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Petrography and Geochemical Study of the Perlite Rocks from Bait Al-Qeyarie, Kawlan Area, Yemen

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Abstract. A sequence of perlite rocks crop out at Bait Al-Qeyarie locality, Kawlan area, which lies at about 60 km SE of Sana'a City. Perlite rocks occur within acidic volcanic rock sequences consisting of rhyolite, greenstone, zeolite, pyroclastic, and tuffaceous rocks. Petrographic examination shows that the perlite rocks are composed mainly of more than 65% silica groundmass with embedded phenocrysts of quartz, chert, chalcedony, k-feldspar, chlorite, pyroxene and iron oxides. They show onion-skin cracks, the characteristic texture of perlite rocks.

Geochemical analysis shows that the majority of the studied perlite rocks have silica content ranging from 65.0 to 75.0 wt%, with an average of 69.6 wt% and water content ranging from 0.35 to 3.94 wt% with an average of 2.14 wt%, compared with the chemical properties of the commercial perlite (silica > 65 wt% and water content range from 2 to 5 wt%). The studied perlite rocks are considered to be of good quality for industrial uses. Their commercial importance comes from their silica-rich groundmass and the combined meteoric water in the structure of the constituent minerals.

Introduction

Perlite rocks are defined as acidic, glass rich volcanic rocks with perlite fabric represented by onion-skin like cracks. These cracks break the rock into millimetre-sized spheres or pearls (Meisinger, 1980; Al-Ta'ae, 2003). Perlite rocks generally occur as lava flows or shallow intrusive rocks. They are grey in colour and are sometimes black to less commonly white. Most industrial perlites occur as vitric outer skin of rhyolitic lava domes or flows and as alteration products of rhyolitic vitric tuff (Chesterman, 1975; Rudnynszky 1978; and Jessica *et al.,* 2006). Due to their low density and relatively low price, many commercial applications for perlite have been developed. These include; rock wool, chemical fertilizers, fillers, paints, insulators…*etc*. Major element contents (*e.g.* SiO_2, Al_2O_3, Na_2O, K_2O, Fe_2O3, MgO, CaO and H_2O) define the chemical properties of perlites and used as parameters in the estimation of their industrial applications. Good industrial perlites have more than 65wt% SiO_2 and average water content of about 2.5wt% (Vassiliou, 1975; Austin & Weber, 1976; Coetzee, 1976; Mathers, 2000; and Jessica *et al.,* 2006).

Perlite rocks are cropping out in Bait AL-Qeyarie locality, Kawlan area, about 60 km southeast of Sana'a city. This area represents a part of the high plateau mountains of the central and western parts of Yemen that ranges in elevation from 2200-2400 m a.s.l and composed of Tertiary and Quaternary volcanic rocks. The studied perlite rocks and the associated volcanic sequences belong to the Tertiary volcanic group of Yemen (Diggens *et al.,* 1988; Kruck *et al.,* 1991 & 1996; Robertson, 1993; Beydoun *et al.,* 1998; Al-Sabri & Al-Razehi 2000; and Al-Ta'ae 2003). The rock sequences are composed (from bottom to top) of basalt, pyroclastic sediments, rhyolite, perlite, rhyolite tuff, dacitic perlite and andestic perlite. The Primary rhyolitic glasses, such as obsidian or pitchstone typically have about 1% combined water of juvenile (magmatic) origin (Bailey & Kadey 1983; Lehman & Rossler 1974; Mathers *et al.,* 2000; and Jessica *et al.,* 2006).

This study aims at examining the petrography and chemical properties of the perlite rocks to determine their mineralogical constituents, textures and structures, and to define their economic potential.

Methodology

Systematic field work has been carried out to examine representative stratigraphic sections of volcanic rocks in Bait AL-Qeyarie region. Facies description and measurements were carried out and stratigraphic log was constructed. Field photographs were taken for the perlite rock sequence.

Twenty five rock samples were systematically collected from the selected stratigraphic sections and thin sections were prepared following the procedure listed in Tucker (1988). The rock samples were cut perpendicular to the bedding planes to recognize all the layers of the mineralogical constituents.

Microphotographs illustrating the mineralogical constituent, crystal shapes, textures and the structures of the perlite were taken.

Five samples were selected for chemical analysis to determine the major oxide contents and the water percentage of the perlites. The chemical analysis was carried out using Perkin Elmer Atomic Absorption instrument. Determination of the major elements was carried out by preparing a solution of the rock powder after burning at 1000°C and the product was digested with Nitric acid. Obtained solution was completed to 250 ml. The concentrations of the major estimated elements were determined by mathematical equation.

The accuracy of the used Atomic Absorption is about 0.03%.

Stratigraphy and Geologic Setting

The acidic volcanic rock successions that host perlites extend for more than 20 km in the high plateau of NW Yemen and in a deep valley beneath Bait Al-Qeyarie Village. The area is mainly composed of Tertiary and Quaternary volcanic rock sequences (Fig.1). The studied perlite rocks and other acidic volcanic rocks belong to the Tertiary volcanics Group (Beydoun, *et al.,* 1988). They are composed of alternative basalt, volcanic ash, rhyolite, perlite, rhyolite tuff, dacitic perlite, and andesitic perlite. The following geological criteria characterize the studied volcanic sequences:

1- The rock successions are lava flow type hosting perlite rocks (Fig. 2).

2- Three layers of perlite rocks crop out in these rock sequences, the three layers are termed A, B, and C (*e.g.* Fig. 3a).

3- The perlite rock layers have thicknesses ranging from 5 to 10 m (Fig. 3b & c) and extend for about 20 km.

4- The perlite rocks are massive, black in colour and of lustrous nature and occasionally banded (Fig. 3c).

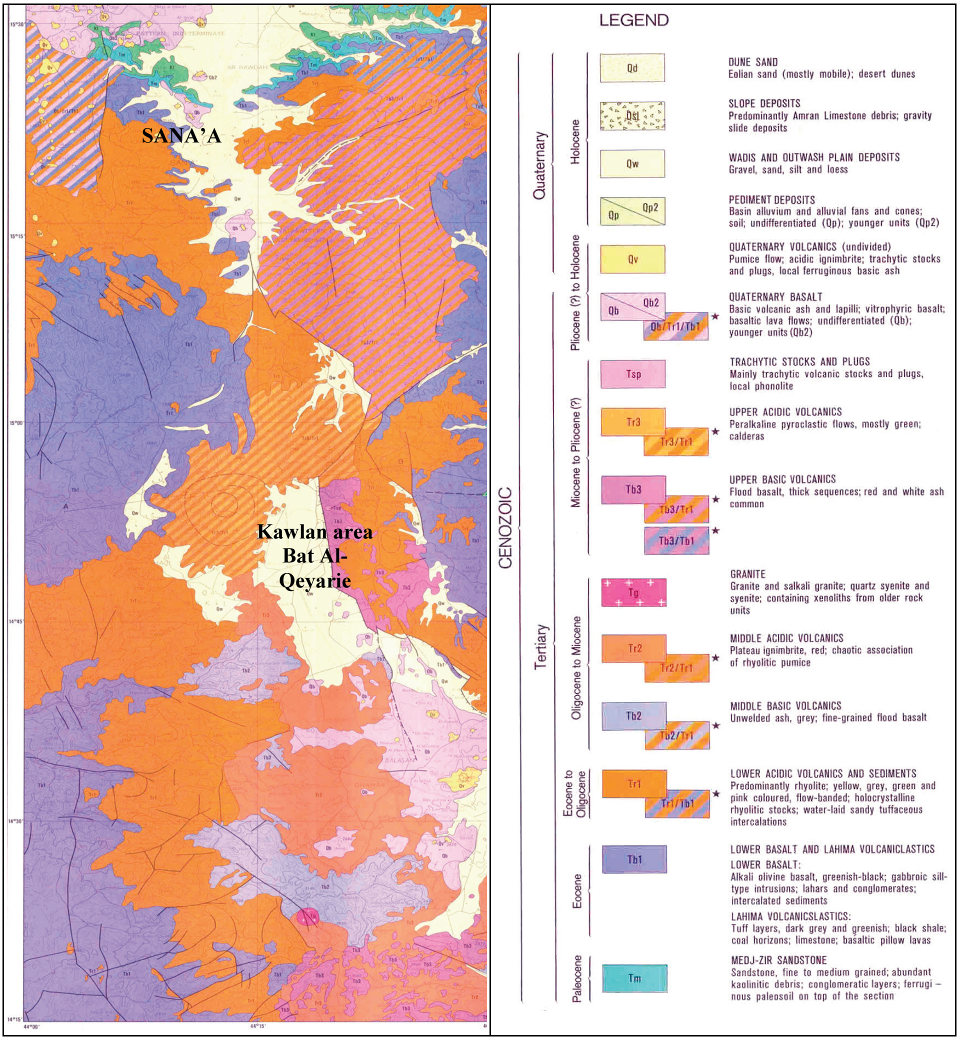

Fig. 1. Geological map of South Sana'a region showing the studied localities of Bait Al-Qeyarie, SE of Sana'a city. The map is adapted from the geologic map of Sana'a sheet prepared by Kruck *et al.*, (1991).

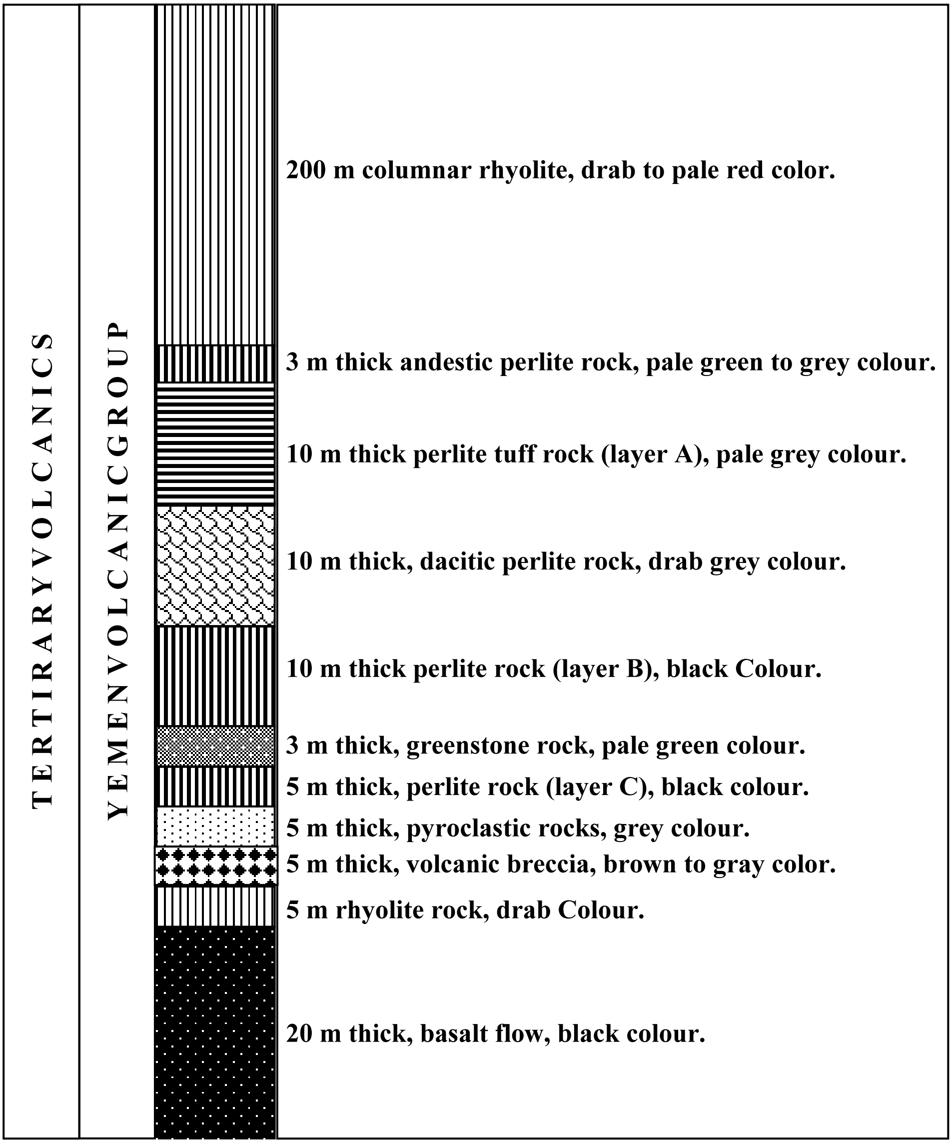

Fig. 2. Stratigraphic section of Baiet Al-Qeyarie locality showing different rock units (including perlite rocks).

Commercial perlite rocks in the world mainly occur in late Tertiary and Quaternary volcanic terrains, which are characterized by highly siliceous volcanism. Most of geologically older volcanic glasses are generally partially or wholly devitrified. The perlite rocks of Yemen belong to the Tertiary Yemen Volcanic Group. The sequences are of acidic lava origin and composed mainly of rhyolite, tuff, obsidian…..*etc*.

The stratigraphic column of Bait Al-Qeyarie area is represented by the following rock units from bottom to top:

1. Basaltic flow, black colour.
2. Rhyolite, drab colour.
3. Volcanic breccia, drab to red colour.
4. Pyroclastic rocks, dark grey colour.
5. Perlite rocks (layer A), lustre black colour and 5-6m thick.
6. Greenstone.
7. Perlite rocks (layer B), lustre black colour and 10m thick.
8. Dacitic perlite, dark grey colour and 10m thick.
9. Perlite tuff (layer C), pale grey colour and 10m thick.
10. Andesitic perlite, pale green to grey colour and 3m thick.
11. Columnar rhyolite, drab to reddish colour and 200-250m thick.

Petrography

The perlite rocks are composed mainly of phenocrysts and silica groundmass. The phenocrysts are k-feldspars (sanidine and anorthoclase), plagioclase, pyroxenes, chlorite, quartz and serpentine. The groundmass attains about 65% of the rock volume and is composed of silica and iron oxides.

Phenocrysts

Euhedral to subhedral crystals are scattered in the silica groundmass forming porphyritic texture. They range in size from 0.1 to 0.7 mm and comprise the following minerals arranged according to their modal percentages

Feldspars

Feldspar is the most common phenocrystic phase in the studied perlite rocks (Fig. 4a & b). K-feldspar and plagioclase are euhedral to subhedral, as well as zoned crystals. Some phenocrysts show evidences of fracture and breakage, suggesting turbulent magmatic transport. Both types of k-feldspar (anorthoclase and sanidine) were noted as well. The sanidine is a characteristic mineral of acidic volcanic rocks whereas anorthoclase is a characteristic mineral of soda-rich acidic and volcanic igneous rocks (Perkins, 2002). Plagioclase (albite and rare oligoclase) is present in the studied rocks as long prismatic euhedral crystals that range in size from 0.3 to 0.5mm. The modal percentages of both feldspar types range from 10 to 20%.

Pyroxene

Subhedral pyroxene phenocrysts are also present in all studied thin sections. Both aegirine and aegirine-augite noted and the latter is often veined. Rounding, embayment and resorption are common features of some pyroxene crystals. Pyroxene minerals are present as large and small euhedral to subhedral crystals. The type of noted pyroxene mineral is a characteristic mineral of soda-rich igneous rocks (Perkins, 2002).

Pyroxene crystals show large phenocrysts as well as microphenocrysts that range in size from 0.3 to 0.7mm (Fig. 4b). Eight-sided phenocrysts of pyroxene are present and of less abundant. The modal percentages of the pyroxenes range from 2 to 5%.

Chlorite

Chlorite is present as small crystals that have green colour and some occur as aggregates in xenoliths shape (Fig. 4c). It is a common secondary mineral after biotite, muscovite and other mafic minerals in igneous rocks (Perkins, 2002). The modal percentages of chlorite range from 5 to 20%. The origin of chlorite is suggested to be alteration product of original pyroxene.

Quartz

Quartz is present in several forms (silica minerals) and in different modal percentages, they range in size from 0.1 to 0.4mm (Fig. 4d & e), these are:

– Quartz occurs as small, clear and euhedral to subhedral crystals present in a range of 2 to 3%.

– Cristobalite occurs as small, unhedral and highly fractured crystals present in a range of 2 to 3%.

– Chalcedony occurs as small, spherical and radiated crystals present in a range of 3 to 10%.

– Chert occurs as fine crystal aggregates that range from 3 to 7%.

Serpentine

Serpentine mineral was recognized as small crystal aggregates in a xenolithic habit (Fig. 4c). The suggested type of serpentine mineral is antigorite; the hydrous magnesium silicate of serpentine (Perkins, 2002). It ranges in modal percentages from 2 to 10%. The serpentine aggregates are mixed with chlorite in the noted xenoliths. The size of aggregates of serpentine and chlorite reaches up to 0.7mm. The suggested origin of serpentine is altered pyroxene.

Iron oxides

Iron oxides were recognized in few modal percentages. Noted black spots represent magnetite, brown to reddish brown crystals of hematite and few six-sided black and opaque crystals of ilmenite. Some hematite is of secondary origin formed as alteration product of mafic minerals (Perkins, 2002). Iron oxides range from 2 to 4%.

Groundmass

The groundmass constitutes the major component of the studied rocks (Fig. 4f & g). It is essentially composed of silica and minor iron oxides. The silica groundmass reveals several forms such as:

1) Amorphous silica of dark colour that confirms the tuffaceous texture.

2) Fine crystalline patches of chert,

3) Radiated small crystals of chalcedony,

and 4) Scattered small crystals of quartz.

Textures

Several types of textures were recognized in the studied volcanic rocks represented by a major groundmass with xenoliths and phenocrysts. The types of textures are: perlitic, porphyritic, cryptocrystalline (tuffaceous), glassy and trachytic textures.

1. Perlitic Texture

Is composed of small onion-skin like cracks, which break the rocks into millimetre-size spheres. This texture is clearly recognized in the studied perlite (Fig. 4a & b).

2. Porphyritic Texture

Is recognized in all the studied rock samples. This texture comprises large crystals of feldspar and pyroxene minerals embedded in the silica-rich groundmass (Fig. 4a & b).

3. Cryptocrystalline (Tuffaceous) Texture

Comprises the very fine to glassy silica groundmass that composed the majority of the perlite rocks. This texture was recognized in the tuffs (Fig. 4g).

4. Glassy Texture

The glassy texture comprises the amorphous silica groundmass and was recognized as obsidian rocks.

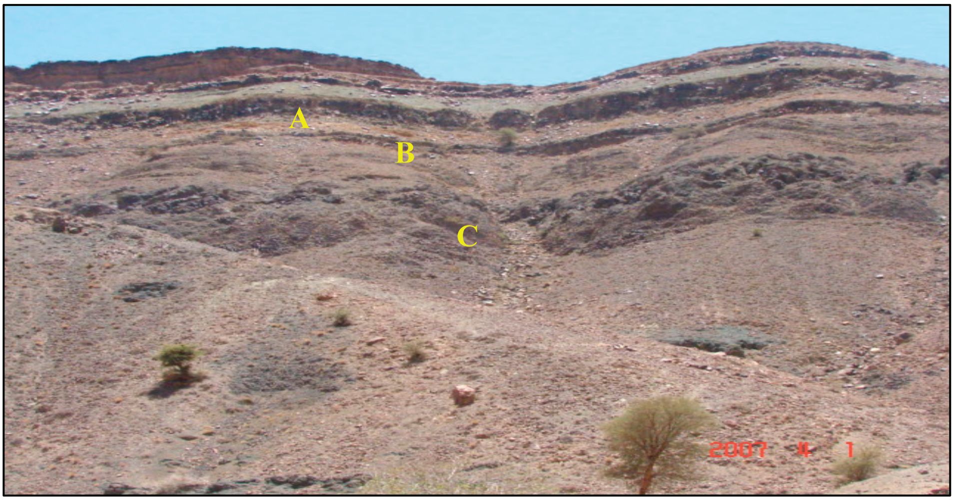

Fig. 3(a). Field photograph showing the volcanic rock sequences including the perlite layers (A, B and C) in the Kawlan area at Bait Al-Qeyarie village.

Fig. 3(b). Field photograph showing layer (A) of the perlite rocks (5-10 m thick).

Fig. 3(c). Field photograph showing layer (B) of the perlite rocks (10 m thick).

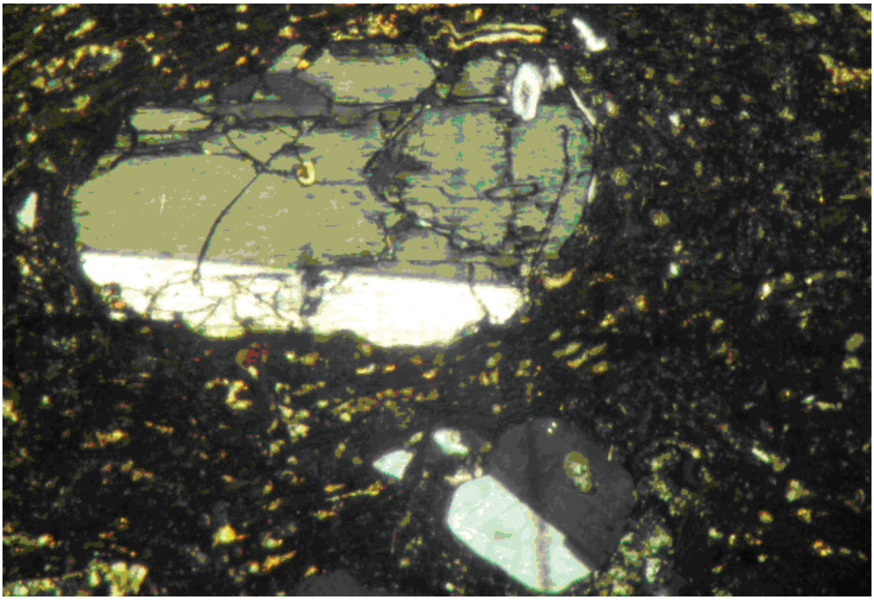

Fig. 4(a). Microphotograph showing subhedral and euhedral sanidine phenocrysts embedded in the silica groundmass of the rhyolite rock (CN-40X).

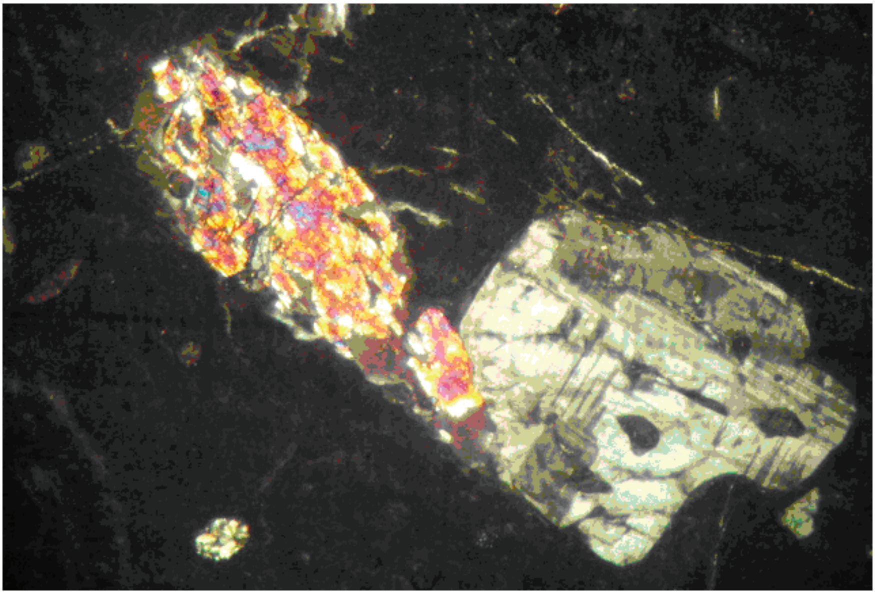

Fig. 4(b). Microphotograph showing anorthoclase and pyroxene phenocrysts in the perlite rocks (CN-40X).

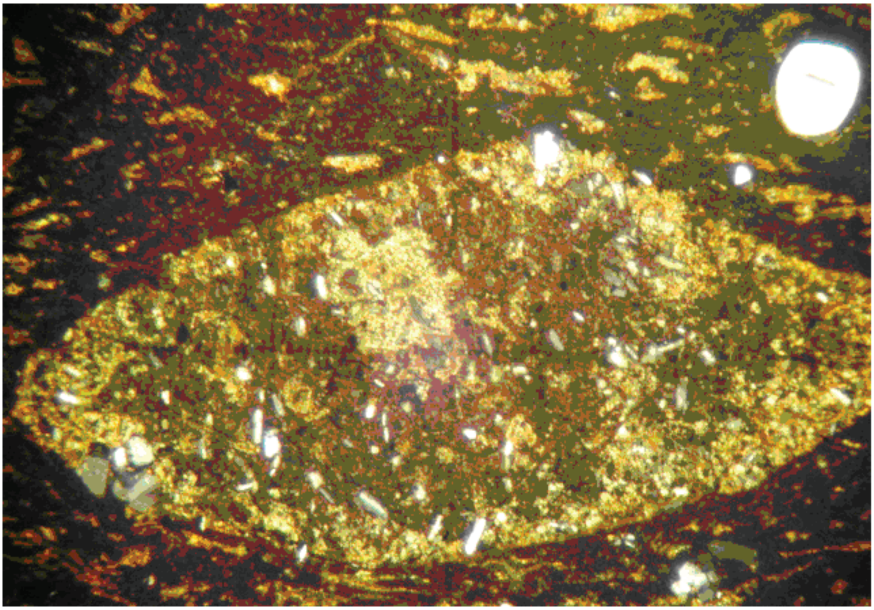

Fig. 4(c). Microphotograph showing chlorite and serpentine crystal aggregates in the perlite rocks (CN-40X).

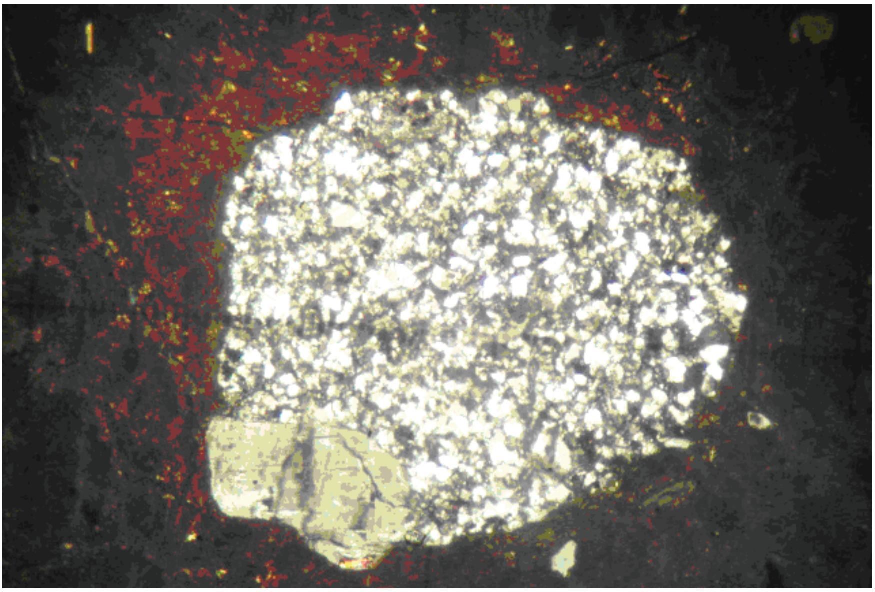

Fig. 4(d). Microphotograph showing chert aggregates and sanidine crystals in the perlite rocks (CN-40X).

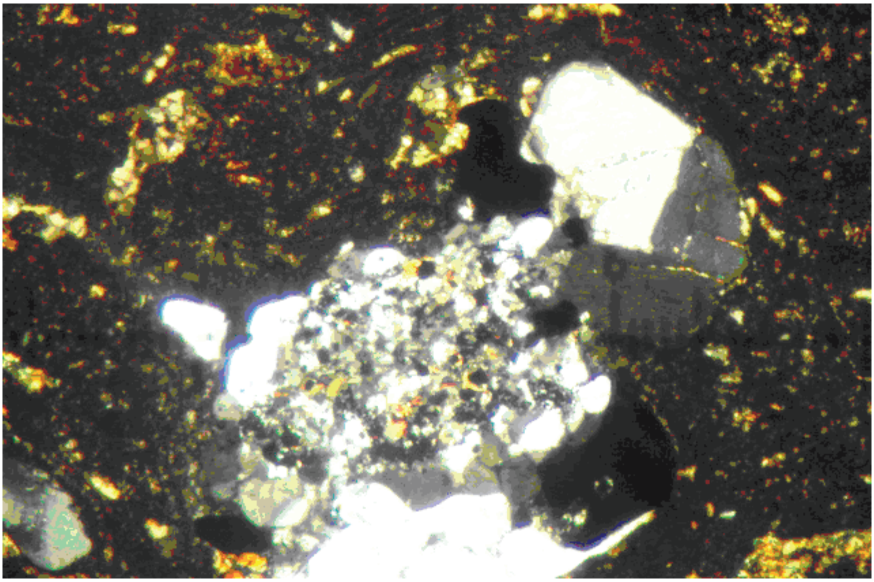

Fig. 4(e). Microphotograph showing chert, pyroxene, serpentine and quartz in the silica groundmass of the dacitic perlite rocks (CN-40X).

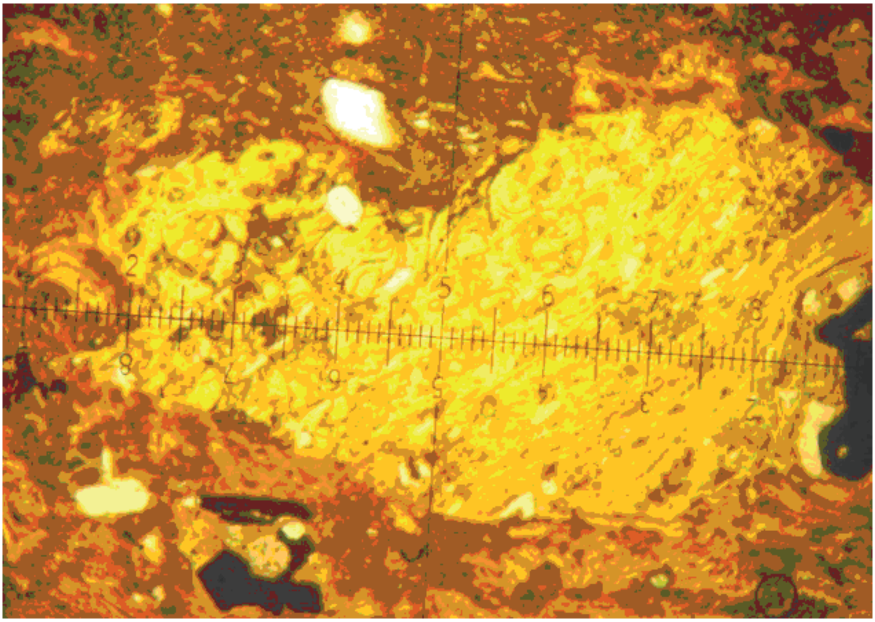

Fig. 4(f). Microphotograph showing perlitic tuff composed of perlite patches in tuffaceous groundmass (CN-40X).

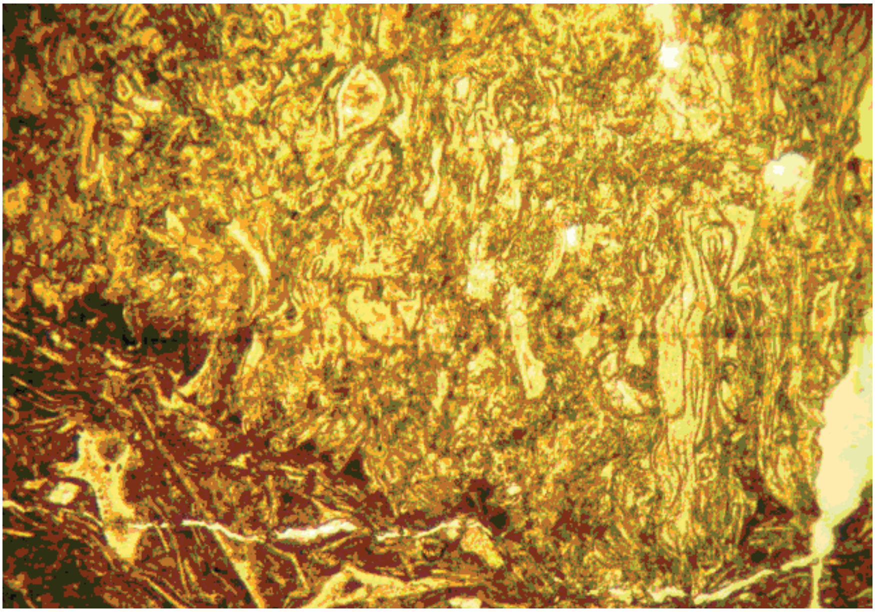

Fig. 4(g). Microphotograph showing silica groundmass and tuffaceous texture in tuff (CN-40X).

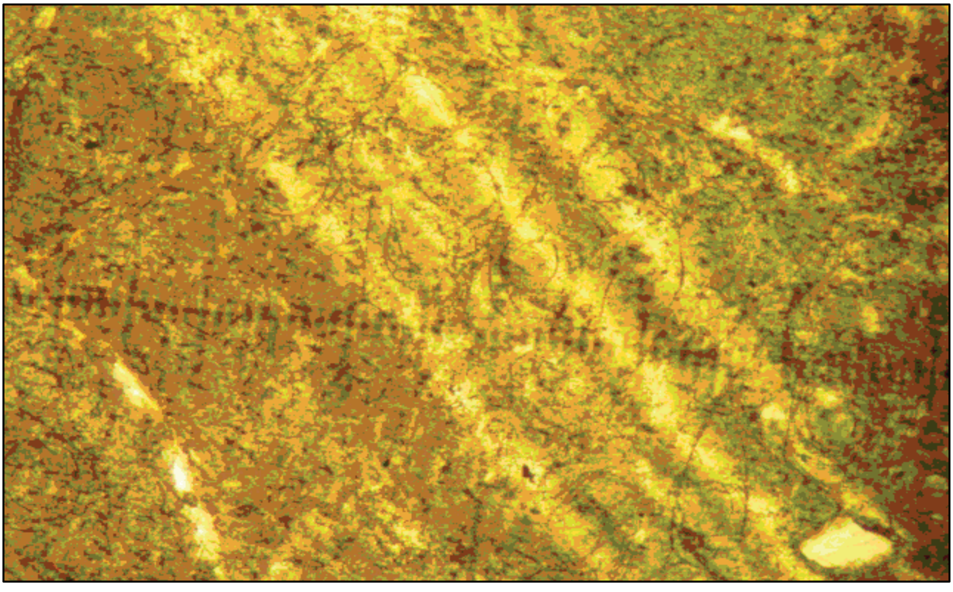

Fig. 5(a). Microphotograph showing the onion skin-like texture of the perlite rocks (CN-40X).

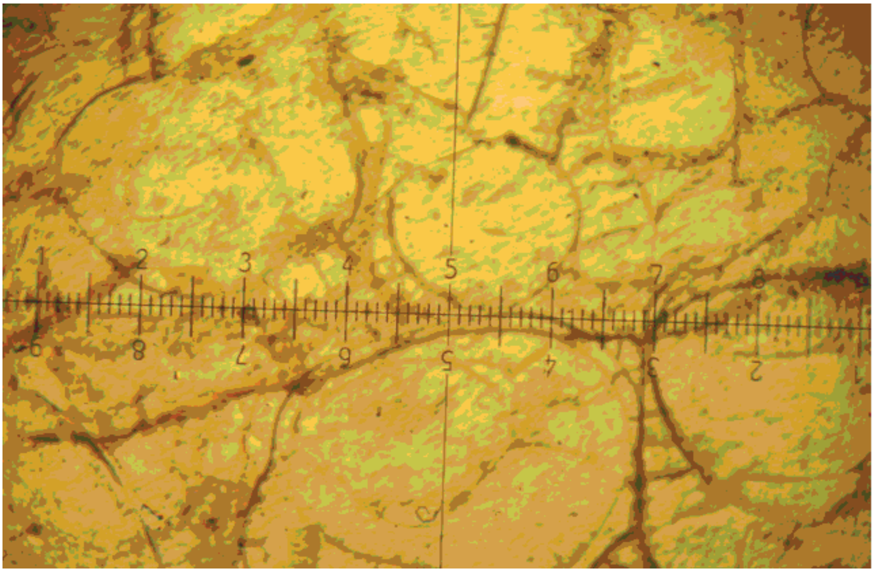

Fig. 5(b). Microphotograph showing large onion skin-like texture with fine spherulitic crystals (CN-40X).

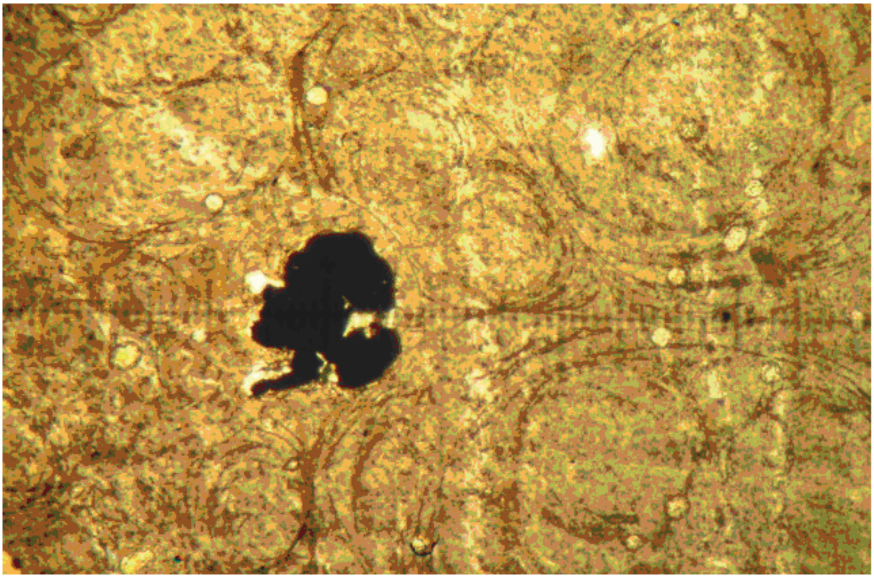

Fig. 5(c). Microphotograph showing the onion skin-like texture of the perlite with iron oxide and fine spherulitic crystals (CN-40X).

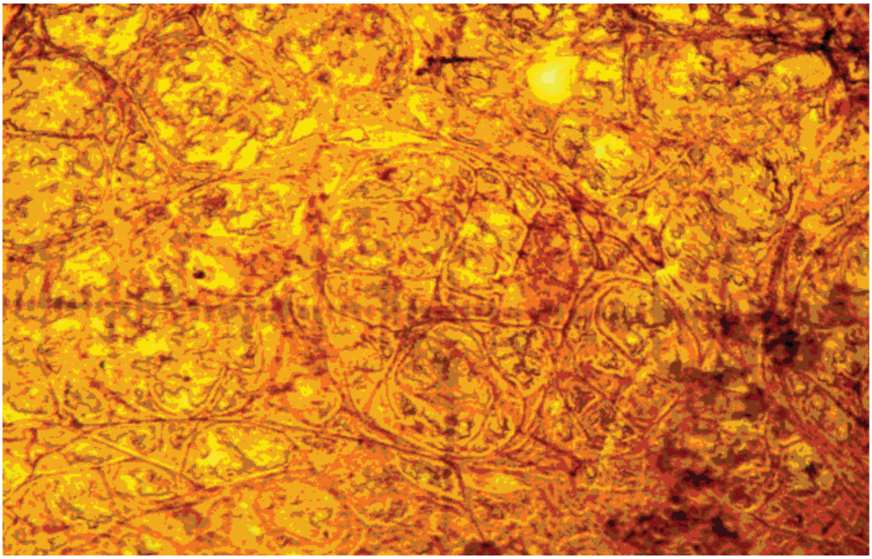

Fig. 5(d). Microphotograph showing the onion skin-like texture of the perlitic rocks with iron oxide stains (CN-40X).

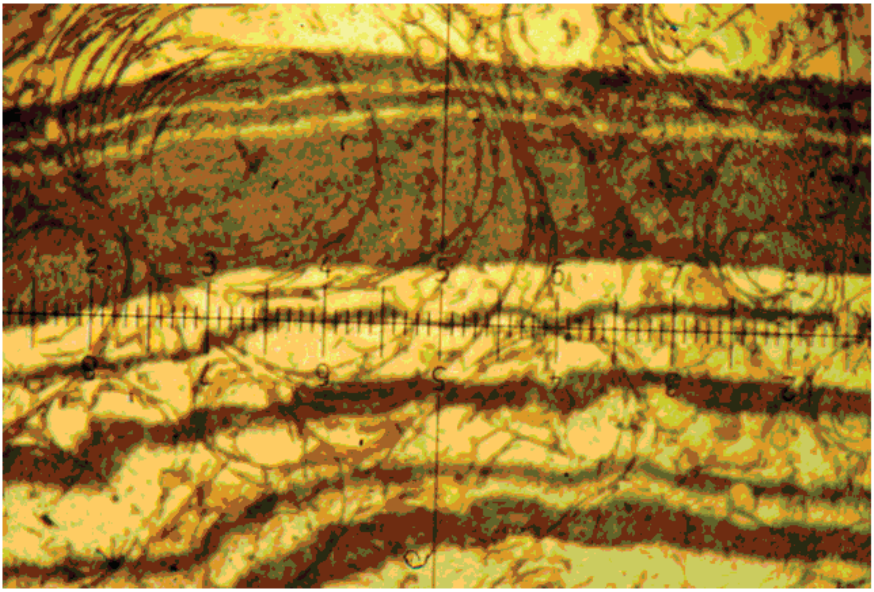

Fig. 5(e). Microphotograph showing banded onion skin-like fractures (CN-40X).

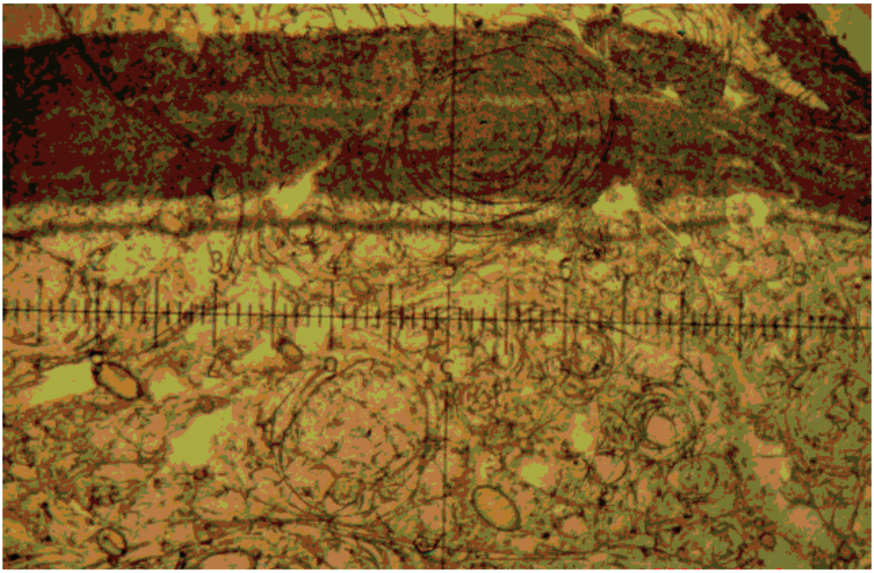

Fig. 5(f). Microphotograph showing banded perlite with onion skin-like fractures and fine spherulitic crystals (CN-40X).

Geochemistry

Chemical analysis of five selected rock samples representing the perlite rock units has been carried out at the laboratories of the geological survey and mineral resources board, Sana'a, Yemen. Samples (S2-P2A, S2-P3A, S2-P4A) were selected from layer-A, while samples No. S2-P1A and S1-p2 were selected from layer-B and C respectively.

The results of chemical analysis are listed in table-1 below. The compositional variation in the major element analyses of the 3 samples (S2-P2A, S2-P3A, S2-P4A) belongs to layer-A of the studied perlites show uniform content of SiO_2 (65-68.75%), Al_2O_3 (11.3-12.8%), Fe_2O_3 (2.68-3.66%), CaO (0.87-1.84%), MgO (0.62-0.93), Na_2O (3.41-4.72%), K_2O (3.0-4.1%), and H_2O (2.82-3.94%). On the other hand, samples (S2P1A and S1-P2) that belong to layer-B and C respectively, are characterized by relatively high SiO_2 content (72.46 and 75.0%), low Al_2O_3 (9.4 and 9.44%), CaO (1.7 and 0.96%), MgO (0.5 and 0.51%) and H_2O (0.35 and 0.35%) respectively. This is suggesting that layer-A was totally altered from acidic volcanic glass (*e.g.* obsidian or rhyolite) to perlite rocks by the hydration process, while layer-B and C were partially altered to perlite rocks. This is evident from the low content of the meteoric water.

Table.1. Chemical analysis data of perlite samples from Kawlan locality.

Sample. No	SiO_2%	AL_2O_3 %	Fe_2O_3%	CaO %	MgO %	Na_2O %	K_2O %	Water content	Total%
S1-P2 (Layer-C)	75.0	9.4	2.97	1.7	0.5	3.55	3.8	0.35	98.01
S2-P1A (Layer-B)	72.46	9.44	2.68	0.96	0.51	3.37	3.6	0.35	94.49
S2-P2A (Layer-A)	65.0	12.8	3.66	1.84	o.93	3.41	3.8	3.94	98.53
S2-P3A (Layer-A)	66.6	12.8	3.39	0.87	0.62	4.72	4.1	2.82	98.21
S2-P4A (Layer-A)	68.73	11.3	2.68	1.55	0.62	4.25	3.6	3.27	98.82
Average	69.6	11.15	3.07	1.4	0.64	3.86	3.78	2.15	

The AFM ternary diagram (Fig.6) shows that the studied volcanic rock sequences plot towards the A (Na_2O+K_2O) apex (acidic volcanics). The total alkali-silica classification diagram (Fig.7) shows that the studied volcanic rock sequences of Kawlan area are acidic volcanic dacite and rhyolite.

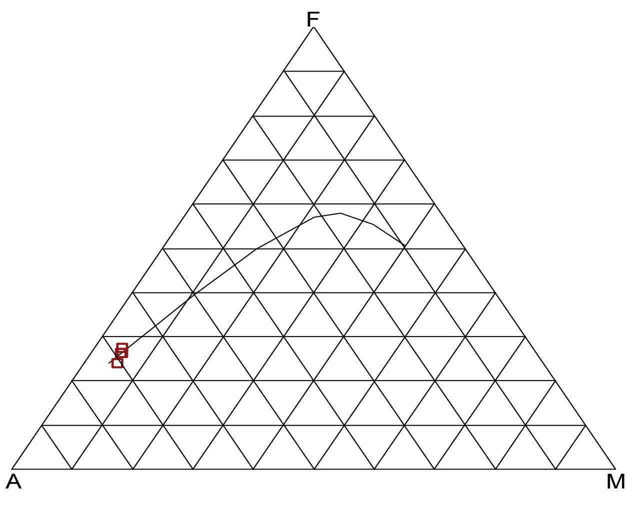

Fig. 6. AFM Ternary diagram (Irvin & Barager, 1971) showing the composition of perlite rocks from the Kawlan area. A=Na_2O+K_2O, F=FeO+Fe_2O_3, and M=MgO. IUGS.

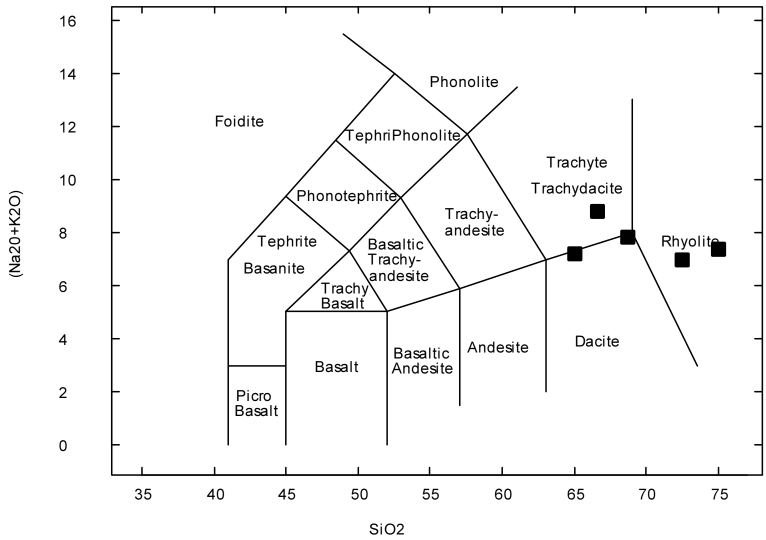

Fig. 7. Total alkali-silica classification diagram after IUGS (Le Bas *et al.,* 1986) showing the dacitic and rhyolitic composition of the studied perlite rocks.

Discussion and Conclusion

The petrographic study of the perlite rocks show that perlitic texture "onion-skin like fractures" is an important characteristic texture and is recognized in all of the studied samples. The bound meteoric water and the onion fractures lead to expand the perlite rocks after heating and make the rocks suitable for industrial uses. The chemical analysis of the studied rock samples of Kawlan locality show that the percentages of combined water ranges from 0.35 to 3.94%. Two samples show percentages of combined water of 0.35%, which means that they will not expand after the flash heating treatment. The other three samples contain combined water percentages range from 2.82 to 3.94%, which is comparable with the commercial perlite (water content ranges between 2 and 5%) and refer to their validity for industrial uses (Frederic & Kadey 1983; Mathers *et al.,* 2000; and Jessica *et al.,* 2006).

The studied perlite rocks were evaluated through the chemical analysis and petrographic study to show their suitability for the industrial uses. The commercial perlite contains 2-5% of combined water in the structure that is juvenile magmatic in origin. Studies of isotopic composition of the combined water indicate that perlite was usually formed by secondary hydration of the glass with combined water (Rudnyanszky, 1978; Fredric & Kadey 1983; and Mathers *et al.,* 2000).

The chemical analysis also show that the percent of silica ranges from 65.0 to 75.0%. The percentages of iron and calcium oxides refer to the presence of pyroxene and Ca-feldspar minerals in the studied perlite samples. While the aluminium, sodium and potassium oxides refer to the feldspar minerals (both plagioclase and potash feldspar).

The silica percentages reflect that the fine silica groundmass constitute the majority of the perlite rocks (more than 65.0%) and this reflects the same quality of the international commercial perlite *e.g.* good commercial perlite tends to have more than 65.0% of silica content (Bailey & Kadey 1962; Frederic & Kadey 1983; Mathers *et al.,* 2000; and Jessica *et al.,* 2006).

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بتروجرافية وجيوكيميائية صخور البرليت في منطقة بيت القيري – خولان – اليمن

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المستخلص. يتكشف تتابع من صخور البرليت في منطقة بيت القيري – منطقة خولان الواقعة على بعد ٦٠ كم جنوب شرق مدينة صنعاء. تظهر صخور البرليت ضمن تتابع من الصخور البركانية الحمضية تتضمن صخور الريوليت، والصخور الخضراء، والزيوليت، والصخور البركانية الفتاتية، وصخور التف. تظهر الدراسة المعدنية النسيجية بأن صخور البرليت تتكون أساسًا من ٦٥٪ من أرضية السليكا مع تضمنها بلورات كبيرة من الكوارتز والشيرت والكالسيدوني والفلدسبار البوتاسي القلوي والكلوريت والبايروكسين وأكاسيد الحديد، وأن هذه الدراسة تظهر التقشر البصلي النسيجي الشكل المميز لصخر البرليت.

يظهر التحليل الجيوكيميائي بأن غالبية صخور البرليت تتكون أساسًا من أرضية السليكا والتي تتراوح نسبتها من ٦٥ إلى ٧٥٪ نسبة وزنية، وبمعدل ٦٩٪، ومحتوى من الماء يتراوح من ٠.٣٥ إلى ٣.٩٤٪ نسبة وزنية، وبمعدل ٢.١٤٪، مقارنة بالمواصفات الكيمياوية للبرليت الاقتصادي (محتوى السليكا < ٦٥٪ ومحتوى الماء يتراوح من ٢ إلى ٥٪ من النسبة الوزنية تباعا).

تعتبر صخور البرليت المدروسة ذات نوعية جيدة اقتصاديًا للاستخدامات الصناعية. وتتأتى قيمتها الاقتصادية من الأرضية الصخرية الغنية بالسليكا ومن محتوى الماء المصاحب في التركيب البلوري للمعادن المكونة للصخور.