GEOLOGY AND GECHEMISTRY OF THE BARITE AND MANGANESE ORE PROSPECTS IN WADI ALMASILA-
MAHRAH PROVINCE, YEMEN

Mattash Mohammed Ali, Al-Ameri Abdullah Ahmed and Shaqra Ali Ahmed

ABSTRACT

The hydrothermally altered area totals about 16 km², in which barite and manganese ores and very less commonly lead-zinc-
vandium, and manganese mineralization zones are distributed through an area of 1 km², in the southern part of the so-called
Wadi, Al-Masila Basin. As part of Hadramawt, Al-Mahrah Plateau this terrain has undergone a complex geologic and structural
history, including transpressional and transtensional processes which were affected, in general, by the synrift (late Oligocene-
early Miocene) and the postrift (late Miocene-Recent) phases and related to the opening of the Gulf of Aden and the Red Sea. Geology is composed of Jurassic limestone, Cretaceous undifferentiated materials composed of shale, marly limestone,
dolomitic limestone, sandstone and clastic material (Saa’r and Qishn Formations respectively). This is overlain by the Tertiary
carbonate of Umm Er Radhuma Formation. Within the prospect several small areas are partially covered by Quaternary basaltic lava flows that were erupted from the NW area, and extended along the southeastern part of the wadi.
The area is affected by hydrothermal activity in which alteration is represented by dolomitization, brecciation, limonitization
(after sulfides, mainly pyrite). Silicification is common feature in the dolomitic limestone, in particular. Gossan also occurs,
indicating oxidation process at the final phase. Mineralization in

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FIELDS OF INTEREST: Geological mapping; minerals exploration, igneous rocks, mainly volcanology, and geothermal
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all prospects consists of fracture-filling in dolomite and dolomitic limestone, and in general, consists mainly of barite and less commonly pyrolusite, hollandite, romanechite, calcite, dolomite, and quartz, including jasper and flint.

Barite veins, veinlets, lenses and dissemination types are common in the prospect area. Residual and bedded barite also occurs. Barite is the most common raw material in Wadi Al-Masilah, forming the majority of the total mineral assemblage. Veins of barite vary in width from 0.6-5 m, and their length can be traced through 1 kilometer. Barite occurs in tabular crystals, in granular form, but mainly in compact masses. It is formed as a result of hydrothermal process, and/or as the result of weathering zone, where Ba mainly reached the solution in the form of BaCl2, but when reacted with SO4-root it formed barite immediately. Barite was formed and concentrated by the affect of hydrothermal process that caused by the Quaternary volcanic eruption extruded throughout the main wadi trend and/or by the action of slightly acidic groundwater which dissolved the soluble carbonate during a long period of earlier cycles of weathering and erosion. Results of geochemical analyses undertaken on barite specimens indicate high quality material with almost an average value of Ba exceeding 560000 mg/kg (96% BaSO4).

Pyrolusite is found as small massive veins ranging up to 1 m in thickness, as small pieces scattered in some areas, ranging up to 20 cm in diameter, as stockwork breccia-filling mineralization cementing the carbonate rocks, and as an association with the underlying Cretaceous sandstone Formation. Oolitic structure is characteristic feature, indicating shallow marine origin that associated with the Tertiary Umm Er Radhuma Formation. Beside pyrolusite, hollandite and romanechite varieties are also reported. Geochemical results indicate high quality manganese ore with MnO content ranging between 61-66%. Anomalous barium, strontium, cobalt, and vanadium contents are reported from pyrolusite and hollandite, in which they may exceed 7%, 3%, 0.15%, and 0.10% respectively.

**ACKNOWLEDGEMENTS**

We are indebted to the Geological Survey and Minerals Resources Board, to the Ministry of Oil and Minerals, for their kind help and guidance, to Naine Minerals Pte., and to MEMC Company for their financial support that facilitated our exploration tasks. We would express our sincere thanks to the Geological Society of Yemen for providing an opportunity to participate in the first issue of their Bulletin. We also are grateful for Mr. Eng. Abdelhafed Seif Nooman and his geophysical team for their kind activity in accomplishing a geophysical survey in the prospect area.
كجزء من هضبة حضرموت والمهره فإن هذه السهول قد مرت بتاريخ جيولوجي وتركيب معقد يشمل عمليات ضغط وتشكل واستغلال النطاق والتي تتأثر بشكل عام بمراحل بناء الأدياف المتزامنة (نهاية الألوجوسين-بداية الباليوسين، والأدياف المتزامنة (نهاية الميوسين-الوقت الحاضر) وارتبطت بانفتاح مجاور وادي البحر، التكوينية المنطقة من الصخور الجيرية التابعة للصخور الجوراسي وغيرها غير مقسمة من العصر الكريتاسي وهي مكونة من الصخور الجيرية الصلصالية والصخور الجيرية الديفاسيات والجبال وسحابات مياه ومواد خالصة (تكويني صفر وشام) يعلو هذين التكوينين كونين أم الرضومي الجيري الديفاسي للعصر الثلاثي.

توجد في إطار منطقة التمعدن العديد من النطاقات الصغيرة المغطاة جزئياً بحمم البازلت من العصر الراباعي والتي صنفت من شمال غرب الوادي وامتدت على طول الجزء الجنوبي الشرقي من وادي المسيلة. هذه المنطقة تتأثر بالنشاط الحرمائي حيث أصبح التغير المناخي يمثل عاملة مريرة، البريشيا، تعتبر من المواقع التجارية (بعد الكربونات، البيرو، على وجه الخصوص) كما أن السلكنة تعتبر مظهر عام لاسيما في الصخور الجيرية الديفاسي.

التمعدن في المناطق الواقعة يحتوي على شقوق مملوءة في الصخور الجوراسي والصخور الجيرية الديفاسي حيث أن التمعدن بصورة عامة يتكون من بارايت، وأقل من ذلك بايرولوزايت، هوللاندايت، رومانيشية، كاليسيت، دوبلوميت، كوارتز، يوجد البارايت بشكل عروق وعرقات وشوابات ونطاقات متتالية في نطاقات التمعدن، يعتبر البارايت المادة الخام الأكثر انتشاراً في وادي المسيلة. عروق البارايت تختلف في عرضها من 60 سم إلى 5 مترين وبالإمكان اقتفاء أثر طولها خلال منطقة بطول كيلومتر. يوجد البارايت بشكل عروق صفيحة أو بتركيبة حبيبية ولكن بشكل أساسي يكون كتل متماسكة.

قد تكون البارايت كنتيجة لعملية النشاط الحرمائي، أو كنتيجة لنطاق التعرية حيث وصل البارايت إلى المحلول بصورة كلوورد البارايت. بيد أنه عند لقاء بجزر الكبريت، (SO4) يتكون على إثر ذلك البارايت. نتائج التحليل الجيوكيميائي التي تمثل عيانات من عروق البارايت المتعددة أكدت على أن الخام ذات نوعية عالية مع معدل قيم لعنصر البارايت قد تتجاوز 560000 مغ/كم3 (%BaSO4 96%).

معدن البارايت يوجد بشكل عروق صغيرة كتلية متساوية تتدرج إلى أحد متر في سمكتها. قطع صغيرة متتالية بطولها 20 سم في قطرها، بصورة بريشية ثلاثية الأبعاد تسمح برؤية صورة كبيرة من الصخور الكربوناتية ونطاقات كيميائية متعددة. التمرد الصخوري الذي يقع على الأطفأ من الصخور الكربوناتية يتقدم إلى النطاقات الصخور الكربوناتية أعلى، تأخذ تلك النطاقات الصخور الكربوناتية إلى النطاقات الصخور الكربوناتية. النتائج التي تظهر على المعادن يوجد على إثر ذلك تابعاً لتشكل الجيري الرضومي الذي يوجد عستانه على أصل 소ام، على أصل الصخور الجوراسي، الذي يمتد على مرحلة متحدة بالصخور الجوراسي. النتائج التي توجد على اكتمال الصخور الكربوناتية.

بينت نتائج التحليل الحكيمية بأن$ معدن البارايت ذو نوعية عالية حيث أن نسبة أكسيد المغنيز تتراوح مابين 67% - 63%. كما يحتوي هذا الخام على شوائب مختلفة كالألومنيوم، الستاتن، الكوبالت، والفاناديم والتي وصلت إلى 0.7، 0.3، 0.15، و0.10 التوالي.
INTRODUCTION

Field trips to barite prospects and their associated anomalous polymetallic trace elements at Wadi Al-Masilah (Al-Kohl-1, Al-Kohl-2, and Al-Qala’nah) in Al-Mahrah governorate had enhanced investigation of the largest barite occurrences in the Republic of Yemen. These occurrences are up to date amongst the nonmetallic occurrences of Yemen that are already partially studied by the GSMRB geologists. Based on a comparative and careful review of the quality, potential, and other physical conditions of the available data on such occurrences from different areas, we found it very important to promote geological and geophysical exploration and to simultaneously commence exploitation programs. In 2005 3S Minerals had obtained an exploration license of the territory and granted a mining concession. In 2006 a joint venture was drawn up between 3S Minerals Company and Naine Minerals Pte., in order to accomplish exploration programs in that area. In 2007 3S Minerals ceded mineral rights to Naine Minerals Pte., in which the latter had got exploitation license on barite. However, the Al-Ghaidah As-Saghirah manganese ore prospect is licensed to MEMC Company Ltd.

REGIONAL GEOLOGY

The geology of this entire region is characterized by Shihr Group deposits assigned to the Oligo-Miocene, originating partially from erosion of the Eocene rocks in Hadramawt and deposited in lagoonal zones. This results in intercalations of variegated clay, sandstone, conglomerate, thin limestone beds, and gypsiferous layers. The permeability of the system is very variable. The Shihr Group unconformably overlies the Hadramawt anticline, essentially Eocene with a Cretaceous core. Detail studies on sidementry cover and sidementry basins are published by As-Saruri and Beydoun (1998); Beydoun and As-Saruri (1998) and Beydoun et al.,(1996). The entire assemblage is faulted in a N70° direction parallel to the coastline, forming segmented panels, which are increasingly subsident towards the sea (Beydoun et al., 1998).

RECENT ACTIVITIES

Extensive field survey, guided by geological, geophysical, geochemical, as well as drilling exploration is carried out by Naine Minerals Company at Al-Kohl1 barite prospect, whereas MEMC Company has achieved, geological, geochemical and geophysical activities at Al-Ghaidah As-Saghirah manganese prospect for the purpose of identifying ultimate economic resource.

GEOPHYSICAL SURVEY NETWORK

Geophysical survey has been achieved on Al-Kohl-1 prospect area, using electromagnetic (EM) method based on geochemical data achieved during geological exploration. The topographical networks are given in figure 1, and the results of their geophysical profiles are drawn in figure 2.

GEOLOGY OF THE PROSPECT

Geology is composed of Jurassic limestone, Cretaceous undifferentiated materials composed of shale, marly limestone, dolomitic limestone (Saa’r Formation), sandstone and clastic material (Figure3). This is overlain by the Tertiary carbonate of Um Er-Rhaduma Formation. Within the prospect several small areas (ranging from 2000 m² up to 20000 m² are covered by Quaternary alkali olivine basalt.
lava flows, that erupted from the NW area, and extend along the southeastern part of the wadi. A very thin layer of Quaternary sediments occurs, consisting of gravel, whereas the uppermost part is composed of thin recent layer of sands.

Structurally the area is controlled by W-NW faults (270-310°). Fractures are widespread and filled with barite and/or calcite. Geophysical survey indicated vertical and near-vertical faults that are filled with mineralization, in addition, number of pockets (caves), which are formed as a consequence of the action of water are sometimes filled with mineralization.

**METHODOLOGY**

Regarding the mineralization of Wadi Al-Masila, no any data is found in the literature, for that our geologic team’s activity aimed to describe and study all the licensed prospects, by use of new geological, geochemical and geophysical tools, presently available throughout the world. All the samples collected were processed and prepared at the geochemical laboratory of Yemen. Analytical methods have already been conducted at ALS Chemex Laboratory, Vancouver, Canada; and some others at the geochemical laboratory of Hannover, Germany. Such a methodology permitted us to obtain excellent results. By use of our new geochemical results, we already interpreted as well as evaluated the data for the mineralized prospects. Our continuous exploration programs, including drilling program would provide some of the basic knowledge necessary to confirm the resources, which would in turn help to enhance our reserve in order to determine ultimate economic value of this potential.

**BARITE PROSPECT AT WADI AL-MASILA**

**Location of the prospect**
Figure 2. Results of horizontal loop EM (in-phase and out-phase) survey, using coil separation 100 m, and frequency of 110Hz, 220Hz, 440Hz, 880Hz, 1760Hz, 3520Hz, 7040Hz, and 14080Hz.
The prospect area is situated in Al-Mahrah governorate to the northwest of Seyhoot town. Distance of about 28 km to the northwest through Wadi Al-Masilah separates the prospect from the paved highway. This hydrothermally altered area totals about 16 km², in which barite mineralization is distributed through an area of 1 km² (Figure 4).

Mineralization and alteration

The mineralized prospect is mainly located at the western bank of Wadi Al-Masilah, and the barite mineralization occurs as singly or in various combinations. They are found in dolomitized limestones of the Jurassic and Cretaceous age, and are found mainly as vein fillings, lenses, bedded, and residual types and also as an association with brecciated and silicified zones of dolomitic limestone (Figure 5). Thickness of barite veins and lenses and in silicified zones may range from centimeters to meters. Barite occurs in tabular crystals, in granular form, or in compact masses. Anomalous barium contents are reported from pyrolusite and hollandite, they may attain

**Figure 3.** Generalized geological map of the Wadi Al-Masilah prospects.

**Figure 4.** This figure shows the location of the geochemical sampling program as well as the distribution of barite veins at Al-Kohl-1 and Al-Kohl-2 prospects.
The area is affected by hydrothermal activity in which alteration is represented by dolomitization, brecciation, limonitization (after pyrite and probably other sulfides), and also by silicification. Occasionally mineralization consists of barite and calcite and in some cases in association with disseminated grains of galena. Gossan occurs, indicating oxidation process at the final phase.

**Geochemical results**

Results of geochemical analyses for the major components of barite (Table 1) and trace elements including Ba indicate high content with excellent quality for the barite veins, in which Ba content approaches an average value of 560000 mg/kg (Table 2), in which the BaSO₄ content ranges between 91 and 98%, and averaging 95-96%.

**Table 1. Average results of major components (%) on barite samples.**

<table>
<thead>
<tr>
<th>SiO₂</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>(SO₃)</th>
<th>LOI</th>
<th>Sum</th>
</tr>
</thead>
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<td>1.50</td>
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<td>31.53</td>
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<td>0.01&gt;</td>
<td>0.001&gt;</td>
<td>0.01&gt;</td>
<td>0.031</td>
<td>0.44</td>
<td>0.020</td>
<td>32.82</td>
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<td>0.48</td>
<td>0.020</td>
<td>32.79</td>
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</table>
Specification of the Wadi Al-Masila barite ore regarding market segmentation and according to quality preference is given in Table 3.

Table 2. Geochemical results of trace elements from barite specimens are given in mg/kg.

<table>
<thead>
<tr>
<th>As</th>
<th>Ba</th>
<th>Bi</th>
<th>Ce</th>
<th>Co</th>
<th>Cr</th>
<th>Cs</th>
<th>Cu</th>
<th>Ga</th>
<th>Hf</th>
<th>La</th>
<th>Mo</th>
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Table 3. Specification of the Wadi Al-Masila raw material comparing to the international quality classification.

<table>
<thead>
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<th>Quality</th>
<th>High</th>
<th>Medium</th>
<th>Low</th>
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<tbody>
<tr>
<td>Over 55% Ba</td>
<td>40-55% Ba</td>
<td>Less than 40% Ba</td>
<td></td>
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<tr>
<td>≥95-96% BaSO₄</td>
<td>Density ≥2.75-4.30 g/cm³ (Yemen ore)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

MANGANESE ORE PROSPECT AT AL-GAYDHAH As-Saghirah

Location of the prospect

The prospect area is situated in Al-Mahrah governorate, 8 km to the northwest of Seyhoot town. Distance of about 6 km to the northwest separates the prospect from the paved highway. The prospect is centered on 0519588 E, and 1686071 N, UTM, and totals an area of about 0.5 km².

Geology of the prospect

Geology is composed of Cretaceous sandstone (Mukalla Formation), overlain by the Tertiary carbonate of Umm Er Radhuma Formation, and Jeza’ Formation and also a layer of Quaternary sediments, including gravel and sands (Figure 6). Structurally the area is controlled by a NW faults (310º). The only alteration observed is represented by brecciation (carbonate cemented by pyrolusite).

Geophysical survey

Geophysical survey has been achieved on Al-Ghaidah As-Saghirah prospect area, using electromagnetic (EM) method based on geological and geochemical results and based on topographical networks. Results of this method indicate both massive as well as disseminated ore mineralogy throughout a zone reaching 80 m in depth (Figure 7).

Mineralization and alteration

Pyrolusite

Mineralization consists of massive pyrolusite veins (up to 1 m in thickness) and grading in composition from 61 up to 66% MnO, and up
**Figure 6.** Generalized geological map of Al-Ghaidah As-Saghirah manganese ore prospect.

**Figure 7.** Location of the geophysical network to be achieved at Al-Kohl-1 area.
to 74-80% MnO₂. Anomalous cobalt contents are reported from pyrolusite and hollandite, in which they may exceed 0.1%. Pyrolusite is mostly characterized by oolitic structure (Figure 8) indicating a shallow marine origin. Pyrolusite composition averaging 45% Mn (Table 4). The only alteration observed is represented by brecciation. Stockwork mineralization is represented by pyrolusite cementing brecciated carbonate rocks (Figure 8). Goethite also occurs to the west and north of the manganese occurrence, attaining 2-3 m in thickness. Pyrolusite is practically related to the shallow marine carbonate of Umm Er Radhuma Formation. It is probably the product of the chemical decomposition of igneous rocks, where released manganese primarily solves and migrates as hydro-carbonate, and rarely as sulfate-complex forms. Manganese has similar characteristic feature to that of iron, where it

Table 4. Average results on major oxides (wt.%) of pyrolusite.

<table>
<thead>
<tr>
<th>Component</th>
<th>SiO₂</th>
<th>TiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>MnO</th>
<th>MgO</th>
<th>CaO</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.30</td>
<td>0.005</td>
<td>&lt;0.05</td>
<td>&lt;0.01</td>
<td>61.612</td>
<td>0.66</td>
<td>1.632</td>
</tr>
<tr>
<td>2.</td>
<td>0.62</td>
<td>0.013</td>
<td>0.07</td>
<td>0.04</td>
<td>61.380</td>
<td>1.00</td>
<td>1.846</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Component</th>
<th>Na₂O</th>
<th>K₂O</th>
<th>P₂O₅</th>
<th>(SO₃)</th>
<th>LOI</th>
<th>Sum</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>0.41</td>
<td>0.224</td>
<td>0.052</td>
<td>0.86</td>
<td>14.24</td>
<td>80.00</td>
</tr>
<tr>
<td>2.</td>
<td>0.44</td>
<td>0.245</td>
<td>0.056</td>
<td>0.62</td>
<td>14.64</td>
<td>80.99</td>
</tr>
</tbody>
</table>

Figure 8. Shows different types of mineralization of manganese ores, including veins, breccias, association with sandstone as well as scattered ore pieces. Pyrolusite is represented by oolitic structure indicating shallow marine origin.
is generally solving near lower Eh values, and precipitates when these values are higher. Diluted and weak acidic environment affects the strongly basic Mn+2 to remain in solution. This can be applied for the occurrence of pyrolusite mineralization, which was precipitated in such an environment. Geochemical results of major components of pyrolusite are given in Table 4.

**Hollandite and romanechite**

**Experimental method**
The samples MAM-432 and MAM-436 were reduced into fine powder to the optimum grain-size range for X-ray analysis (<10µm) grinding under ethanol in a vibratory McCrone Micronising Mill for 7 minutes. Step-scan X-ray powder-diffraction data was collected over a range 3-80° 2θ with CoKα radiation on a standard Siemens (Bruker) D5000 Bragg-Brentano diffractometer equipped with an Fe monochromator foil, 0.6 mm (0.3°) divergence slit, incident- and diffracted-beam Soller slits and a Vantec-1 strip detector. The long fine-focus Co X-ray tube was operated at 35 kV and 40 mA, using a take-off angle of 6°.

**Table 5. Results of quantitative phase analysis of manganese ore (wt.%)**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Ideal formula</th>
<th>MAM-432 (wt.%)</th>
<th>MAM-436 (wt.%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hollandite</td>
<td>Ba(Mn4+,Mn2+)8O16</td>
<td>100</td>
<td>27</td>
</tr>
<tr>
<td>Romanechite</td>
<td>(BaH2O)2(Mn4+,Mn3+5)O10</td>
<td>-</td>
<td>45</td>
</tr>
<tr>
<td>Quartz</td>
<td>SiO2</td>
<td>-</td>
<td>18</td>
</tr>
<tr>
<td>Anhydrite</td>
<td>CaSO4</td>
<td>-</td>
<td>9</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>100</td>
<td>99</td>
</tr>
</tbody>
</table>

grain-size range for X-ray analysis (<10µm) grinding under ethanol in a vibratory McCrone Micronising Mill for 7 minutes. Step-scan X-ray powder-diffraction data was collected over a range 3-80° 2θ with CoKα radiation on a standard Siemens (Bruker) D5000 Bragg-Brentano diffractometer equipped with an Fe monochromator foil, 0.6 mm (0.3°) divergence slit, incident- and diffracted-beam Soller slits and a Vantec-1 strip detector. The long fine-focus Co X-ray tube was operated at 35 kV and 40 mA, using a take-off angle of 6°.

**Results and discussion**
The X-ray diffractograms were analyzed using the International Center for Diffraction Database PDF-4 using Search-Match software by Siemens (Bruker). X-ray powder-diffraction data were refined with Rietveld program Topas 3 (Bruker AXS). The results of quantitative phase analysis by Rietveld refinement are given in Table 5. These amounts represent the relative amounts of crystalline phases normalized to 100%. As the diffraction patterns are of very low intensity with poorly resolved peaks, the relative amounts of the phases should be considered semi-quantitative. The Rietveld refinement plots for the samples are shown in Figures 9-10.

Based on our geochemical results and also on a comparative study of the geochemical composition of other occurrences throughout the world, including market segmentation, it is found that the Al-Gaydhah As-Saghirah prospect has high pyrolusite quality (Table 6), irrespective of the relatively small occurrence and limited resource.

**SECONDARY MINERALS**

**Calcite (CaCO₃)**

Calcite is the most significant secondary mineral. It occurs as fracture and cavity filling material (Figure 13), sometimes encrusting dolomite and fine grains of desclusite. Calcite forms colorless transparent crystals, and/or translucent white color masses.

**Dolomite CaMg(CO₃)₂**

Dolomite crystals with a distinctly brownish color and pearly luster have been found encrusted by barite and calcite. They are characterized by their distinguished orange-red fluorescence.
Figure 9. Rietveld refinement plot of sample ALS “MAM-432” (blue line - observed intensity at each step; red line - calculated pattern; solid grey line below—difference between observed and calculated intensities; vertical bars, positions of all Bragg reflections). Colored lines are individual diffraction patterns of all phases.

Figure 10. Rietveld refinement plot of sample ALS “MAM-436” (blue line - observed intensity at each step; red line - calculated pattern; solid grey line below—difference between observed and calculated intensities; vertical bars, positions of all Bragg reflections). Colored lines are individual diffraction patterns of all phases.
Quartz (SiO$_2$)

Quartz is found as drusy filling the cavities or in form of silification in the dolomitic limestones that associated with barite mineralization. In addition, silica is found as flint and jasper.

CONCLUSIONS

Barite is formed as a result of hydrothermal process, and/or as the result of weathering zone, where Ba mainly reached the solution in the form of BaCl$_2$, but when reacts with SO$_4$-root it forms barite immediately. Barite can be easily solved, but because of increasing in redox-potential (Eh), again it precipitates as barite. The economic minerals of Wadi Al-Masila prospect occur almost entirely in the residual blanket, which overlies the late Proterozoic basement rocks. Wadi Al-Masila prospect includes two main areas, Wadi Al-Kohl, and Al-Qala’nah. This important area is selected for exploration due to the widely distribution of alteration and also due to anomalous mineralization of Ba, and Mn. Barite in some cases may attain 1 kilometer in length, whereas the width is variable ranging from 0.6 to 5 meters. The occurrence of barite veins, the occurrence of bedded structure and silicified zones rich in barite on or near the surface as well as the high Ba content. The ore minerals are usually disseminated in a variety of structures such as solution breccias and pipes, shear zones, fractures and cavities. The mineralized zones usually occur in the upper

<table>
<thead>
<tr>
<th>Quality</th>
<th>High (Yemen)</th>
<th>Medium</th>
<th>Low</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Over 45% Mn Yemen Ore</td>
<td>30-45% Mn</td>
<td>Less than 30% Mn</td>
</tr>
</tbody>
</table>

Table 6. Market segmentation according to quality preference of the pyrolusite raw material.

Figure 13. Calcite veins and cavities within the dolomitic limestones Aggregates of celestine crystals are also shown.
portion of the sedimentary sequence (Saa'r Formation).

However, Al-Gaydhah As-Saghirah manganese ore prospect is selected for exploitation due to good accessibility, the occurrence of mineralization near the surface, as well as the relatively high MnO content, and favorable mining conditions. In additions, highly anomalous Ba, Sr, Co and V are associated with the manganese ore in which their contents may reach 7%, 3%, 0.15%, and 0.10% respectively. All these factors had encouraged us to continue our previous work in order to identify economic potential in this area. Furthermore, the finished product has excellent prospects mostly in the export market and to the developed countries wherein the pyrolusite dioxide is extensively used in the industry. However, preliminary estimation of the resource indicates prospective ore potential.

Whatever the ultimate resource of barite, and manganese, the ore minerals were formed and concentrated by the affect of hydrothermal process that caused by the Quaternary volcanic eruption extruded throughout the main wadi trend and/or by the action of slightly acidic groundwater which dissolved the soluble carbonate during a long period of weathering and erosion.

It is possible that such mineralization occurrences, as well as all other occurrences within the Hadramawt Plateau had been accumulated particularly during earlier cycles of weathering and are therefore closely related to peneplains, which are later uplifted and dissected due to the opening of the Gulf of Aden.

**REFERENCES**


