

## BUCHITE FROM FESHARK AREA NORTHEAST ISFAHAN CENTRAL IRAN: A PRELIMINARY STUDY

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### Abstract

Buchitic glassy rocks appear within the skarn of contact metamorphic aureole of Feshark intrusive complex situated 30 km northeast of Isfahan. Intrusive complex is a multistage intrusion. Noritic gabbro is the first intrusion which is invaded later on by a granitic melt. Granitic melt has metasomatically altered the gabbro and as a consequence a suite of hybrid rocks like monzogabbro, monzodiorite, and diorite has been formed. A remnant of the original rocks in buchite is biotite bearing feldspathic quartzite or biotite gneissic rock, by fusion of which a granitic melt is formed. Subsequent supercooling of this melt resulted in glassy buchitic rock. Buchites of Feshark have a glassy, columnar jointed character at both contacts with the skarn host rock and a semiglassy character with contorted foliation in the middle part. Buchites are generally very rich in glass, in which minute, very rare, fine crystals of high disordered sanidine, high disordered oligoclase, mullite, orthopyroxene, Fe-Ti oxides, corundum and biotite have been recognized. This mineral assemblage strongly reflects the condition of sanidine or spurrite-merwinite facies [14] which implies the existence of spurrite-merwinite facies assemblages in skarn host rock. The lack of such an assemblage is interpreted as resulting from the metasomatic and retrogressive effect of granite intrusion which reverted very high grade assemblages of spurrite-merwinite facies to normal pyroxene hornfels assemblages in host skarn rock. It is probable that the buchitic melt originated in the deeper part of the contact metamorphic aureole and was injected into fractures of a higher level.

### Introduction

Buchites are partially or totally fused pelitic rocks occurring in very high temperature realms of metamorphism. Buchites are found in the following geological environments: (1) At the contact with basic and ultrabasic minor intrusions; (2) As inclusion xenoliths in volcanic rocks; (3) At contacts with burned coal seams interbedded with sandstones and shales; (4) As the external melted fringe of xenoliths in lava flows; (5) In contact

aureole of basaltic neck cutting sandstone and shale [17]; (6) In the major thrust zone by fusion of pelitic rock due to the combustion of hydrocarbon gases [20].

Buchites have the following general characters: (1) They are very rich in glass which implies the prevalence of very high temperatures during the melting of original rocks [3]; (2) The glass contains very tiny crystals of cordierite, sillimanite, mullite, tridymite, corundum, orthopyroxene, sanidine, Fe-Ti oxides and many other types of very high temperature minerals; (3) Relicts of original rock are frequently found in glassy buchites; (4) Columnar jointing is not uncommon in buchite [17]. The

**Keywords:** Buchite; Feshark; Iran; Pyrometamorphism; Skarn

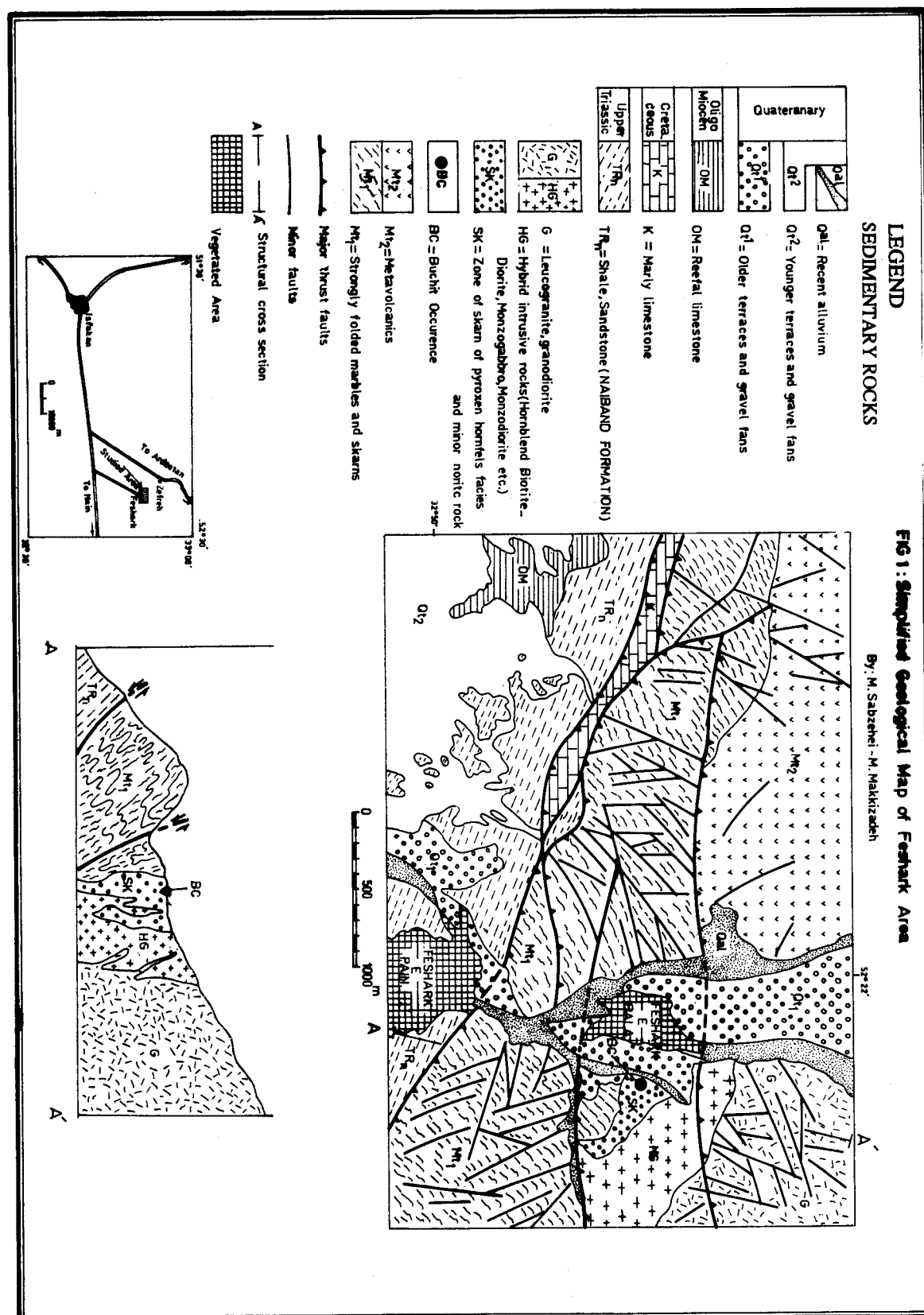


Figure 1. Simplified geological map of Feshark area

axis of prism in columnar jointing is approximately perpendicular to the general trend of isotherms in contact aureole [18]. Contorted planar structures are found in some buchites which implies some kind of flow in buchites [18]; (5) Buchites are produced from the fusion of sandstone, shale, arkosic sandstone, greywacks, granitoids and the metamorphic equivalent of these rocks like quartzite, micaschist and gneiss; (6) Buchites are mostly found in contacts of basic magmas. They are never reported from contacts of granitic bodies.

Prior to their discovery in the Feshark area, buchites had not previously been reported in Iran. Feshark glassy rocks were interpreted by Moinvaziri *et al.* [13] as obsidian dykes formed by the injection and rapid cooling of a granodioritic magma in the fracture zone. The same authors suspected a pseudotachylitic origin for these glassy rocks, but this origin was subsequently rejected by them.

In the summer of 1995, a first visit by the authors and a preliminary study revealed that the glassy rocks of Feshark contact aureole were in fact typical buchite. However, problems arose firstly because of the existence of buchite in the aureole of a granite body, which seemed rather strange, and secondly because of the contrast of temperature between buchites and enclosing pyroxene hornfels skarns.

The main aim of this article is to find solutions to these problems.

### General Geological Framework

The area studied is situated 70 km northeast of Isfahan (Fig. 1). Zahedi [22] published the first 1: 250000 map of this area. In his map, a granodioritic intrusion of possibly Late Tertiary is shown which intrudes the Mesozoic limestones. Ahmadi [1] undertook the study of contact metamorphism in Feshark. He reported two hyaline dykes which he interpreted as the injection of granodioritic magma into the water-saturated fracture zone that passes the contact metamorphic aureole.

Feshark area is part of the northeastern extremity of the Sanandaj-Sirjan structural subzone of a wider central Iran zone [19]. It is located to the southeast of the Qom-Zefreh main fault which trends NW-SE. The area has a clear imbricate structure with NW-SE trend of major thrust faults. The oldest lithological units are metamorphic rocks of unknown age. They are composed of plastically folded marbles and skarns (Mt1) which are overlain by metavolcanics (Mt2). These units (Mt1, Mt2) are most certainly dynamothermal regional metamorphic rocks. Many authors thought that these metamorphic rocks were the product of contact metamorphism of Mesozoic and Tertiary sedimentary rocks by Late Tertiary Feshark intrusion. The lack of thermal metamorphism in the Naiband Formation (Upper Triassic) and the existence of

metamorphic pebbles in the conglomerate of the base of the latter, along with the nonmetamorphic nature of the Cretaceous limestone slice(k), strongly invalidates this belief. In fact, contact metamorphism, which produced skarns of exocontact at Feshark, is a metamorphic event superposed on earlier regional metamorphism. Near the contact, all the previous deformational fabrics of Mt1 and Mt2 units are obliterated by thermal contact metamorphism and the foliated fabrics of Mt1 and Mt2 units are turned into an isotropic fabric. Relicts of foliated early fabric are still discernible within the isotropic skarns (SK).

The intrusive body of Feshark is a multistage intrusion to which two main stages can be attributed with confidence: (1) An early noritic gabbro intrusion in direct contact with skarns of contact aureole. (2) A later granodiorite to granitic intrusion which intrudes both the earlier gabbro and the skarns. Metasomatic exchange between the early solidified gabbro and granodioritic melt produced a suite of hybrid rocks like monzogabbro, monzodiorite, diorite, etc. (HG Unit). This granitic melt also intrudes the already formed skarn at contact with gabbro and by metasomatic exchange of granite melt and skarn a new generation of monomineralic skarns like wollastonite and garnetite etc. are formed in this aureole (Sabzehei and Shirani in preparation). Studies on skarns (SK) of Feshark area by Ahmadi [1] revealed a mineral assemblage of pyroxene hornfels facies.

The Mt1 and Mt2 units in Feshark area are probably Paleozoic or Upperproterozoic and the intrusive complex was probably emplaced in the pre Upper Triassic period possibly during the Early Kimmerian orogenic phase. More regional field and laboratory studies are required to elucidate the age of intrusive and metamorphic rocks of Feshark.

### Plate 1

- (1) Two anastomosing buchite glassy rocks cutting the isotropic skarn (SK) of Feshark area
- (2) Association of marginal columnar jointed brown glassy buchite (CGB) and central foliated buchite (FB)
- (3) and (4) Two views of columnar jointing in glassy marginal facies buchite



Plate 1





Plate 2

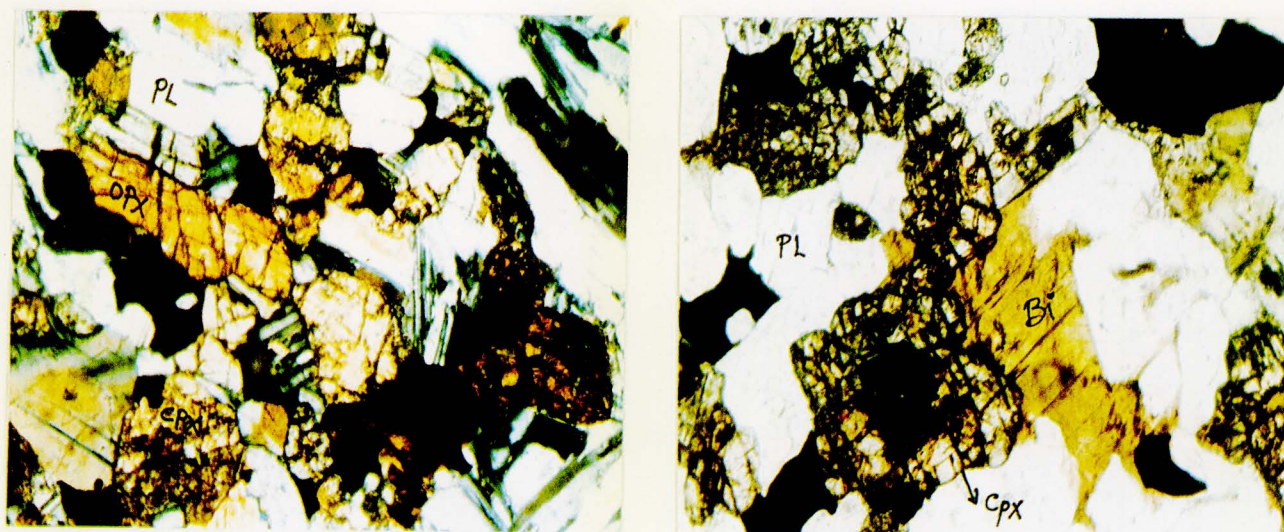


Plate 2

(1) (XPL) Microscopic view of norite

PL= Plagioclase OPX=Hypersthene CPX=Clinopyroxene.

(2) PPL view of transform to metasomatic action of granite on norite

### Buchitic Glassy Rock

#### 1- Field Relations and Fabrics

Two lenses of buchitic glassy rock are found within the isotropic skarn east of Feshark-e-Bala. They seem to be somehow connected and anastomosing which implies injection of melt into the skarn. The maximum length and width do not exceed 30 m and 2 m respectively. The buchites are symmetrically zoned. Each buchite lens has two brown glass-rich borders of maximum 30 cm in contact with skarn and a central dark-grey to light-grey section which is less rich in glass. The glass-rich border facies is columnar jointed. The direction of axis of prisms in the columnar jointed part is perpendicular to the strike of contact with enclosing skarns. The central part, which is richer in crystals, has a contorted foliation which implies plastic flow during injection. The central part shows faint layering very similar to the flow layering of gas-rich rhyolites or obsidians. Contact of buchite with enclosing skarn is very sharp. No offshoots or tongues of buchite penetrate into the skarns. In the central part of the buchite, thin layers of brown-coloured glass very similar to the glass in the border zone is observed (see Plate 1).

#### 2- Mineralogy, Petrography and Geochemistry

Buchite of the border zone is characterized by a high content of glass in which very fine crystals are dispersed.

These crystals are mostly identified by X-ray and optical methods. Some electron microprobe analyses have yielded information on the chemical composition of plagioclase. The following minerals are identified:

(1) Feldspars: Feldspars are the most abundant, conspicuous minerals of Feshark buchite. They show a general swallow tail form. They are very small, ranging in size from 0.05 mm in the border facies up to 0.2 mm in the central facies. They are much more abundant in the central facies.

Two procedures are followed for the identification of these minerals: (1) Microprobe analysis (2) X-ray diffractometry. Two chemical analyses of feldspars are obtained by microprobe analysis and the results are presented in Table 1.

If the sum of  $\text{SiO}_2$ ,  $\text{Na}_2\text{O}$ ,  $\text{K}_2\text{O}$ ,  $\text{CaO}$ ,  $\text{Al}_2\text{O}_3$  is considered and recalculated to 100%, the following composition is obtained:

|                         |       | Mole  |
|-------------------------|-------|-------|
| $\text{SiO}_2$          | 66.60 | 1.10  |
| $\text{Al}_2\text{O}_3$ | 21.66 | 0.212 |
| $\text{CaO}$            | 3.36  | 0.06  |
| $\text{Na}_2\text{O}$   | 7.63  | 0.123 |
| $\text{K}_2\text{O}$    | 0.75  | 0.007 |

If  $\text{K}_2\text{O}$ ,  $\text{Na}_2\text{O}$  and  $\text{CaO}$  are taken into the structure of a

**Table 1.** Chemical analysis of feldspar crystals in glass-rich buchite of Feshark area (M2 sample)

| Oxide \ No                     | (1)   | (2)   |
|--------------------------------|-------|-------|
| SiO <sub>2</sub>               | 66.43 | 66.04 |
| TiO <sub>2</sub>               | 0.02  | 0.00  |
| Al <sub>2</sub> O <sub>3</sub> | 21.61 | 22.00 |
| FeO                            | 0.17  | 0.18  |
| MnO                            | 0.01  | 0.03  |
| MgO                            | 0.01  | 0.00  |
| CaO                            | 3.35  | 3.34  |
| Na <sub>2</sub> O              | 7.61  | 7.45  |
| K <sub>2</sub> O               | 0.75  | 0.93  |
| Total                          | 99.96 | 99.97 |

feldspar, neither Al<sub>2</sub>O<sub>3</sub> nor SiO<sub>2</sub> are totally consumed. Excess Al<sub>2</sub>O<sub>3</sub> and SiO<sub>2</sub> can be obtained by the following calculation:

Al<sub>2</sub>O<sub>3</sub> = 0.212 - (0.06 + 0.123 + 0.007) = 0.022 excess in mole

SiO<sub>2</sub> = 1.10 - {(0.007\*6) + (0.123\*6) + (0.06\*2)} = 0.2 excess in mole

It is clear that this chemical analysis does not correspond to a real feldspar composition and there must be an interference of certain processes in the chemical analysis procedure. Two plausible possibilities exist:

(1) As feldspars are very tiny crystals floating in enclosing glass, the analysis may represent a combined chemical analysis of glass and crystal. As the SiO<sub>2</sub> content of glass is much higher than buchite (see below) the excess SiO<sub>2</sub> may well be accommodated with the composition of glass. This does not eliminate the problem of the excess Al<sub>2</sub>O<sub>3</sub>.  
(2) Evaporation of Na during the microprobe analysis is a classic difficulty. If Na is partially evaporated then Al<sub>2</sub>O<sub>3</sub> excess is probably due to the deficiency of Na<sub>2</sub>O in chemical analysis.

It can be assumed tentatively that the excess Al<sub>2</sub>O<sub>3</sub> corresponds to the equivalent mole of Na<sub>2</sub>O which has been lost by evaporation during microprobe analysis. The Na<sub>2</sub>O moles are then increased by 0.022 so Na<sub>2</sub>O, K<sub>2</sub>O and CaO are respectively corrected as follows:

CaO 3.36-----> 0.06 Mole  
Na<sub>2</sub>O (0.123 + 0.022)\* 62 = 8.99 = 0.145 Mole  
K<sub>2</sub>O 0.75-----> 0.007 Mole

If equivalent SiO<sub>2</sub> for these amounts of K<sub>2</sub>O, CaO and Na<sub>2</sub>O is calculated and all SiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, CaO, Na<sub>2</sub>O and K<sub>2</sub>O are recalculated to 100%, the following result is obtained:

SiO<sub>2</sub> = 64.05    Al<sub>2</sub>O<sub>3</sub> = 22.41    CaO = 3.47    Na<sub>2</sub>O = 9.30  
K<sub>2</sub>O = 0.77

and the composition of feldspar in terms of Ab, An and Or is Ab<sub>78.31</sub>, An<sub>17.16</sub>, Or<sub>4.53</sub>.

It should be noted that these calculations are quite assumptive and may not correspond to the real composition of plagioclase. It is concluded therefore that our feldspar may well be compared to an oligoclase and chemical analysis of Table 1 can be considered to glass-bearing oligoclase or simply glassy oligoclase [6]. Finally, it should be stated that in many diffractograms carried out at several laboratories, high-disordered calcian albite or high-disordered oligoclase has been reported. It should be emphasized that the existence of many tiny different crystals like quartz, mullite, corundum, biotite, etc., and the presence of the glass, create serious difficulties in the exact determination of feldspars. A few X-ray laboratories reported the existence of high-disordered sanidine while others did not, so the presence of high-disordered sanidine is rather speculative until high precision X-ray diffractometric studies are carried out.

(2) Biotite: Biotite is crystallized as minute crystals on which needles of very small crystals of a high relief, negative elongation mineral are grown perpendicular to (001) surface. These needle-like crystals are tentatively identified as corundum.

(3) Mullite: The presence of this mineral is reported from the study of some diffractograms. A high refractive index mineral in the form of very fine prismatic crystals is attributed tentatively to mullite.

(4) Corundum: In some of the glass-rich samples, minor amounts of a high relief anhedral crystal are seen which is attributed to the identified corundum in diffractograms.

(5) Inverted tridymite: In some of the buchite from the central facies, spherulitic patches of quartz are observed which may indicate the inversion of tridymite to quartz (see Plate 3, Fig. 2)

(6) Fe-Ti oxides are present in the form of globular aggregate in samples which are rich in biotite microlites.

Relict minerals and rock fragments from original rocks are observed in different samples (Plate 4). In one sample from the central facies, a fragment of unfused original rock is observed. This fragment is composed mainly of quartz. Minor biotite is also present. This rock fragment may be the relict of a biotite-bearing quartzite of metamorphic origin (Fig. 3). It has a granoblastic texture and the fused rim on the quartz grain is very clearly developed (Plate 4, Figs. 1&4). It can be deduced that this rock fragment is a xenolith engulfed and entrained by buchitic melt from the country rock. The existence of unfused biotite, quartz and plagioclase in the form of

sporadic crystal points strongly to the disintegration and melting of once coherent masses of biotite quartzite or biotite gneiss of which the rock fragment is a tectonite. The nonexistence of other types of rock fragments, other than biotite quartzite, also reinforces our first interpretation.

Quartz, biotite and plagioclase as relict minerals of original rock are observed in glass-rich buchite. Only one alkali feldspar, quartz and plagioclase-bearing rock fragment is observed which may indicate a gneissic origin.

Buchites of the central part show a patchy texture. The patches are made of spherulitic quartz which may indicate an inverted tridymite. These buchites are richer in microlitic crystals than glass-rich buchite is. The microlites show a subparallel orientation giving rise to a sort of fluidal texture.

Ten chemical analyses of Feshark buchite are available (Table 2). These analyses are from both the glass-rich and central part. They show a small variation in major elements. Common characteristics are as follows:

a- They are all characterized by a high silica content,

low iron oxide, low magnesium oxide and high alkalis.

b- An outstanding character is high L.O.I. content of

### Plate 3

(1) PPL microscopic view of glass-rich buchite. Af = alkali-feldspar (high sanidine) with swallow tail form. Bi = biotite with fine needles of a high refractive index, negative elongation mineral (possibly corundum) G = Glass X = 100

(2) The same as (1) Af = swallow tail alkali feldspar (high sanidine). Al = albite (calcian, disordered). (1) and (2) are from marginal glass-rich buchite. M = Mullite G = Glass. PPL X = 100

(3) Spherical patches of quartz in buchite, interpreted as inverted tridymite (IT). X = 100. PPL

(4) Microlite-rich buchite of central facies. Microlites are swallow tail alkali-feldspar (high sanidine) and high oligoclase. X = 100. (PPL)

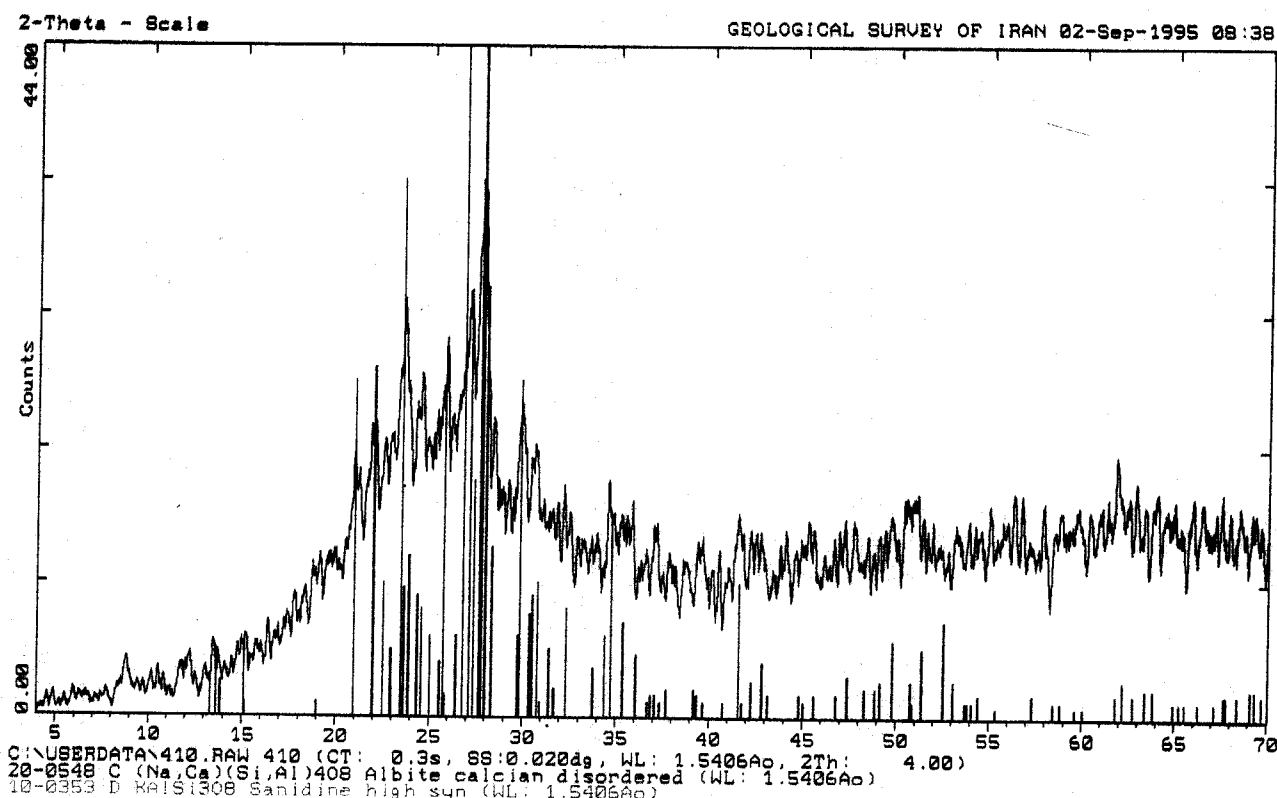


Figure 2. X-ray diffractogram of glass-rich buchite of Feshark area



Plate 3

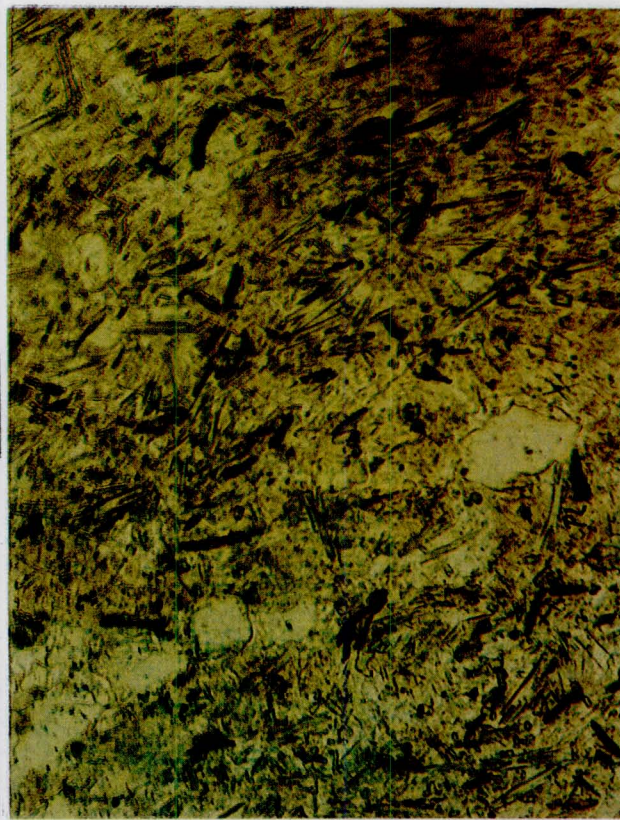
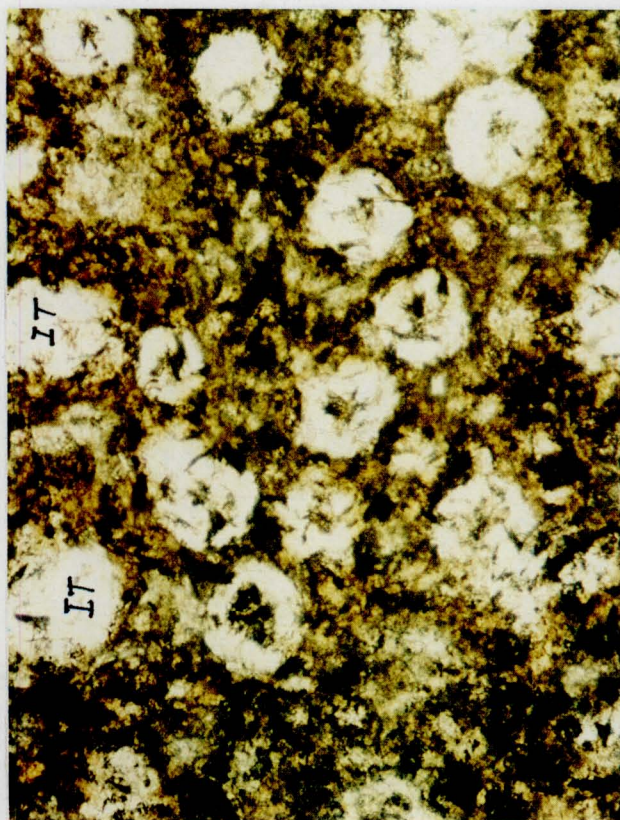
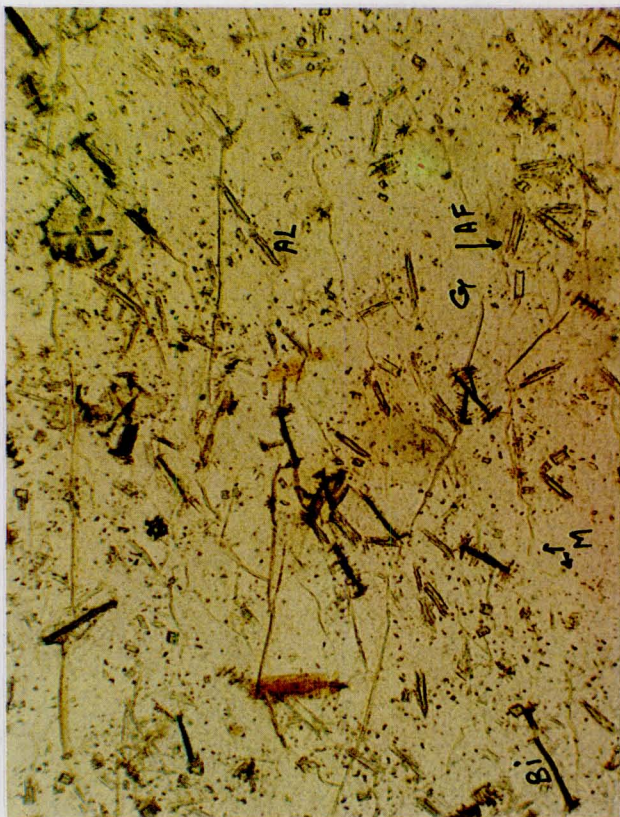
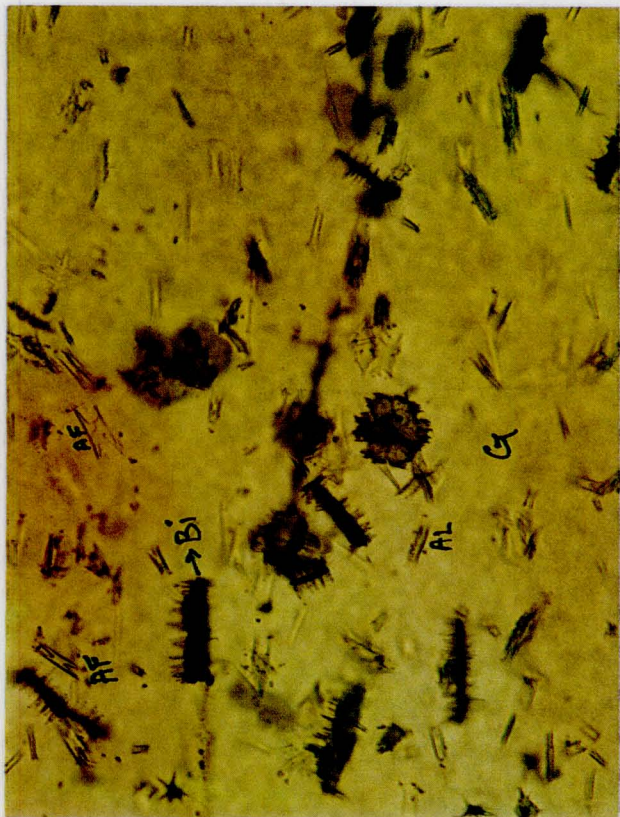
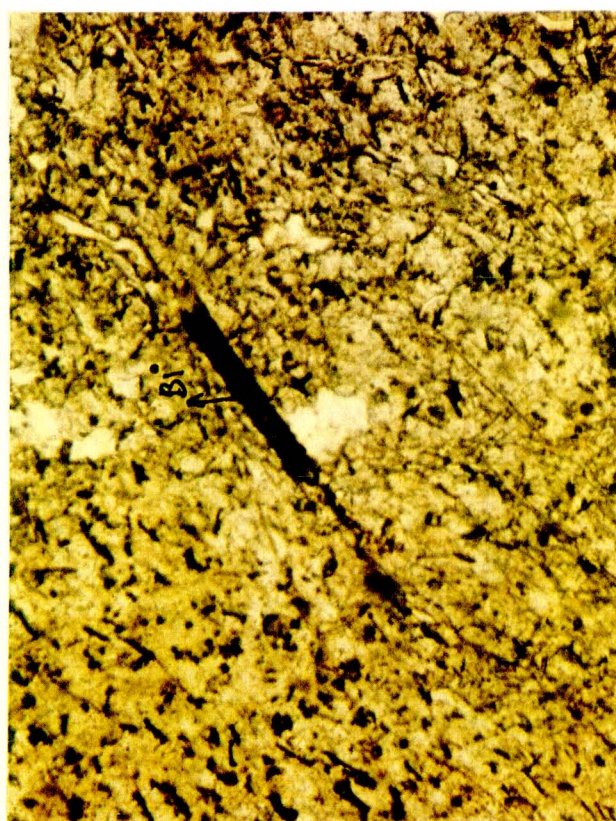
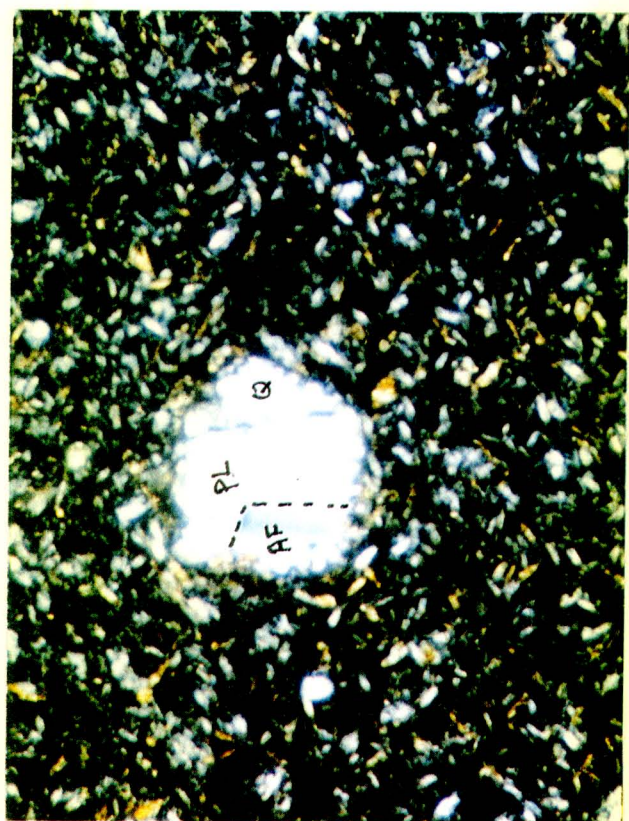
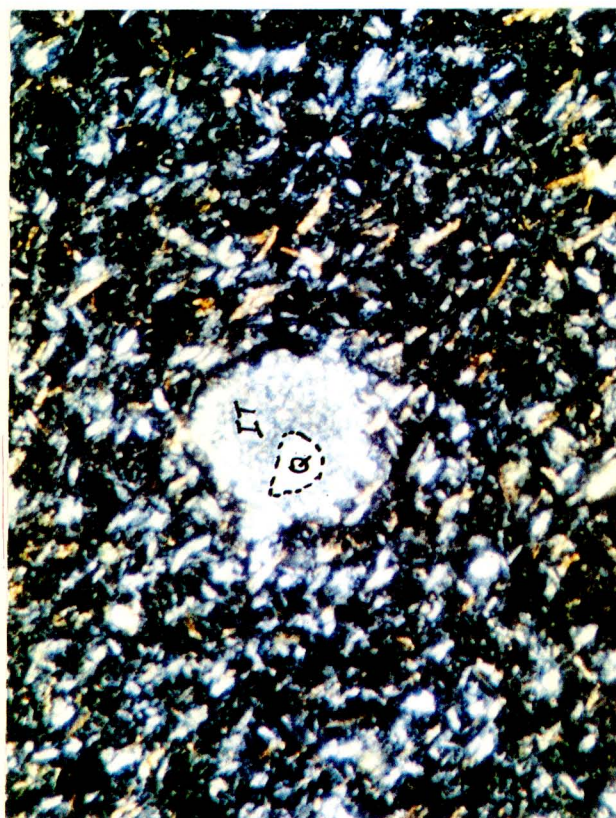
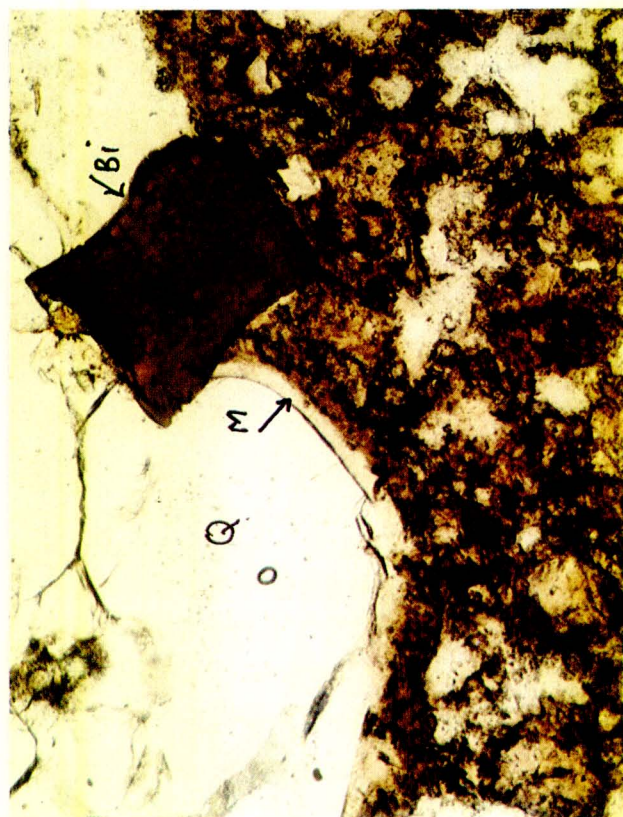




Plate4





all samples, which varies from 2.16 to 7.84 averaging approximately to 5%. Water is the main constituent of L.O.I. This indicates that the melting process has occurred in the presence of high amounts of water.

Table 3 shows the chemical analysis of glass in buchite of sample No. M2 (see Table 2). L.O.I. values are calculated on the basis of 100-oxides. The glass is analyzed by microprobe while the M2 sample is analyzed by wet method, therefore it should be noted that the problem of measuring Na, as in the case of feldspars, should be considered. Although calculated L.O. I. of glass is much higher, a part of this difference should be attributed to the volatilized Na during microprobe analysis. A minor part of the difference is due to the consideration of all iron in the form of divalent iron. In spite of all these problems, it seems that the major part of L.O.I. resides in the glassy part of buchite with only a minor portion in biotite.

c-The melt is depleted in CaO and K<sub>2</sub>O after the crystallization of plagioclase, alkali feldspar and biotite. Crystallization of biotite strongly depletes the residual melt (glass) in MgO. The Al<sub>2</sub>O<sub>3</sub> does not show important variation while SiO<sub>2</sub> is higher in glass. This is well in accordance with feldspar crystallization which results in the SiO<sub>2</sub> enrichment of residual melt.

d- Calculation of normative plagioclase composition of glassy buchite in sample No. M2 and relevant residual glass yielded the following results:

-Normative feldspar content of glass is 25±9% while M2 buchite is about 57% causing higher free SiO<sub>2</sub> in glass than buchite.

-An content of the glass (12.5±3.5%) is slightly lower than corresponding M2 buchite but this amount is higher where the glass is richer in SiO<sub>2</sub>.

#### Plate 4

(1) An unfused rock fragment of biotite (Bi) quartzite (Q). The fused quartz-enriched buchite in silica at its margin (M). X = 50. PPL.

(2) Remnant of quartz from original rock which is probably melted and probably metastably crystallized into tridymite which in its turn is inverted to a new generation of quartz (IT). X = 50. XPL

(3) Photo shows an unfused rock fragment composed of alkali-feldspar (af), plagioclase (pl) and quartz in buchite of central facies X = 50. PPL

(4) Biotite possibly remained unfused from original rock. This photo is from central facies buchite X = 50. PPL

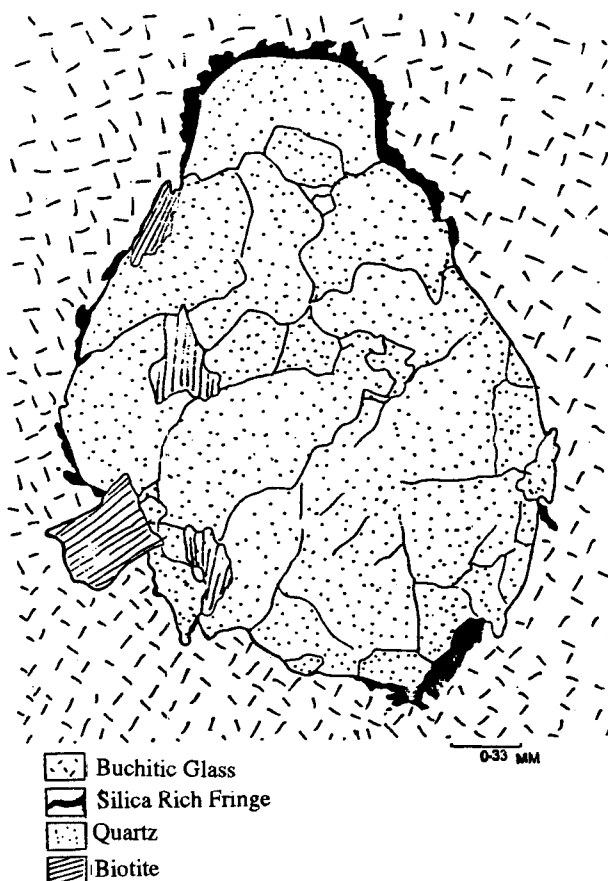


Figure 3. View of a biotite quartzite rock fragment which escaped fusion. Note the silica-rich fringe due to melting of quartz

-Ab content is much lower in glass than corresponding buchite which leads to a much higher value of 100 An/(Ab+An) ratio for glass.

Apparently, as for An, the Ab content is as much higher as the SiO<sub>2</sub> content is higher in glass.

-The relative content of Or is much higher in glass than in buchite.

e-The plots of buchite samples on the Maniar and Piccoli [11] diagram clearly indicate that buchite samples are all peraluminous granite (Fig. 4). In fact all CIPW norms contain normative corundum and a very high content of normative feldspars. Such a peraluminous, silica-rich melt can be easily produced by the fusion of biotite bearing metaarkosic sandstone or biotite gneiss. Note that biotites themselves can contain up to 20% Al<sub>2</sub>O<sub>3</sub> in metamorphic rocks [6,8].

#### Discussion

All field, mineralogical and petrographical data indicate



Table 2. Wet chemical analysis and CIPW norms of buchite of Feshark area

|                                | M1    | M2    | M4    | M6    | M7    | M10   | S1    | S2    | S3    | D2    |
|--------------------------------|-------|-------|-------|-------|-------|-------|-------|-------|-------|-------|
| SiO <sub>2</sub>               | 70.67 | 71.72 | 76.28 | 75.29 | 72.53 | 73.96 | 69.93 | 70.58 | 70.98 | 63.32 |
| TiO <sub>2</sub>               | 0.09  | 0.07  | 0.09  | 0.08  | 0.08  | 0.08  | 0.09  | 0.08  | 0.09  | 0.07  |
| Al <sub>2</sub> O <sub>3</sub> | 12.40 | 12.61 | 12.55 | 12.57 | 12.86 | 12.68 | 12.64 | 12.52 | 12.65 | 16.56 |
| Fe <sub>2</sub> O <sub>3</sub> | 0.70  | 0.67  | 0.52  | 0.65  | 0.62  | 1.22  | 0.70  | 0.84  | 0.55  | 0.51  |
| FeO                            | 0.53  | 0.18  | 0.52  | 0.20  | 0.44  | 0.06  | 0.28  | 0.13  | 0.35  | 0.44  |
| MnO                            | 0.07  | 0.07  | 0.03  | 0.04  | 0.06  | 0.03  | 0.07  | 0.06  | 0.63  | 0.00  |
| MgO                            | 0.70  | 0.80  | 0.50  | 0.70  | 0.50  | 1.40  | 0.81  | 1.29  | 1.00  | 1.60  |
| CaO                            | 1.40  | 1.38  | 1.39  | 1.51  | 0.95  | 0.65  | 0.70  | 0.55  | 0.70  | 2.23  |
| Na <sub>2</sub> O              | 2.65  | 2.88  | 2.30  | 2.43  | 2.83  | 2.15  | 2.71  | 2.87  | 2.80  | 3.44  |
| K <sub>2</sub> O               | 3.20  | 3.95  | 3.24  | 3.07  | 2.97  | 3.33  | 3.15  | 3.14  | 3.12  | 3.60  |
| P <sub>2</sub> O <sub>5</sub>  | 0.03  | 0.02  | 0.01  | 0.01  | 0.01  | 0.00  | 0.00  | 0.00  | 0.00  | 0.00  |
| L.O.I.                         | 6.70  | 4.77  | 2.16  | 2.92  | 5.27  | 3.65  | 7.84  | 6.92  | 6.73  | 7.26  |
| Q                              | 42.08 | 37.90 | 47.84 | 46.79 | 44.60 | 47.35 | 43.26 | 42.28 | 43.00 | 24.24 |
| Co                             | 2.29  | 1.20  | 2.83  | 2.62  | 3.50  | 4.58  | 3.84  | 3.68  | 3.68  | 3.22  |
| Or                             | 20.60 | 24.74 | 19.66 | 18.80 | 18.71 | 20.59 | 20.44 | 20.10 | 19.98 | 23.19 |
| Ab                             | 24.42 | 25.83 | 19.97 | 21.30 | 25.52 | 19.03 | 25.17 | 26.30 | 25.67 | 31.72 |
| An                             | 7.35  | 7.12  | 7.01  | 7.69  | 4.95  | 3.31  | 3.81  | 2.96  | 3.76  | 4.64  |
| Hy                             | 2.89  | 2.11  | 1.72  | 1.78  | 1.57  | 3.65  | 2.21  | 3.48  | 2.86  | 0.81  |
| Mt                             | 0.11  | 0.64  | 0.77  | 0.56  | 0.96  | 0.06  | 0.95  | 0.41  | 0.86  | 0.81  |
| Hm                             | -     | 0.27  | -     | 0.29  | -     | 1.23  | 0.11  | 0.62  | 0.00  | 0.00  |
| Il                             | 0.17  | 0.14  | 0.18  | 0.16  | 0.16  | 0.16  | 0.19  | 0.16  | 0.19  | 0.14  |
| Ap                             | 0.08  | 0.05  | 0.02  | 0.02  | 0.03  | 0.02  | 0.00  | 0.00  | 0.00  | 0.00  |

CIPW norm calculated on anhydrous basis

M1, M2, M4, M6, M7, M10, S1, S2, S3 are samples taken by the authors, D2 is from Ahmadi [1].

Normative plagioclase (sample M2)

Ab<sub>77.4</sub> An<sub>21.6</sub> (weight percentage)

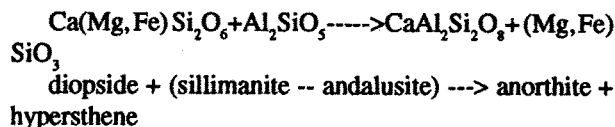
L.O.I. is calculated on basis of 100-oxides.

Table 3. Microprobe analysis and CIPW norm of the glass of (sample No. M2 of Table 2) buchite of Feshark area.

|                                | (1)              | (2)                | (3)                | (4)                | (5)                | (6)                | (7)                | (8)                |
|--------------------------------|------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|--------------------|
| SiO <sub>2</sub>               | 74.82            | 72.90              | 74.32              | 76.33              | 74.47              | 71.88              | 78.58              | 79.22              |
| TiO <sub>2</sub>               | 0.09             | 0.07               | 0.04               | 0.07               | 0.08               | 0.02               | 0.06               | 0.10               |
| Al <sub>2</sub> O <sub>3</sub> | 12.09            | 12.15              | 11.98              | 12.37              | 11.45              | 14.16              | 12.99              | 11.92              |
| FeO                            | 0.16             | 0.16               | 0.27               | 0.18               | 0.20               | 0.17               | 0.21               | 0.19               |
| MnO                            | 0.02             | 0.05               | 0.10               | 0.08               | 0.07               | 0.04               | 0.05               | 0.08               |
| MgO                            | 0.00             | 0.00               | 0.01               | 0.00               | 0.00               | 0.01               | 0.01               | 0.00               |
| CaO                            | 0.68             | 0.54               | 0.65               | 0.66               | 0.57               | 1.34               | 0.70               | 0.59               |
| Na <sub>2</sub> O              | 0.42             | 1.29               | 0.27               | 0.76               | 0.44               | 2.70               | 0.42               | 0.63               |
| K <sub>2</sub> O               | 3.38             | 3.87               | 3.54               | 1.58               | 3.73               | 2.67               | 2.09               | 2.50               |
| L.O.I.                         | 8.34             | 8.96               | 8.83               | 7.96               | 9.00               | 7.02               | 4.94               | 4.77               |
| Q                              | 63.17            | 54.16              | 63.07              | 69.85              | 61.80              | 46.14              | 69.86              | 67.80              |
| Co                             | 7.10             | 5.34               | 7.15               | 8.92               | 6.21               | 4.72               | 9.21               | 7.46               |
| Or                             | 21.80            | 25.13              | 22.95              | 10.15              | 24.22              | 16.97              | 12.99              | 15.52              |
| Ab                             | 3.88             | 11.99              | 2.51               | 6.99               | 4.09               | 24.57              | 3.74               | 5.60               |
| An                             | 3.68             | 2.94               | 3.54               | 3.56               | 3.11               | 7.15               | 3.65               | 3.07               |
| Hy                             | 0.20             | 0.30               | 0.70               | 0.39               | 0.40               | 0.41               | 0.42               | 0.35               |
| Il                             | 0.19             | 0.15               | 0.08               | 0.14               | 0.17               | 0.04               | 0.12               | 0.20               |
| Normative Plagioclase          | An <sub>41</sub> | An <sub>19.7</sub> | An <sub>38.5</sub> | An <sub>33.7</sub> | An <sub>43.2</sub> | An <sub>22.5</sub> | An <sub>49.4</sub> | An <sub>35.4</sub> |

CIPW norms are calculated on anhydrous basis L.O.I. is calculated on basis of 100-oxides.

that glassy rocks of Feshark area are typical buchites formed by the fusion of biotite-bearing metaarkosic rocks (quartzite and/or gneiss) in exocontact of gabbroic intrusions of noritic type. Mineral assemblages in buchitic glassy rock indicate that the highest realm of temperature of contact metamorphism, that is condition of spurrite-merwinite facies [14], is reached in this contact. It is unlikely that this temperature can be supplied by a granitic melt and our observations confirm that the first thermal event was in fact the invasion of a basaltic magma. It is quite logical to think of a basaltic magma intruding a suite of preexisting metamorphic rock and bringing some of the suitable rocks of its country rock, such as micaschists, quartzites or gneisses, to the fusion point. It can be suggested that noritic composition is achieved through the assimilation or complete digestion of high aluminous rock by the following famous reaction [21].



It is probable that the later granitic melt, which invades both gabbro and its contact metamorphic rocks aureole, is also formed by crustal anatexis of suitable metamorphic rocks due to thermal energy of the basic magma. Confirmation or rejection of such a hypothesis is beyond the scope of this article. Therefore, one can only speculate that the original melt of buchite glass represents a coeval melt with granitic melt of Feshark granitic intrusion.

The estimation of maximum temperature of buchite could be based on the following considerations:

- 1) Eutectic temperature of noritic gabbro.
- 2) Temperature of fusion of biotite gneiss or biotite-bearing metaarkosic rocks.
- 3) Temperature based on mineral assemblages in enclosing skarns.
- 4) Temperature based on geothermometry of coexisting feldspars in buchite.
- 5) Data on the stability of mullite.

Sood [16] revised the eutectics of basalt systems. The saturated part of the basalt system has all eutectics over 1000°C, so the minimum temperature given to country rock at the time of basaltic magma invasion is not less than 1000°C. Maaloe and Wyllie [10] studied the melting of granodiorite at a pressure of 2kb with varying amounts of H<sub>2</sub>O at different temperatures (Fig. 5). They examined the sequence of disappearance of minerals in an assemblage of plagioclase + alkali feldspar + quartz + biotite. Using their data, and assuming an average of 5% H<sub>2</sub>O for original starting material, we obtain a minimum melting temperature

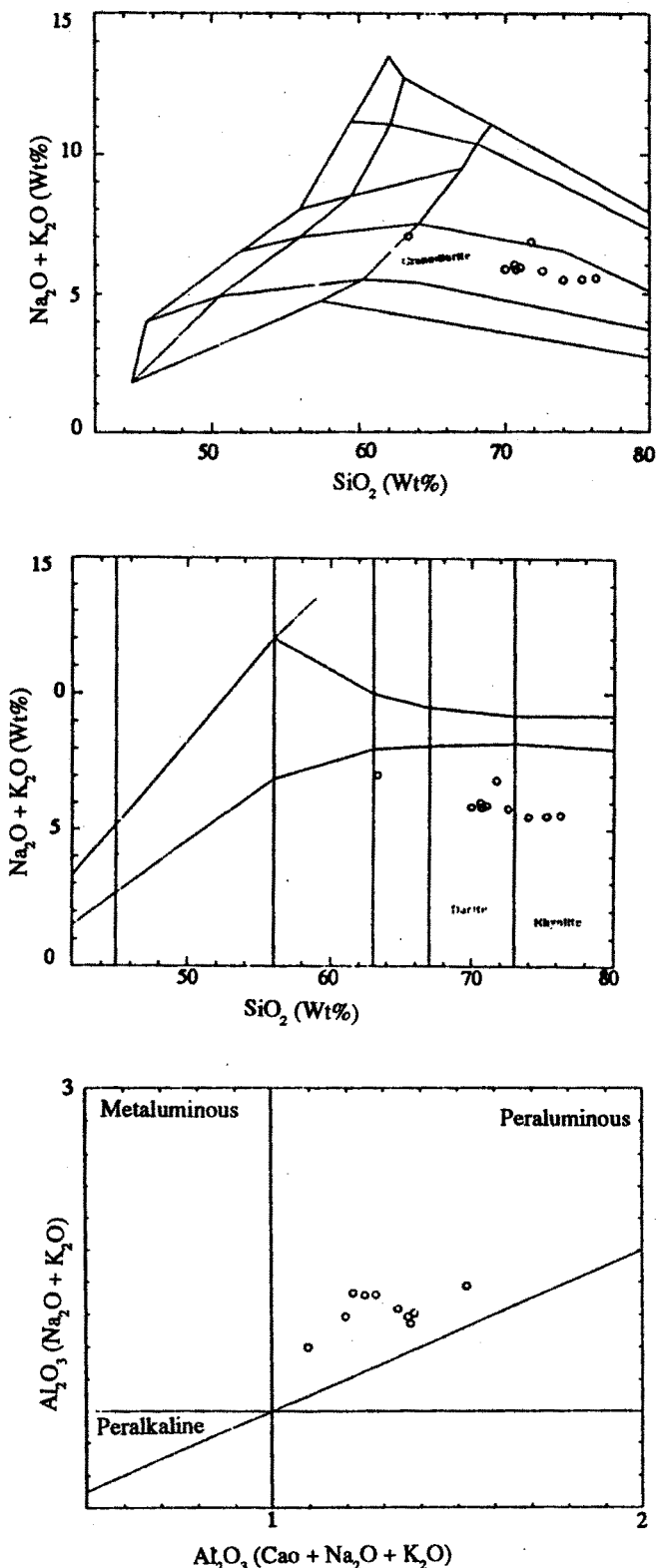


Figure 4. Projection of chemical analysis of buchite of Feshark area in : Diagram of Middlemost [12] (1, 2), Maniar & Picoli [11] (3)



H<sub>2</sub>O is about 5%, biotite disappears below 900°C and of 920°C, beyond which none of the minerals are stable. If plagioclase at 920°C.

The geothermometry of buchite can be based on coexisting alkali feldspar-plagioclase [9], but unfortunately, no chemical analysis of alkali feldspar is available.

Aramaki [2] has established that in xenoliths in lavas that have been metamorphosed at 1000°C and 200-300 bar pressure only sillimanite and andalusite are formed, so mullite must be stable only at temperatures above 1000°C. All experimental data on the stability of mullite confirms Aramaki's conclusions [4, 7].

All this evidence suggests that the skarn at Feshark area within this realm of temperature should bear assemblages of spurrite-merwinite facies. Why then is this assemblage lacking? This is one of the most important problems of Feshark skarns. The mineral assemblage of Feshark - according to Ahmadi [1] - displays typical pyroxene hornfels facies. Why then are minerals like spurrite; merwinite, scawtite, rankinite, tilleyite, etc., which are typical of spurrite-merwinite, lacking, despite the prevalence of suitable thermal conditions? We may answer this question by considering the following points:

1) Mineral assemblage of spurrite-merwinite may be overlooked due to a lack of systematic sampling. Careful study by detailed sampling may reveal the existence of the relicts of spurrite-merwinite facies assemblages.

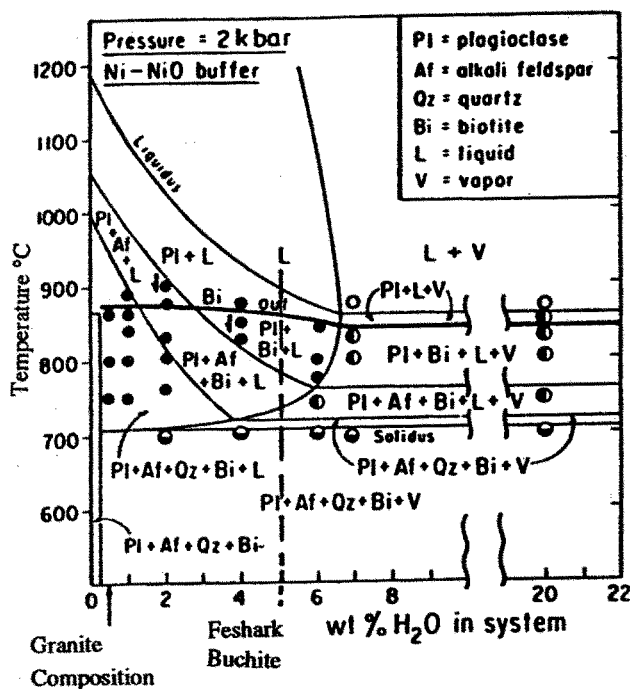


Figure 5. T-H<sub>2</sub>O projection of melting relation of granite [10]

2) Intrusion of granite magma, which has a strong metasomatic effect on both gabbro and early skarn paragenesis, may obliterate and convert all very high temperature assemblages of spurrite-merwinite facies to assemblages of a lower temperature, that is, pyroxene hornfels facies assemblages.

Reverdatto [14] has already explained this problem in the skarns of many areas. He cited many examples from Rhum Island, Carlingford area in which an earlier gabbroic mass was intruded by granitic intrusion and hybrid igneous rocks were formed by the interaction of granitic melt and early solidified gabbros. In these cases, early paragenesis of spurrite-merwinite facies is converted to pyroxene hornfels facies assemblage.

3) It should be noted that buchite glassy rocks may be derived from the injection of superheated melt which has been produced by anatexis of suitable rocks by gabbro intrusion. This melt is probably produced in deeper parts of contact aureole where it was in equilibrium with skarns of spurrite-merwinite facies which have never been exposed. The melt is injected into some fractures that brought it to a lower depth where assemblages of pyroxene hornfels facies are present in the skarns.

With our knowledge at its present level, it is impossible to find a definite solution for this problem, and more elaborate studies in this area are clearly required. Despite conclusive evidence in favour of the metasomatic effect of granite on gabbros and skarns of Feshark area, the authors prefer the hypothesis that buchitic melt was injected into shallower levels via fractures from the deeper part of the contact metamorphic aureole and cooled rapidly; the melt being produced by partial anatexis of metaarkosic rock by strong thermal gradient imposed by gabbroic intrusion.

### Conclusion

From the above-mentioned results we may draw the following conclusions:

1) Feshark glassy rock has many textural, mineralogical and geochemical features in common with the so-called "buchites" described in the highest realms of pyrometamorphism and produced from the fusion of pelitic and psammitic rocks.

2) To our knowledge, this is the first report of buchite occurring in the exocontact of deep-seated intrusions.

3) The mineral assemblage of Feshark buchites clearly indicates a condition of spurrite-merwinite or sanidinite facies. The thermal energy of this metamorphism is supplied by the basic magma which is materialized by the noritic gabbro.

4) All field and laboratory studies indicate that a later granitic magma was injected into the early contact metamorphic aureole and gabbro. The metasomatic effect of the granite melt with gabbro produced a suite of hybrid

rocks.

5) Skarns of Feshark area are the product of a suite of polymetamorphic events. The suite of events starts with regional dynamothermal metamorphism (foliated skarn) and continues to gabbroic intrusion in which isotropic skarns are developed at the expense of earlier foliated skarns. Monomineralic skarns (garnetite, wollastonite, vesuvianite) are the latest skarns developed by the metasomatic action of granitic magma on the previous two types of skarns.

6) The authors propose that buchites of Feshark area are probably produced by injection via fractures and rapid cooling at a shallow depth of a granitic melt which was produced by the anatexis of suitable rocks at contact of first gabbroic intrusion in a deeper part of the contact metamorphic aureole.

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