MINERALOGY AND THE TEXTURES OF THE VOLCANIC ROCKS OF THE
HARRAH AL-HAMAD OF SAUDI ARABIA

BY

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Abstract:- In the Arabian peninsula, Cenozoic basalts occur in the form of isolated, but vast lava fields which are called harrahs. A total of 13 volcanic fields exist in Saudi Arabia covering an area of about 100,000 sq. km with variable locations relative to the Red Sea. The nearest volcanic field occurs at the coastal plain, whereas the farthest is about 500 km east of the eastern coast of the Red Sea (Arno et al. 1980). The volcanic field of Harrah Al-Hamad lies in the northwest of Saudi Arabia out of the Arabian Shield boundaries (Fig 1a, 1b). A total of 215 thin sections and 20 polished sections were studied, where the mineralogical composition as well as the textural features of the volcanic rocks were identified and described. An excellent section is exposed in the vicinity of Kaf area where 4 distinguishing successive volcanic episodes of Harrah Al-Hamad are exposed with interlayered sedimentary rocks composed of chalky, silicified, phosphatic limestones, chert and calcareous sandstone of Eocene, Miocene and Pliocene age (Ell. Naggar et al. 1982). Based on sample locations and rock types of these basaltic rocks, five episodes can be grouped in the study area. Mineralogically the oldest to youngest volcanic rocks of Episode 1-5 are composed essentially of plagioclase laths (40-60%), olivine phenocrysts partially to completely replaced by secondary mineral (iddingsite) and clinopyroxene crystals. The accessory minerals are calcite and epidote. Euheral to subhedral crystals of olivine, pyroxene and plagioclase are more developed in Older Episodes (1-3) and are fine-grained in Younger Episodes (4-5). Groundmass is normally cryptocrystalline. Polished sections study indicates that opaques occur as disseminated triangular, square and rhombic grains of haematite, magnetite and ilmenite. Geochemically (using APL program of Glazner, 1984) volcanic rocks of Episode 1-3 are found as Alkali Olivine Basalts with normative Ne, &/or Hy and Ol (Ne<5%); Episode 4 as Basanite with normative Ol, Ne & Ab (Ne >5%); and Episode 5 as olivine Nephelinite with normative Ol, Ne and Lc.

INTRODUCTION

The volcanic field of Harrah Al-Hamad covers an area of about 15000 sq.Km. in the form of isolated patches of volcanic rocks. Previous geological work on the volcanic rocks of Harrah Al-Hamad is minimal, but sedimentary rocks in the area have been investigated to explore the sedimentary phosphate deposits, the underground water, and brines in the region mainly by Riofinex Geological Mission (1979). Powers et al. (1966) distinguished three types of basalts in this region: (a) older highly weathered basalts, exposed at Quryyat Al-Milh, (b) middle basalts without amygdaloidal phase, at places; and (c) a younger lava at Umm Mu'al resting directly on the Eocene surface.

The occurrence of interstratified sedimentary rocks with the volcanics has been found to be of significance in distinguishing successive volcanic episodes.

An excellent section for this is exposed in the vicinity of Kaf (Fig. 2). Based on this section, as well as other observations, a general sequence for the volcanic and interlayered sedimentary rocks of Harrah Al-Hamad has identified (Section A).

SECTION A (FROM YOUNGEST TO OLDEST)

- Post-Volcanicity Sediments
- Fifth Outcrapping Cinder-cones. And Other Volcanic Rocks (Episode 5)
- Fourth Outcropping Volcanic Rock Layer (Episode 4).
- Third Interlayered Sedimentary Rocks
- Third Outcropping Volcanic Rock Layer (Episode 3)
- Second Interlayered Sedimentary Rocks
- Second Outcropping Volcanic Rock Layer (Episode 2)
- First Interlayered Sedimentary Rocks
- First Outcropping Volcanic Rock Layer (Episode 1)
- Pre-volcanicity (Older) sedimentary Rocks
Fig. 1. Index map of western Saudi Arabia showing cenozoic volcanic fields referred to in this report (After Coleman and others, 1983, and SAMRAR, 1980-1981).

Fig. 2. Location map showing the area of investigation (Harrah al-Hamad).
Fig. 2: A panoramic view showing the First, Second, Third and Fourth Outcropping Volcanic Rock Layers exposed near Kaf, in northern part of Wadi as-Sirhan. The paved meandering road leads north westward to al-Hadithah.

Fig. 3a. Photograph of hand-specimen showing weathered nature of the First Outcropping Volcanic Rock Layer (Episode 1), collected from road-side exposure in the vicinity of Kaf. Amygdales are completely to partially filled with calcite (Sample 170).
MINERALOGY AND THE TEXTURE OF THE VOLCANIC ROCKS

A total of 215 volcanic rock sample collected from all the outcropping volcanic layers and interlayered sedimentary rocks have been investigated for their mineralogical and textural characteristics. Twenty semis polished slabs have been studied for opaque minerals.

The First Outcropping Volcanic Rock Layer (Episode 1)

The thin-section study of samples from the first layer reveals that the volcanic rocks are composed essentially of plagioclase laths (40-50%), phenocrysts of olivine (20-25%) and clinopyroxene (10-15%). The extinction angle of plagioclase laths is between 32 and 36°, indicating a labradorite variety showing poor albite twinning (Fig. 3b). The clinopyroxene is mostly masked by yellow palagonite/timonite (Fig. 3b). Olivine is completely replaced by dull brown weakly pleochroic occurs as pherocrysts and interstitial matrix. Numerous vesicles are partially or completely filled with calcite producing pherocrysts and interstitial matrix. Numerous vesicles are replaced by dull brown weakly pleochroic occurs as yellow palagonite/limonite (Fig. 3b). Olivine is completely replaced by iddingsite. Some grains show corroded outline due to resorption (Fig. 3a). The clinopyroxene occurs as parted crystals displaying a pinkish-voilet, blue, and strong green interference colour. Calcite and apatite are present as necessary minerals. Opaques including hematite, magnetite and ilmenite occur as disseminated triangular, square; and rhombic grains.

The Second Outcropping Volcanic Rock Layer (Episode 2)

Under microscope the samples indicate that these volcanic rocks are composed essentially of plagioclase laths (50-60%), olivine (20-25%), pyroxene crystals (10-15%), opaques (3-5%) and accessories (about 2%). The plagioclase laths exhibit lamellar and Carlsbad twinning (Fig. 4a) and extinguish between 32 and 38°, indicating presence of labradorite as well as bytownite varieties. Electron microprobe analysis carried out on some laths (shown in table I) records the composition of plagioclase to be An 67-73. The Olivine is present as phenocrysts as well as fine crystals in the matrix, and partially to completely altered to iddingsite. Some grains show corroded outline due to resorption (Fig. 4b, 4c). The clinopyroxene occurs as parted crystals displaying a pinkish-voilet, blue, and strong green interference colour. Calcite and apatite are present as necessary minerals. Opaques including hematite, magnetite and ilmenite occur as disseminated triangular, square; and rhombic grains.

The Third Outcropping Volcanic Rock Layer (Episode 3)

The microscopic study of the rocks from the third volcanic layer indicates that they are composed essentially of plagioclase laths (59-60%), olivine phenocrysts (20-25%), pyroxene crystals (10-15%), opaques (about 4%) and accessories (about 2%). The plagioclase laths are quite fresh and well developed showing both albite and Carlsbad twinning. Extinction angle is between 29 and 35°, indicating labradorite composition (Fig. 5a, 5b). Olivine occurs as phenocrysts and fine crystals in the matrix. These are partially to completely replaced by iddingsite. The fresher olivine shows olive-green and pink interference colours. The interference colour of clinopyroxene are pinkish-voilet, yellow and purple (Fig. 5a, 5b). The accessories are calcite and epidote while opaques are hematite, magnetite and ilmenite.

The Fourth Outcropping Volcanic Rock Layer (Episode 4)

The fourth volcanic rock layer is composed essentially of microlites of plagioclase and clinopyroxene (40-50%), phenocrysts of olivine (25-30%), opaques about (10%) and accessories (5%). The plagioclase microlites extinct between 22 and 30°, indicating andesine-labradorite varieties of plagioclase. Olivine phenocrysts and granules are replaced by iddingsite which form narrow irregular external rind along partially altered olivine phenocrysts (Fig. 6a). Some phenocrysts have been resorbed to amoeba-form (Fig. 6b) and skeletal-form. The atomic percentage of Mg dominates over Fe as detected by electron microprobe for several olivine phenocrysts.

Occasionally olivines (at places irregularly fractured) are surrounded by reaction rims (Fig. 7a, 7b). Epidote and granules of olivine and pyroxene? May be the main constituents of reaction. The size of grains in the reaction rims increases towards the inner margin of the rims.

Cryptocrystalline calcite which fills the vesicles and fractures, is strongly birefringent. Other filling material includes feldspar and epidote. Feldspar crystals display grey birefringence. Zeolite (picotite?) is rarely present as crystals displaying deep yellow color with opaque margins in plane-polarized light (Fig. 8a). Under cross nics, however, zeolite (picotite?) crystals appear dark brown (Fig. 8b). Electron microprobe analysis carried out on zeolite (picotite?) grains detects an increase in Fe and Ti elements from the center to the rim (table II).

In reflected light, the metallic luster is steel-grey black for hematite, black for magnetite, and blue-black for ilmenite. Groundmass glass, occasionally, makes contrasting black and grey layers, and at places displays flow texture around olivine phenocrysts.

Euhedral to subhedral phenocrysts of olivine are embedded in glassy groundmass. Olivine is also present as hexagonal to polygonal phenocrysts. Texturally these are amygdaloidal, vesicular, and porphyritic fine-grained basalts.
Fig. 3b. Photomicrograph of the First Outcropping Volcanic Rock Layer (Episode 1) showing glomerocrylate of pseudomorphic hexagonal to polygonal olivine an pyroxene, both are completely replaced respectively by iddingsite and palagonite (?). Plagioclase laths are completely to partially replaced by sericite and iron oxide.

Fig. 3c: Photomicrograph of the First Outcropping Volcanic Rock Layer (Episode 1) showing partial to complete replacement of phenocrysts as well as groundmass olivine. Pyroxene crystals and plagioclase laths are present; weathering product is more pronounced (Sample 161, 165x, x-polars).

Fig. 3d. Another photomicrographic view showing the mineralogical features as observed in Fig. 3c except complete.
**Fig. 4a.** Photomicrograph showing cluster of well developed plagioclase (labradorite) laths in the second Outcropping Volcanic Rock Layer (Episode 2). Bright orange and pale small grains are of olivine (Sample 184, 165x, x-polars)

**Fig. 4b.** Photomicrograph of the Second Outcropping Volcanic Layer (Episode 2) showing reddish brown iddingsite replacing olivine phenocrysts at margins. Proxene (diopside on top centre) side shows partially preserved two cleavage directions. Plagioclase (labradorite-biotite) laths are quite clear here. Epidote grains showing characteristic green interference color are seen in the lower half of the picture (Sample 160, 175x, x-polars).

**Fig. 4c.** Photomicrograph of the Second Volcanic Rock Layer (Episode 2). Fractured olivine phenocrysts are mostly replaced by iddingsite. Plagioclase (labradorite) laths and hematite, magnetite and ilmenite (black grains) are also seen (Sample 142, 185x, x-polars).
**Fig. 5a, 5b.** Photomicrographic views showing the subophitic textures in the Third Outcropping Volcanic Rock Layer (Episode 3). It consists of olivine and pyroxene crystals with interpenetrated plagioclase laths. Iddingsite makes pseudomorphs by completely or partially replacing olivine phenocrysts. (Sample 16a, 32x, x-polar)

**Fig. 6a.** Photomicrograph of the Fourth Outcropping Volcanic Rock Layer (Episode 4) showing yellowish, and brown iddingsite after altering subhedral to anhedral olivine crystals. Groundmass is composed of black hematite, magnetite, ilmenite grains and glass (Sample 20, 100x, x-polars).

**Fig. 6b.** Photomicrograph of porphyritic basalt (The Fourth Outcropping Volcanic Rock Layer). Anophele from olivine occupies most of the area. Olivine is also present as fine-grained crystals. Groundmass consists of microlites of plagioclase and pyroxene. Opaques are hematite, magnetite, and ilmenite to (Sample 59, 175x, x-polars).
Fig. 7a. Photomicrograph of basalt (The Fourth Outcropping Volcanic Rock Layer). Large olivine phenocrysts, having irregular fractures, are surrounded by reaction rim which is composed of minute olivine, epidote granules and opaque grains (Sample 82, 200x, x-polars).

Fig. 7b. Photomicrograph of the Fourth Outcropping Volcanic Rock Layer (Episode 4) showing a large mixed-zoned phenocryst consisting of olivine, pyroxene? And opaques (mostly iron oxides). Smaller olivine phenocrysts are present in the fine-grained groundmass. (Sample 32, 200x, x-polars)

Fig. 8a. Photomicrographs of basalt (The Fourth Outcropping Volcanic Rock Layer) showing zeolite (picotite?) Crystal which is yellow with black margin in plane-polarized light (38a), and dark brown with black margin under cross-nicols (38b). (Sample 59, 185x, PP Light & x-polars)

Fig. 8b. Photomicrographs of basalt (The Fourth Outcropping Volcanic Rock Layer) showing zeolite (picotite?) Crystal which is yellow with black margin in plane-polarized light (38a), and dark brown with black margin under cross-nicols (38b). (Sample 59, 185x, PP Light & x-polars)
**Fig. 9a.** Photomicrograph of a scoriaceous Cinder-cone (Episide 5) pycroclastic material showing porphyritic texture. Corroded olivine phenocrysts are embedded in a reddish glass. Vesicles are without filling material. (Sample 23, 200x, PPLight).

**Fig. 9b.** Photomicrograph of Rock from Cinder-cone (Volcanic Episode 5). Excellent hexagonal, fractured olivine phenocrysts are generally corroded as well as embayed by resorption. Groundmass is totally composed of black glass and opaques (Sample 8A, 200x, x-polars).

**Fig. 9c.** Photomicrograph of Rock from Outcropping Cinder-cones (Volcanic Episode 5) showing circular amygdales (generally filled with calcite) as well as hexagonal and birefringence in a fine-grained groundmass (Sample 2, 200x, x-polars).
The Fifth Outcropping Cinder-Cones and Other Volcanic Rocks (Episode 5)

The microscopic study of the samples from cinder-cone material reveals that these rocks are extremely fine-grained with olivine phenocrysts (Fig. 9a, 9b). The phenocrysts are also replaced by secondary minerals. So their visual modal estimation is totally difficult.

The plagioclase and pyroxene occasionally occur as microlites, generally camouflaged by finely disseminated opaques and glass. Olivine occurs as completely to partially replaced phenocrysts, which are commonly resorbed and corroded. Numerous vesicles are completely or partially filled with cryptocrystalline calcite producing spherical, ovoid, and coalesced amygdales (Fig. 9c). Granular opaques as well as brownish red and black glass are present in groundmass.

Euhedral to subhedral, hexagonal to polygonal, olivine phenocrysts are embedded in glassy groundmass. Texturally these are amygdaoidal, scoriaceous, porphyritic, fine-grained basaltic rocks.

CONCLUSION

The petrographic study reveals that the basaltic rocks are essentially composed of plagioclase (labradorite mostly) laths, clinopyroxene (diopside) crystals, and olivine phenocrysts. The olivines mostly show resorption, and are abundant in the groundmass. Alkali-feldspar is also present in young volcanic rocks (Episode 4 & 5). Quartz is totally absent. Presence of olivine as phenocrysts as well as in the groundmass (more iron rich, similar to one described by Brown, (1968), Nagao and Sakaguchi (1990) and Shoji and Natsue (1995) is a common feature of alkali olivine basalts. Based on these salient petrographic features, these volcanic rocks are considered as alkali olivine basalts. The work of Izumi et al., (1975) Nagao and Sakaguchi, (1990) also showed that alkali olivine basalt containing upto 12% normative nepheline (Shozi and Natsu, 1995) is also in accordance with the normative nepheline value of episode 5 basalt of the research project area. According to Graham et al., (2003) secondary mineral assemblages are enriched in Ca, Na, K and (CO₃)²⁻. They are divided into three distinct varieties.

The Older Alkali Olivine Basalts (Episode 1,2,3)

These are exposed at Kaf and characterized by plagioclase (40-60%), olivine (20-30%), and pyroxene (15-20%). The opaques and accessory minerals are also in considerable amount. These rocks display amygdaoidal, vesicular, porphyritic, fine-grained texture. These layers are limited to the vicinity of Kaf area. Microscopically the volcanic rocks exposed at Tall al-Hibr display similar mineralogical and textural features as those of second volcanic rock layer present at kaf.

The Younger, Fragmental Basalts (Episode 4)

These are characterized by replaced plagioclase and pyroxene, and olivine phenocrysts. Texturally these are compact, partially amygdaoidal, porphyritic, fine-grained rocks with olivine phenocrysts in cryptocrystalline groundmass.

The Youngest, Cinder-cone and other Basaltic Rocks (Episode 5)

These are composed of pyroclastic, amygdaoidal, scoriaceous, porphyritic fine-grained rocks. Although absent at kaf, they are exposed over all Harrah Al-Hamad.

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REFERENCES


