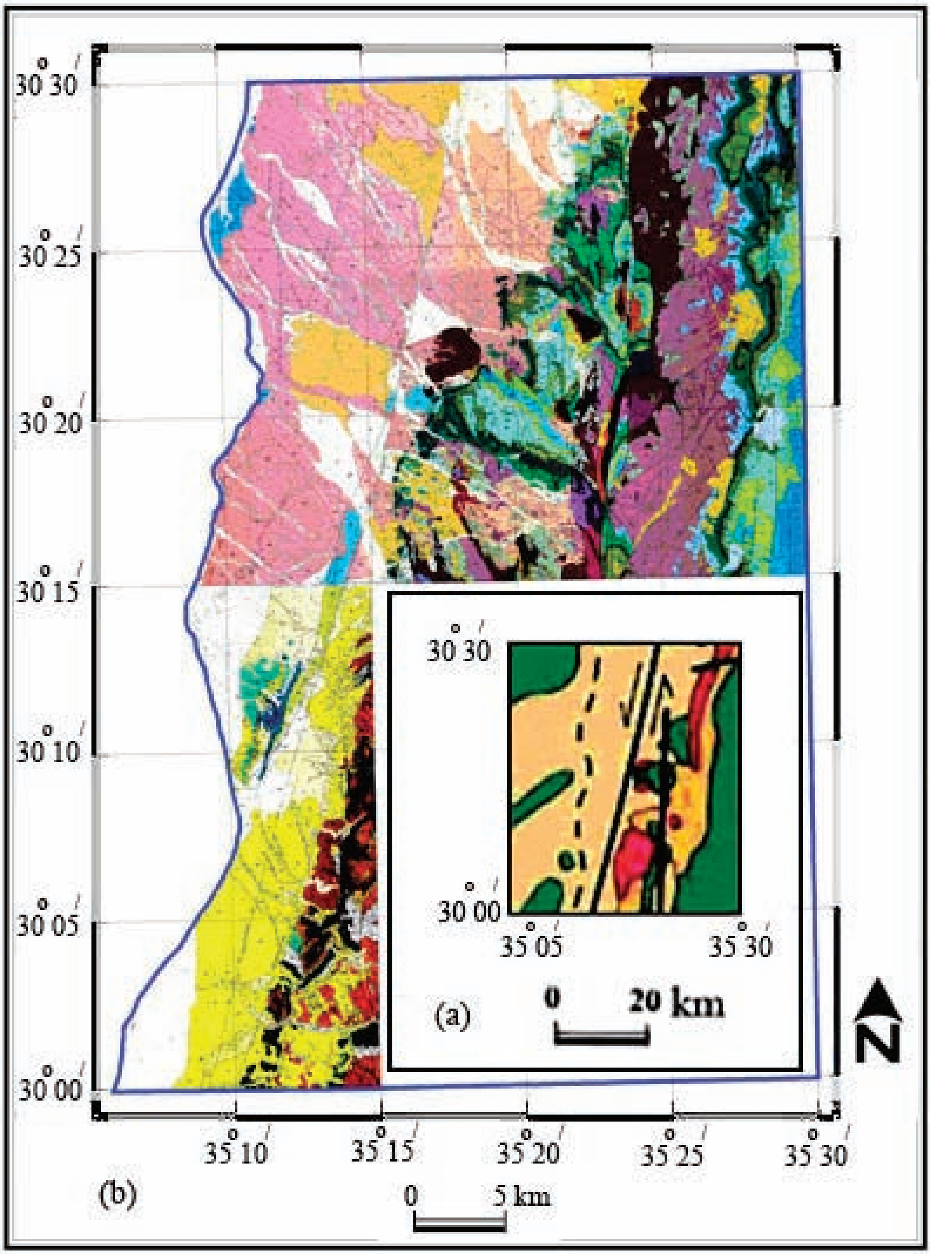

Fig. 2: (a) Geological map of the study area modified after Natural Resources Authority of Jordan (1996).
(b) Geological map of the study area modified after Ibrahim and rashdan, (1988) and Barjous, (1995).

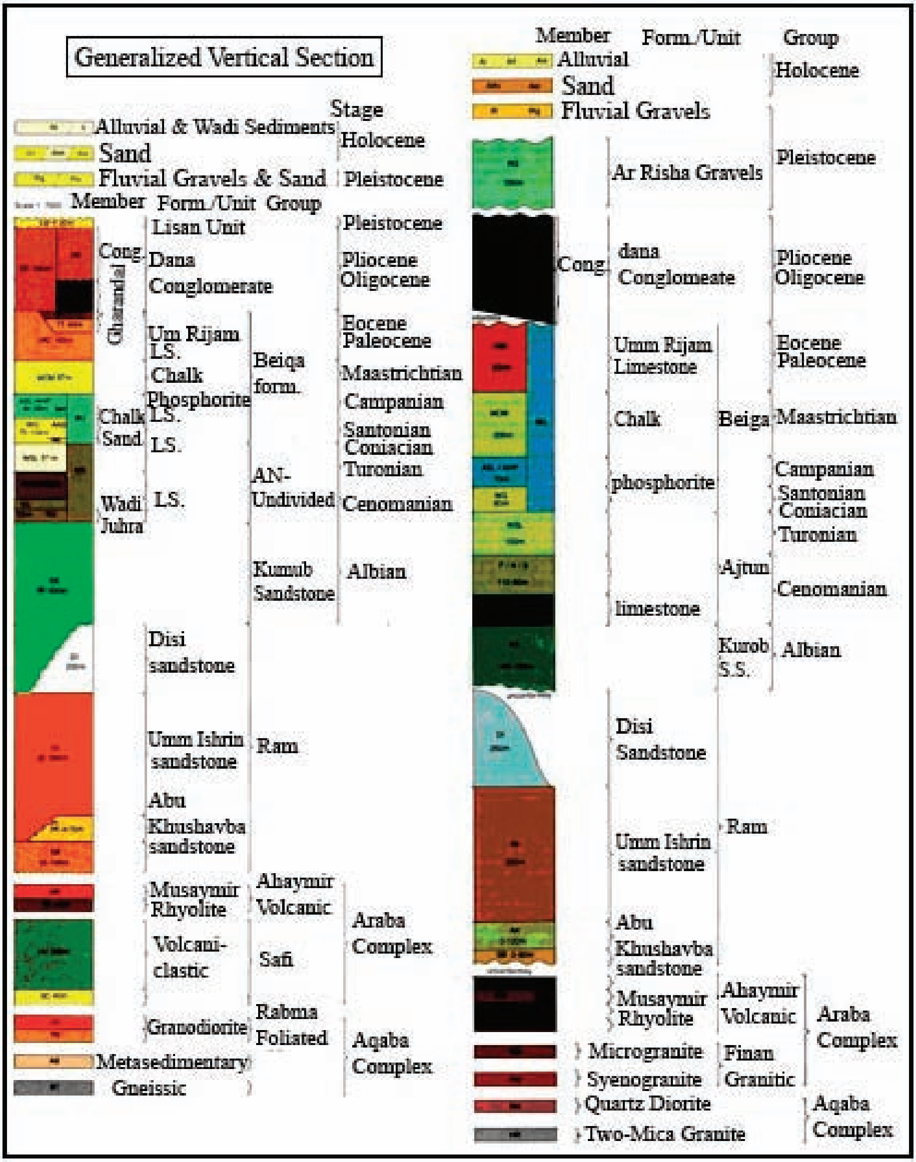

Fig. 2. Contd. Legend of Fig. 2 a & b.

The southeastern part of the study area (Ras An Naqab) is not mapped yet and will be mapped and published (in progress) in the scale of 1 : 50,000 in future work by the same authors.

The northern part of the study area (Fig. 2b) is covering Petra – Wadi Al Lahyana. It comprises basement rocks and younger sedimentary cover. The basement rocks are related to the Late Proterozoic Aqaba and Araba complexes (mainly syenogranite to granodiorite and volcanic rocks) (Fig. 2b). Two units, Abu Burqa metasedimentary suite and Andesite volcanic unit are not previously mapped on the 1:50,000 Petra and Wadi Al Lahyana map (Barjous, 1995). They are recorded during the gold project detailed mapping (Rabba *et al.,* 2000 and 2005) where the Abu Burqa Metasedimentary Suite is the oldest rock unit in the map area and Andesite Volcanic Unit is considered to be older than the Ahaymir Volcanic Suite. On the other hand, the sedimentary sequence comprises Cambrian-Ordovician. Early Cretaceous, Late Cretaceous-Eocene and Pleistocene and Holocene.

The southern half of the study area (Fig. 2b) covers Ras An Naqab – Wadi Gharandal area. It is covered by two topographic maps at a scale of 1:50,000; Wadi Gharandal sheet which is located in the western part of the map area and geologically mapped at a scale of 1:50,000 by the Jordanian Natural Resources Authority (Ibrahim, and Rashdan, 1988), and Ras An Naqab sheet which is located in the eastern part of the map area and will be mapped by the authors in the near future at scale of 1 : 50,000. The discrimination of the rocks covering this map depends on the correlation of the false color composite Landsat images and on the other published geological maps. These maps are the Dead Sea-Wadi Araba map at 1:250,000 scale, (produced by the Jordanian Natural Resources Authority) which covers partly the present map area, and the gold project maps (the geological map of Wadi Sabra and the geological map of Northwest Wadi Abu Khushayba), produced at a scale of 1:10,000 (Rabb'a *et al*., 2000 and 2005). The new map area comprises basement rocks of Late Proterozoic and sedimentary rocks of Cambrian to Holocene age.

Data used and Methodology

The pre-processing procedures of image processing techniques were carried out on the Landsat satellite imageries such as geometric corrections, subsets of the study area and contrast stretching enhancement. All used satellite imageries were geometrically corrected and rectified using topographic maps (image to map method) or using another rectified image (image to image method) of the study area. The first order affine transformation was applied and the root mean square error (sigma) was about 0.5 during rectification processes.

Merging (fusing) remote sensed data method was expressed as transformation between RGB and IHS space and then substituting the intensity using panchromatic ETM+ band 8 (Lillesand *et al*., 2004). Merging has been carried out, in this study, between Landsat ETM multispectral data (28.5 m spatial resolution) and SPOT panchromatic (10 m spatial resolution) as shown in the Fig. 3. ENVI 3.4v software package was used in the present study, for performing the merging process. In the present work, structural lineaments of the study area are automatically extracted from digital satellite data using Geomatica PCI (9.1v) package. The algorithm of extraction consists of edge detection, threshold and linear extraction steps. The automatic extraction process for lineaments could be carried out under the default or selected parameters of the Geomatica shown in Table 1.

Lineaments Extraction from Digital Satellite Landsat and SPOT Imageries

Extraction of Lineaments for the investigated area has been carried out under the default parameters of PCI Geomatica (Table 1) using the satellite imageries of Landsat ETM+ panchromatic band-8 (15 m) and the SPOT panchromatic (10 m).

Extraction of Lineaments using Landsat ETM+ panchromatic band-8 is shown in Fig. 4. The visual inspections of the extracted lineaments have been carried out for editing and delete the false (incorrect) lineaments. The total number of the extracted lineaments was 342.

Lineaments extraction from the panchromatic (10 m) SPOT imagery is shown in Fig. 5. The total numbers of the extracted lineaments was 784. The number of extracted lineaments from SPOT was greater than the number of lineaments extracted from Landsat imagery, so the SPOT imagery was taken as a base for optimal extraction of structural lineaments for the study area.

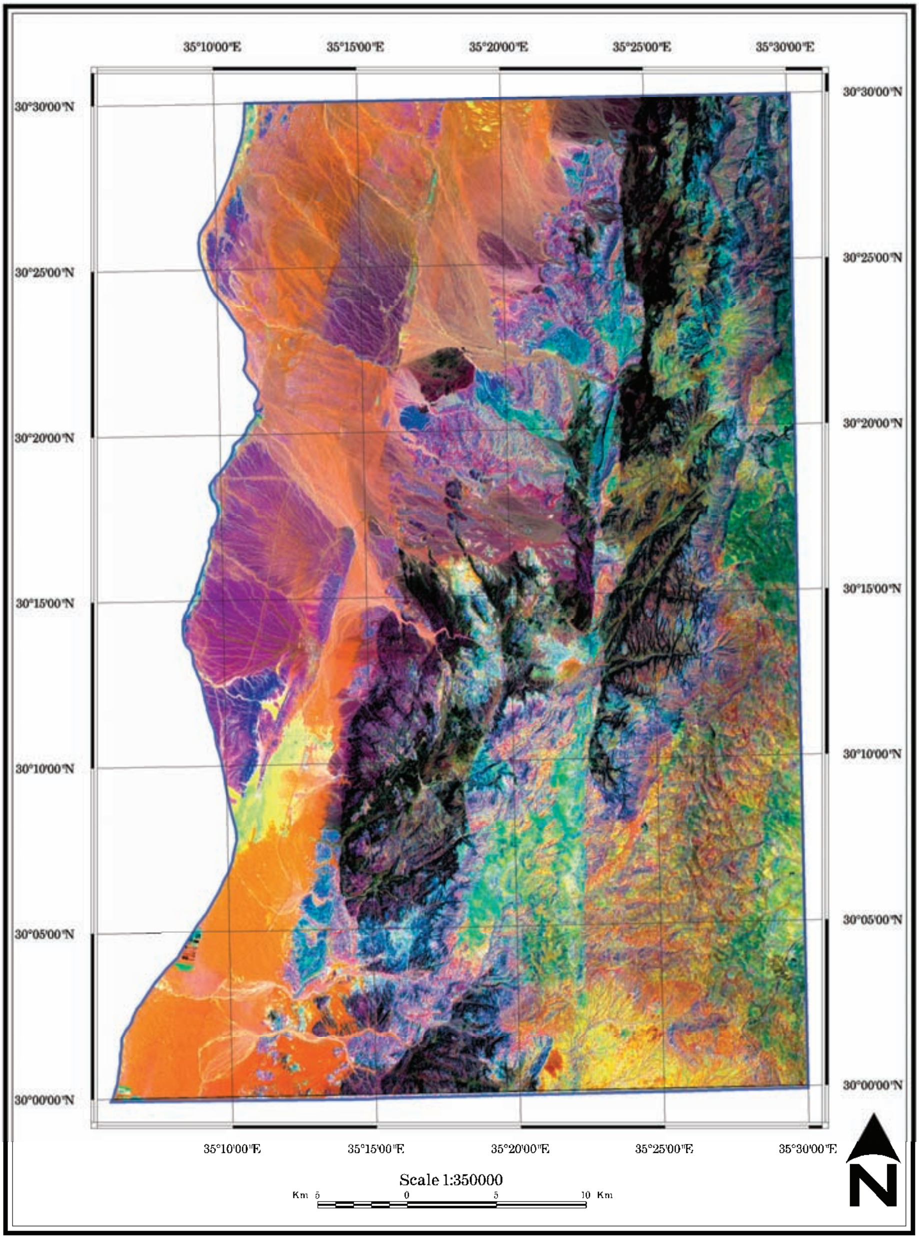

Fig. 3. Fused image has been produced between Landsat ETM Multispectral bands and SPOT of the study area.

Table 1. Default and optimal parameters of Geomatica software package used in lineaments extraction of the study area.

Parameters	Default Values	Optimal Values
Edge Filter rdius	10 (Pixels)	50 (Pixels)
Edge Gradient threshold	100 (Pixels)	30 (Pixels)
Curve length threshold	30 (Pixels)	100 (Pixels)
Line fitting Error threshold	3 (Pixels)	3 (Pixels)
Angular difference threshold	30 (Degree)	30 (Degre)
Linking distance threshold	20 (Pixels)	70 (Pixels)

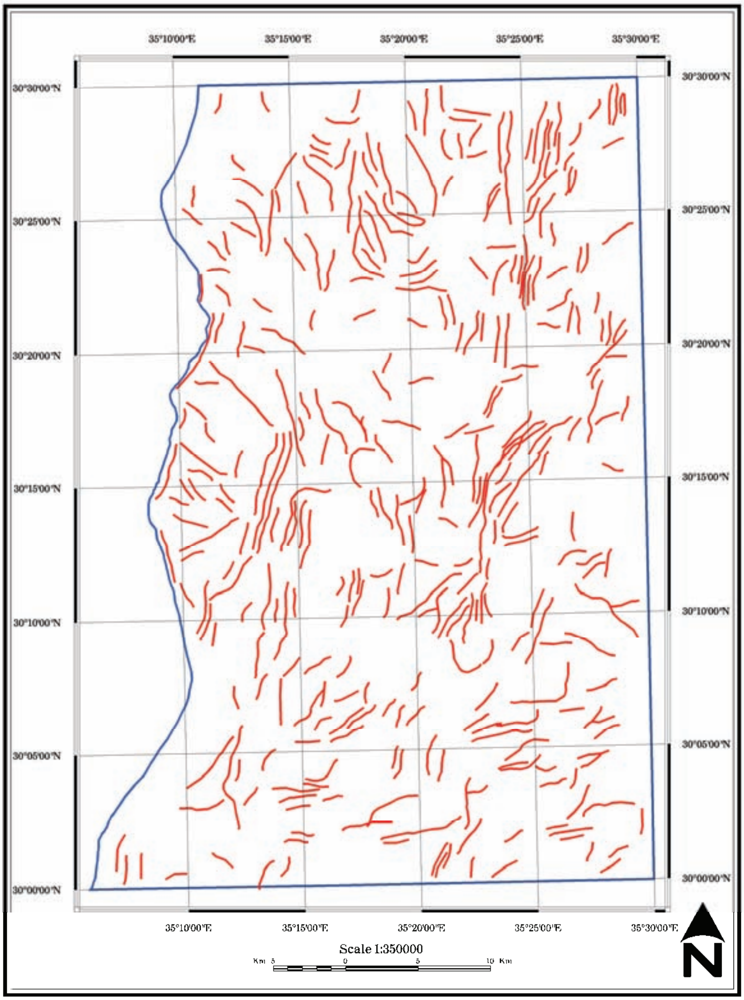

Fig. 4. Lineaments map of the investigated area as interpreted from the digital data of Landsat ETM+ panchromatic (band 8) image under the default parameters of PCI program.

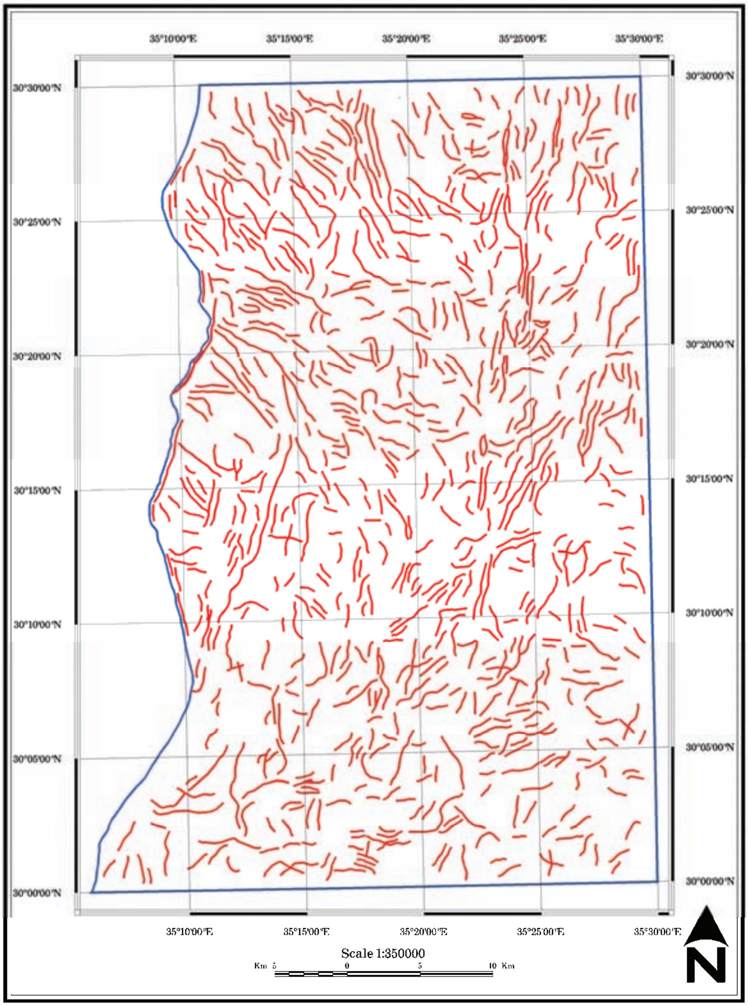

Fig. 5. Lineaments map of the investigated area as interpreted from the digital data of SPOT panchromatic image under the default parameters of the PCI program.

Optimal Extraction of Lineaments

Lineaments have been extracted from SPOT panchromatic imagery under the optimal parameters (determined by the authors) as shown in Table 1. The total number of the extracted lineaments from SPOT image was 784. According to the numbers of the extracted lineaments and the fitting of lineaments with the known regional faults in the study area, lineaments map extracted from SPOT image (Fig. 5) was selected to produce the structural lineaments map for the investigated area. The optimal structural lineament map (Fig. 6) for the investigated area was produced from the optimal lineaments map after correcting and editing of these lineaments. The editing included adding the faults detected on the previous geological maps and the lineaments that were detected visually from the SPOT panchromatic image. Figure 6 shows the optimal structural lineaments after editing, which scored 1092.

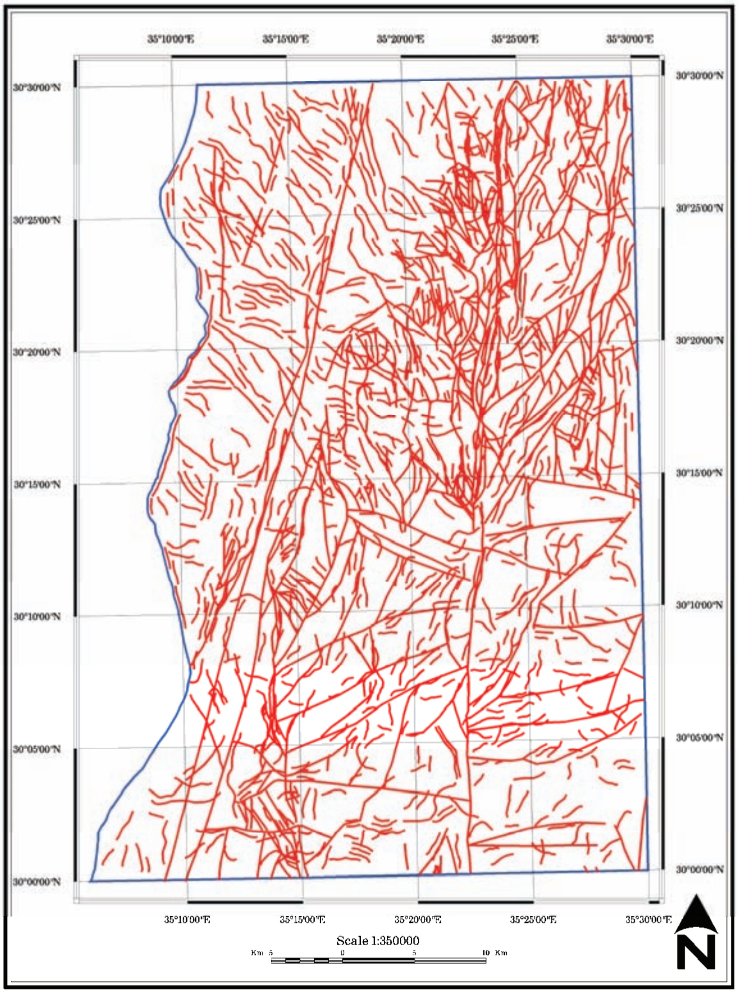

Fig. 6. The optimal structural lineament map of the investigated area, as interpreted from the digital data of SPOT panchromatic image under the optimal parameters.

Applying Selective Image Processing Technique (SIPT) for Structural Lineaments of the Study Area

Selective image processing technique (SIPT) was applied on the optimal structural lineament map (Fig. 6) where the total number of lineaments is 1092. The rose diagram of the lineaments in this map shows that the main trends of the structural lineaments of the study area are NNE-SSW, NNW-SSE and NW-SE (Fig. 7 a & Table 2). In order to determine the structural lineament pattern (SLP) for the lithologic rock units of the study area, igneous and sedimentary rocks have been grouped into several groups depending on the known structural history of Jordan. The known structural history of Jordan will be checked by analyzing the SLP for each lithologic group using the structural lineaments map shown in Fig. 6. Rose diagram for each rock group as detected on the extracted structural lineaments of the study area is shown in Fig. 7. Table 2 shows the number of extracted structural lineaments and their dominant trends for the different rock groups of the study area. The structural lineaments map of study area (Fig. 6) and the rose diagrams of rock groups (Fig. 7) show that the main lineament trends, within the study area, which are related to the Dead Sea Transform Fault System and the Transverse Faults system. The lineaments which are trending NE-SW could be related to the Syrian Arc Fault system.

The structural lineaments pattern of the basement rocks as a whole (Fig. 6 & 7b), shows main trends in the directions NW-SE and N-S which are related to the Transverse and Dead Sea fault systems, respectively. On the other hand, the dominant trend in Aqaba basement rocks (Fig. 7c) is related to Transverse Fault system (NW-SE), while the Araba basement (Fig. 7d) shows the Syrian Arc System (NE-SW), Dead Sea System (N-S) and Transverse System (NW-SE).

The Paleozoic rocks (Fig. 7 e) show the Syrian and Transverse fault systems (NE-SW and NW-SE) while the Dead Sea and transverse fault systems are dominant within the Cretaceous rocks (Fig. 7 f). The rocks of Paleocene-Eocene and Oligocene-Miocene show Dead Sea and Syrian Arc Systems while Pleistocene deposits show Dead Sea and Transverse Fault Systems, and NE-SW trend (Fig. 7 g, h, i).

The Holocene sediments show the trends of Transverse (NW-SE) and the Dead Sea Fault Systems which are the active faults at the present time (Fig. 7 j). For geological mapping, the structural maps of the Petra-

Wadi Al Lahyana and Ras An Naqab-Wadi Gharandal areas were prepared and some of the main structural elements are verified in the field.

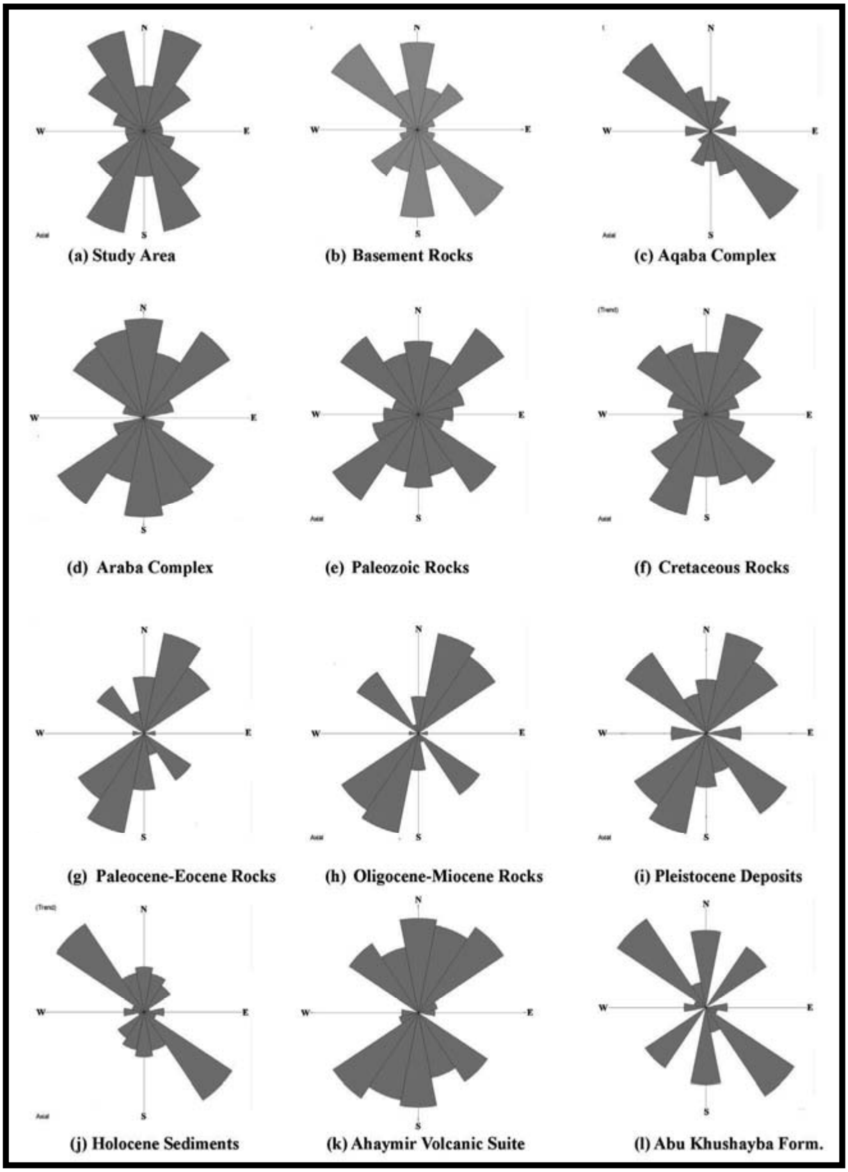

Fig. 7. Rose diagrams of the different rock groups as detected on the extracted structural lineaments of the study area.

Table 2. The number of extracted structural lineaments and their dominant trends for the different rock groups of the study area.

	Rock Type	No. of extracted Lineaments	Dominant Structural Trends
a	The whole rock units	1092	NNE , NNW & NW
b	Basement Rocks	247	NW & N-S
c	Aqaba Basement Rocks	47	NW
d	Araba Basement rocks	216	NE & N-S
e	Paleozoic Rocks	447	NE & NW
f	Cretaceous Rocks	637	NNE, NW & NNW
g	Paleocene – Eocene Rocks	36	NNE & NE
h	Oligocene – Miocene Rocks	39	NNE & NE
i	Pleistocene eposits	185	NNE, NW & NE
j	Holocene Sediments	453	NW &N-S
k	Ahaymir Volcanic Suite	169	NE & N-S
l	Abu Khushayba Sandstone Formation	191	NW, N-S & NE

Applying SIPT of Lineaments for Gold Mineralization

Gold mineralization occurs within the Ahaymir Volcanic Suite. The distribution of Ahaymir Suite and its units are shown in Fig. 8. The structural lineament map extracted from the SPOT panchromatic imagery (Fig. 6) shows the Ahaymir suite which hosts gold mineralization and is located between the regional Dead Sea Transform and Al Quwayra Faults, which control the surface distribution of the mineralization. The mineralization is located within the upthrown block of the two faults. The structural pattern map of the Ahaymir Suite (Fig. 9) was construced using SIPT with a total number of 169 lineaments. This map shows that the lineaments within the Ahaymir Suite trend in the directions of NE-SW and N-S and to a less extent in the direction of NNE-SSW, NNW-SSE and NW-SE. The Dead Sea Transform fault system is represented by NNE-SSW and N-S directions, Syrian Arc System is represented by NE-SW and the traverse fault System is represented by the NW-SE and NNW-SSE direction. The discovered gold-bearing trend was in the direction of the NW-SE which could be belonging to the Traverse Fault System.

The images and structural interpretation of these extracted lineaments as well as field verifications (Fig. 10 & 11) reflect that the Gold mineralization is mainly restricted to Ahaymir Volcanic Suite and controlled by trends of structural lineaments in the NE and N-S directions. According to the investigation of the lineament distribution of

Ahaymir suite and the discovered locations of gold deposit, seven new locations have been suggested to be prospecting locations for gold bearing deposits (Fig. 9).

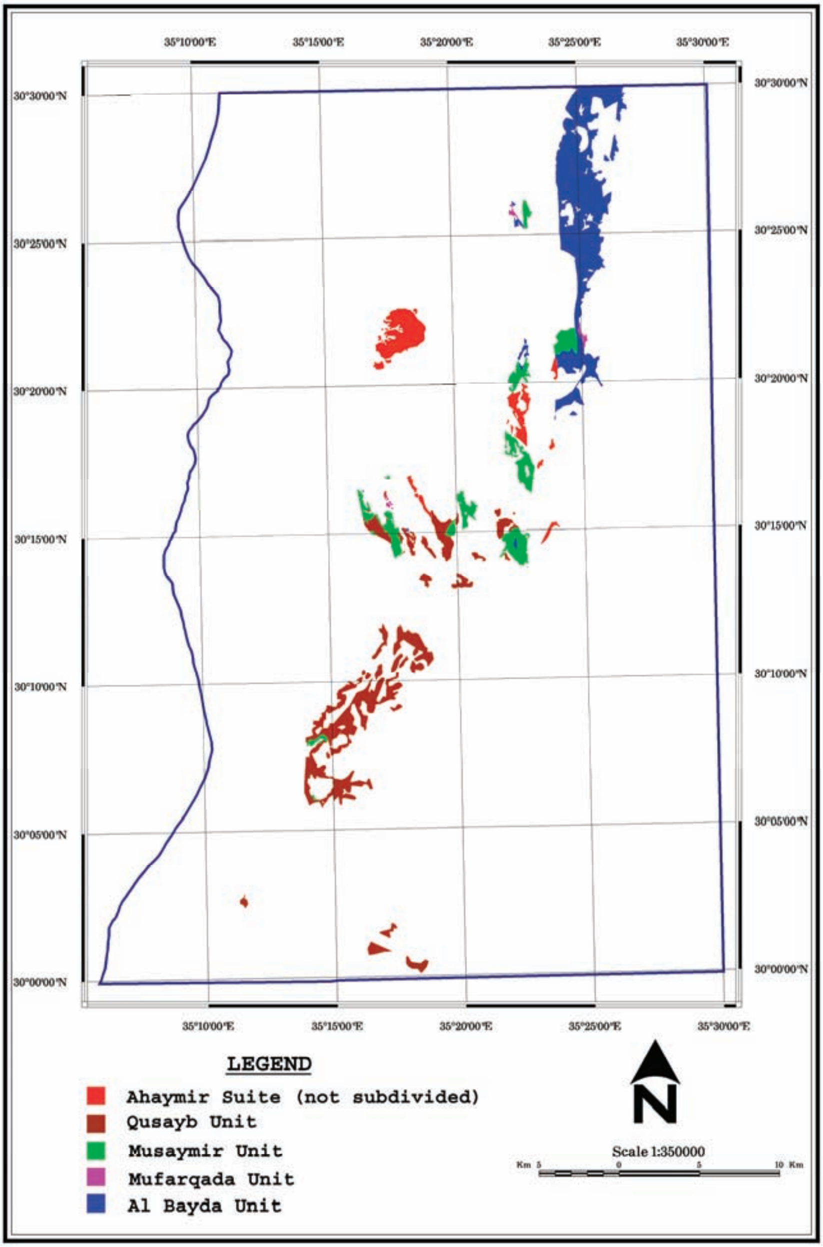

Fig. 8. Distribution of Ahaymir Volcanic Suite and its units.

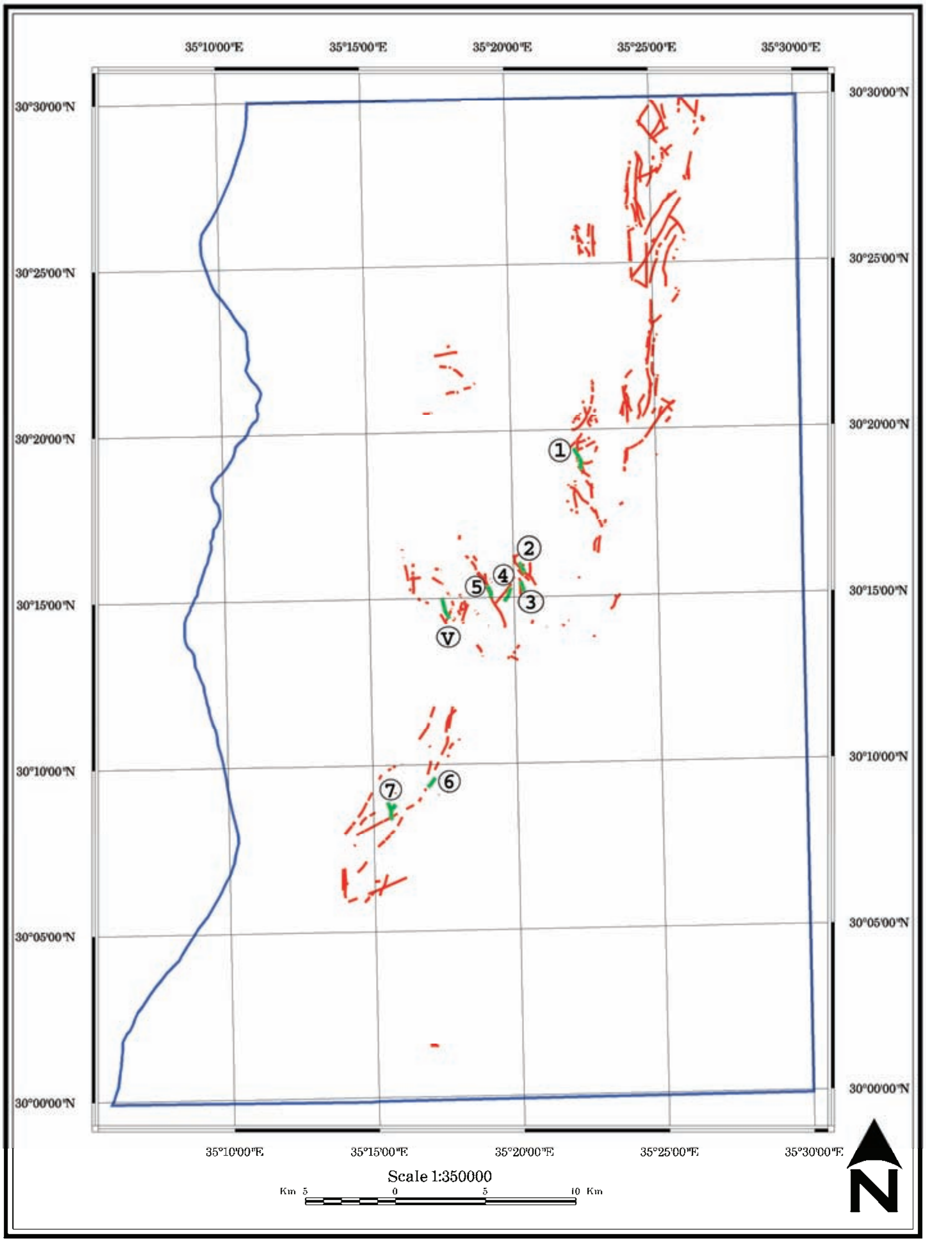

Fig. 9. Structural lineaments pattern of the Ahaymir Volcanic Suite and the suggested gold target areas (1-7) and the location of gold-bearing vein (V).

Fig. 10. The rhyolitic dykes which caused the rose linear feature on the false color composite image, Wadi Abu Khushayba area. Photo looking NE.

Fig. 11. Fragments of Gneiss and Orthoclase within the Au-bearing vein, Wadi Abu Khushayba area. Photo looking SE.

Applying SIPT of Lineaments for Copper Mineralization

Copper mineralization occurs in the investigated area within Cambrian Abu Khushayba Sandstone Formation. The structural lineament map extracted from the SPOT panchromatic imagery (Fig. 6) shows that the Abu Khushayba Sandstone Formation is located between the regional Dead Sea Transform and Al Quwayra Faults which could be controlling the exposures of mineralization where this mineralization is located within the upthrown block of the two faults. Figure 12 shows distribution of copper bearing Abu Khushayba Sandstone Formation within the study area, which was construced using SIPT. The structural pattern map of the Abu Khushayba Formation shown in Fig. 13 indicates that the dominant structural lineaments within the Abu Khushayba Formation are trending in the direction of NW-SE, others are in the direction of N-S and NE-SW. These trends could be related to the Transverse (NW-SE), Syrian Arc (NE-SW) and Dead Sea (N-S) fault Systems.

The distributions of Abu Khushayba sandstone Formation as well as their structural lineaments pattern are shown in Fig. 12 & 13 respectively. The total number of lineaments is 191 for this Formation (Table 2).

The images and structural interpretation of these extracted lineaments as well as field verifications (Fig. 14) reflect that the Copper mineralization is mainly restricted to Cambrian Abu Khushayba Sandstone Formation and controlled by trends of structural lineaments in the NW, N-S and NE directions.

Discussion and Conclusion

Although utilization of high resolution remote sensing data is required, this study succeeded to determine main structural lineaments of the investigated area and detect the main structural trends affecting gold and copper mineralizations. The Structural lineaments map extracted for the hosting rocks shows the main trends which controlled the mineralization. Throughout the field work, the gold vein discovered by NRA is recorded. The shear zone in NW-SE trend also was recorded with no gold anomalies observed in this zone but it has anomalous Ba, Zr, Cu, and Sr content. On the other hand, the copper mineralization is highly affected by faulting. The occurrence of gold and copper mineralization is controlled by the Dead Sea Transform fault and Al Quwayra fault, where these exposures of mineralizations are restricted to the up thrown block in between the two faults.

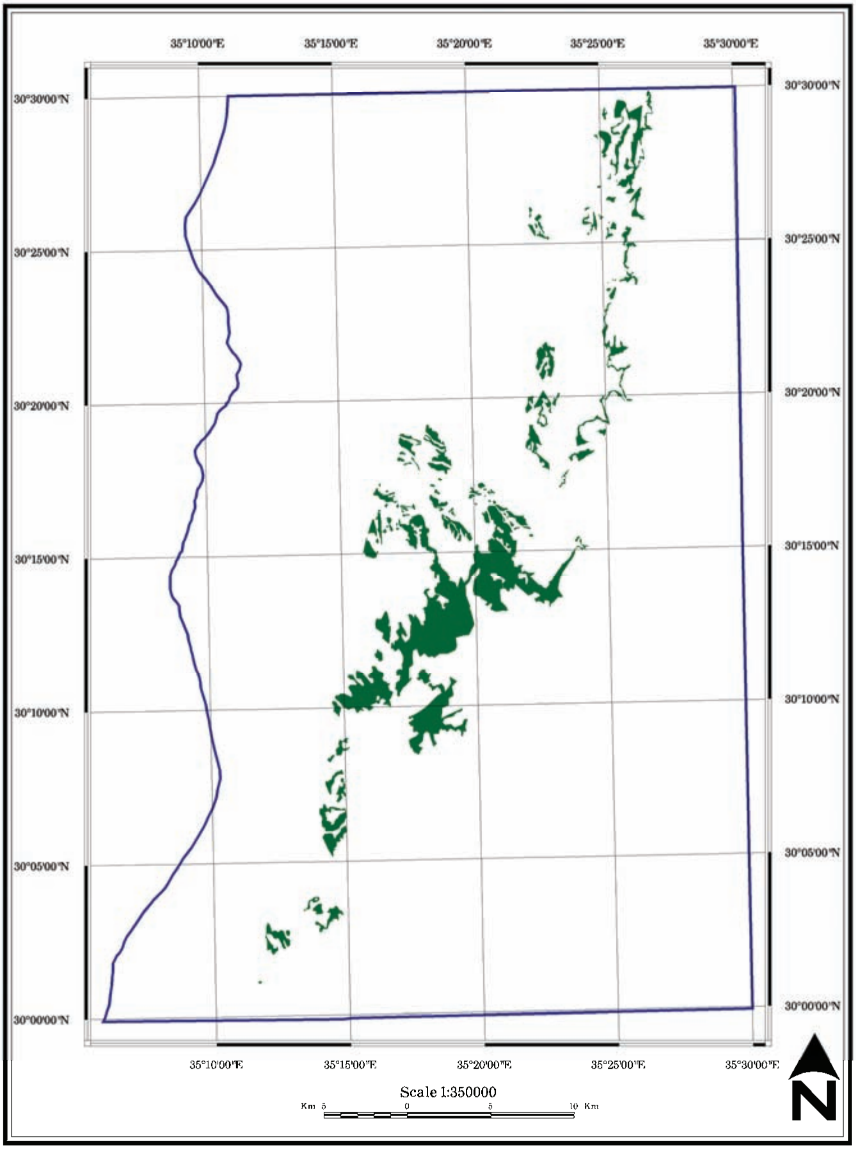

Fig. 12. Distribution of copper bearing Abu Khushayba Sandstone Formation within the study area.

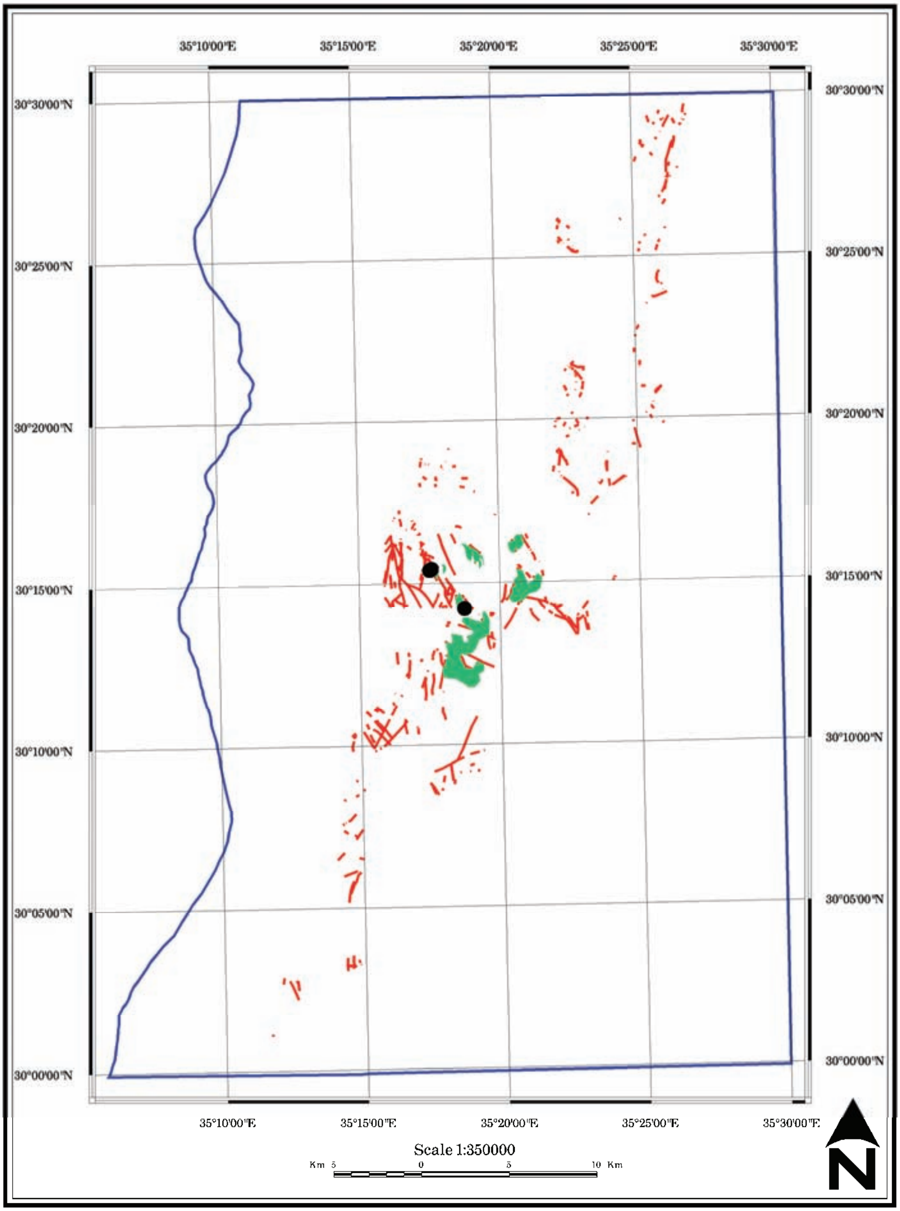

Fig. 13. Structural lineaments map of Abu Khushayba sandstone formation, showing promising areas of copper mineralization (green) and location of known copper mines (closed black circles).

Fig. 14. Copper mineralization at the entrance of the northern Roman copper mine. Photo looking NE.

The structural lineaments map (Fig. 6) and the rose diagrams (Fig. 7) show that the main lineament trends, within the study area, are in the direction NNE-SSW, NNW-SSE and NW-SE which are related to the Dead Sea Transform Fault System and the Transverse Fault system.

The lineaments which are trending NE-SW could be related to the Syrian Arc Fault system. The structural lineaments pattern of the basement rocks as a whole (Fig. 6), shows main trends in the directions NW-SE and N-S which are related to the Transverse and Dead Sea fault systems, respectively. On the other hand the dominant trend in Aqaba basement rocks is related to Transverse Fault system (NW-SE), while the Araba basement show the Syrian Arc System (NE-SW), Dead Sea System (N-S) and Transverse System (NW-SE). The Paleozoic rocks show the Syrian and Transverse fault systems (NE-SW and NW-SE) while the Dead Sea and transverse fault systems are dominant within the Cretaceous rocks. The rocks of Paleocene-Eocene and Oligocene-Miocene show Dead Sea and Syrian Arc Systems while Pleistocene deposits show Dead Sea and Transverse Fault Systems, however the Pleistocene show also a NE-SW trend. The Holocene sediments show the trends of Transverse (NW-SE) and the Dead Sea Fault Systems which are the active faults at the present time.

The images and structural interpretation using SIPT as well as field verifications reflect that the Gold and copper mineralizations are mainly restricted to Ahaymir Volcanic Suite and Abu Khushayba Sandstone Formation respectively. These mineralization are controlled by trends of structural lineaments in the NE and N-S directions for Gold and in the NW, N-S and NE directions for Copper.

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استخدام الخطيات المستخلصة من بيانات الأقمار الصناعية في التخريط التركيبيِ والاستكشاف المعدني، وسط وادي عربة، جنوب غرب الأردن

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المستخلص. تستعمل هذه الدراسة الخطيات المستخلصة من بيانات الأقمار الصناعية في التخريط التركيبي والاستكـشاف المعـدني، وسط وادي عربة، جنوب غرب الأردن. ولقـد تـم اسـتخلاص الملامح الخطية آليًا من البيانات الرقمية لاندسات بانكروماتك (١٥ مترًا) وكذلك من بيانات سبوت بانكروماتـك (١٠ أمتـار) وذلـك باستخدام مجموعة برامج بي ســي آي PCI-Geomatica. الأعـداد الكلية للخطيات المنتزعة من مرئيات لاندسات وسبوت كانـا ٣٤٢ و٧٨٤، على التوالي، لذا تم اختيار خريطة الملامح الخطيـة مـن مرئيات سبوت لإنتاج خريطة الملامح التركيبية لمنطقة الدراسـة. يكشف تفسير التاريخ التركيبي لمنطقة الدراسة بأن أغلب الملامـح التركيبية تتعلق بالنظام التركيبي للبحر الميت و قد تكـون متعلقـة بدرجة أقل بنظام القوس السوري. هذا العمـل نجـح فـي تمييـز التراكيب الرئيسية التي سيطرت على تمعدنات الـذهب والنحـاس بمنطقة الدراسة.

تعكس معالجة البيانات الفضائية والتحقق الحقلي بأن تمعدنات الذهب والنحاس في منطقة الدراسة يحدد بشكل رئيسي في مجموعة بركانيات أحيمر (Ahaymir) وتشكيل صخر أبوخشيبة (Abu Kushayba) الرملي على التوالي. كما إنه تم استنتاج تمعدنات الذهب والنحاس تحت سيطرة التراكيب ذات الاتجاهات شمال شرق، وشمال جنوب، وفي اتجاهات شمال غرب، وشمال جنوب على التوالي.