

Sempah volcanic complex, Western Belt of Peninsular Malaysia. Preliminary study of petrology and geochemistry

Azman A Ghani¹ and Navpreet Singh²

¹Department of Geology, Faculty of Science, University of Malaya, 50603, Kuala Lumpur, Malaysia

²Sarawak Shell Berhad, Locked Bag No 198009, Miri, Sarawak, Malaysia

ABSTRACT The Sempah volcanic complex occupies the central part of the Main Range Batholith to the east of Kuala Lumpur. The complex intruded the Selut Schist (Pre – Devonian), Gombak Chert (Late Devonian – Early Carboniferous, Sempah Conglomerate (Permian) which were collectively known as the Bentong Group. The complex consists of two main rock types namely rhyodacite and orthopyroxene rhyodacite. Geochemical evidence indicate that the rhyodacite and orthopyroxene rhyodacite are not related by simple fractional crystallization. The difference is indicated by a compositional gap at 69.1 to 70.7% SiO₂, different ACNK values, different ACNK trends, with increasing SiO₂ and contrasting behaviour for the major and trace elements, particularly K₂O and Ba. This is supported by major element modelling where both rhyodacite and orthopyroxene rhyodacite have different mineral extract proportions.

ABSTRAK Komplek volkanik Sempah terletak di bahagian tengah Batholit Banjaran Utama di sebelah timur Kuala Lumpur. Komplek ini menerobos batuan-batuan dari Kumpulan Bentong. Komplek ini terdiri dari dua jenis batuan yang utama iaitu rhyodacit dan orthopiroksin rhyodacit. Bukti geokimia menunjukkan kedua-dua batuan ini tidak berkait dengan penghabluran fraksinasi mudah. Kelainan ini juga disokong oleh nilai dan tren ACNK yang berlainan dan kelakuan unsure major dan surih yang berlainan terutamanya K₂O dan Ba. Ini disokong oleh permodelan unsure major dimana kedua rhyodacit dan orthopiroksin rhyodacit mempunyai nisbah ekstrak mineral yang berlainan.

(petrology, geochemistry)

INTRODUCTION

Associated volcanic or subvolcanic rocks that are contemporaneous with granitic bodies are not uncommon [1], [2]. The relationship between both volcanic and their granitic counterparts is crucial as the former can indicate the character of near liquidus phases. In addition, the textural and the composition of the phenocrysts can be used to establish the early crystallization history of magma and the composition of the liquid [3]. In the Western Belt granite of the Peninsular Malaysia the best known volcanic complex is the Genting Sempah volcanic complex, that is related, both temporally and spatially, to the granite. The complex comprises units of tuff lavas, lavas and a distinctive porphyry subvolcanic unit that contains orthopyroxene phenocrysts [4], [5]. These rocks were known as rhyolite and as porphyritic pyroxene microgranodiorite respectively by previous

workers [4], [6], [7]. The rocks have been well studied and documented by many workers since the beginning of the century [8], [9], [10], [11]. Many of the discussions of the workers centered on the relation of this complex to the Main Range granite. Hutchison [11] suggested that the Sempah complex rocks are not related to the Main Range granite because of their radically different mineralogical and textural nature. He suggested that the complex is more likely to be related to the roof pendant of greenschist facies metasediments (Selut schist ?) of lower Paleozoic age. Liew [7] stated in his thesis, 'The undeniably pyroclastic nature of the rhyolitic rocks (rhyodacite in this paper) seems to make it clear that they are unlikely to represent a marginal modification of the Main Range granite. Bignell [12] dated (Rb/Sr whole rock method) the rhyodacite as Carboniferous-Permian and the orthopyroxene rhyodacite as late Silurian – late Devonian. Liew [7] noted that if this age is

accepted, it would reflect a Devonian intrusive episode distinct from the dominant Permian to Triassic intrusions of the Main Range granites. In this paper we report an ongoing work on the petrochemistry of the complex. New outcrops from the development of the Karak Highway have enabled us to study in detail the nature of the contact between these two rocks. Detailed petrogenetic modelling will be presented elsewhere.

General Geology

The volcanic complex occupies the central part of the Main Range Batholith to the east of Kuala Lumpur, and is located principally between two major faults: the Bukit Tinggi fault zone on the north east flank which separates it from the Bukit Tinggi Pluton; and the Kongkoi fault zone to the southwest, which separates it from the Kuala Lumpur Pluton.

The complex intruded the Selut Schist (Pre – Devonian), Gombak Chert (Late Devonian – Early Carboniferous, Sempah Conglomerate (Permian) which were collectively known as the Bentong Group [9]. Alexander [9] believed that the schist, chert and the conglomerate rocks mentioned above are part of a roof pendant that has resulted from different episodes of granitic intrusions. The Selut schist occurs at the western portion of the roof pendant (Figure 1). It is overlain by the Gombak Chert along a major fault; which is represented by a zone of sheared rocks [13]. An angular unconformity separates the chert from the overlying Sempah Conglomerate. Along a stream on the Genting Highlands slip road, two small bodies of metaconglomerate (Sempah Conglomerate) overlie the rhyolitic rocks [14]. Throughout the complex, the rocks are fairly uniform. Some surfaces reveal small enclaves (longest axis = 8 cm) only faintly darker than the overall body colour of the rock. Liew [7] mentioned the occurrence of several types of enclaves such as spinel-cordierite-sericite-biotite-plagioclase-cordierite, surmicaceous, quartz epidote hornfelsic and hypersthene-quartz-plagioclase-biotite enclaves. Aplite dykes, calcite veins and minor quartz veins are common features present throughout the complex

Petrology

Megascopically, both the rhyodacite and orthopyroxene rhyodacite are medium grained bluish grey rocks. In weathered samples, the

rhyodacite is easily recognized from the orthopyroxene rhyodacite as the feldspar phenocrysts in the rock appear to be whitish. Apart from the presence of hypersthene and labradorite in the orthopyroxene rhyodacite, both rocks show many similarities in thin section. We will describe the petrography of both rocks in the same section.

Phenocrysts of twinned plagioclase, biotite, hypersthene and quartz, all averaging between 1 – 4 mm in diameter, are present in an aphanitic grey groundmass. Typical phenocryst assemblages consist of andesine, biotite, quartz and microperthite in a quartzfeldspathic groundmass. Accessory minerals include magnetite, apatite and zircon. The groundmass of the rhyodacite is slightly finer grained (tuffaceous) than the groundmass of the orthopyroxene rhyodacite; which averages from 0.01 to 0.02 mm. Most phenocryst phases are commonly fragmented with resorption features.

Quartz occurs as phenocrysts and as an essential constituent of the groundmass. Two kinds of quartz phenocrysts are identified: large (~ 4 mm) grains and smaller (0.3 – 0.5 mm) rounded grains. Quartz sometimes occurs in quartz – plagioclase aggregates. Many of the phenocrysts are deeply and intricately embayed; the embayments being filled with groundmass.

Plagioclase occurs as individual euhedral to subhedral laths, as glomeroporphyritic aggregates, and very commonly as angular fragments. Twinning and zoning are all present. Anorthite contents in cores and rims of zoned plagioclase range from An₃₈ – An₅₀ [4]. It is inferred that plagioclase was an early liquidus phase having a reaction relationship with evolving melts. This is based on the fact that plagioclase exist both as discrete phenocrysts, and also as glomeroporphyritic aggregates. Inclusions of plagioclase were also observed in hypersthene phenocrysts of the orthopyroxene rhyodacite.

Biotite occurs as euhedral to subhedral phenocrysts up to 3 mm in diameter. It is relatively rare as a groundmass constituent where it occurs as small shreds, which have probably been dislodged from phenocrysts. Although euhedral biotite may be fairly common, the bulk of the biotite is present as ragged elongate shreds. Some biotite phenocrysts, cleaving into sheets

separated by groundmass in the rhyodacite, indicate the initial stages in this type of mechanical breakdown. Most biotite flakes are warped to some degree and kink bands are common. Reaction rims of biotite are also observed around hypersthene. The pleochroism scheme is typically pale brown to foxy reddish brown. Inclusions of biotite in quartz suggest that biotite was an early crystallizing phase.

The presence of subhedral hypersthene in the orthopyroxene rhyodacite is characterized by high relief, low birefringence in sections of normal thickness and parallel extinction. Liew [7] presented the range as $En_{60}Fs_{40}$. Schillerized grains with aligned iron oxides, reaction rims consisting of biotite, and Fe – Ti oxides were also observed. Glomeroporphyritic clots of hypersthene in the orthopyroxene rhyodacite suggest accumulation of this phase during crystallization.

Microperthite phenocrysts are often ornamented by internal zones and blebs of groundmass materials, indicative that the grains continued to grow in optical continuity beyond its original outline [7]. Microperthite vary in size from 1 – 4 mm typically displaying embayment structures with various inclusions of accessory minerals and occasional biotite and apatite. Mymerkites are extensively developed where microperthites are in contact with plagioclase.

Geochemistry

In general the orthopyroxene rhyodacite is more basic compared to the rhyodacite with SiO_2 ranging from 65 - 69.11% and 70.73 - 74.5% respectively. They are separated by a gap of about 2% SiO_2 . The rhyodacite also contain significantly low CaO (1.52 to 2.07%), MgO (0.75 to 1.11%), Zr (131 – 215 ppm), Ba (230 – 565 ppm) and Sr (68 – 108 ppm) but higher Rb (332 – 390 ppm) compared to the orthopyroxene rhyodacite (CaO: 2.63 – 3.05% ; MgO: 1.72 – 2.09% ; Zr: 231- 259 ppm ; Ba: 770 - 965 ppm ; Sr: 128 – 148 ppm and Rb: 245 – 258 ppm) (Figure 2). The ACNK values for the orthopyroxene rhyodacite range from 0.63-1.03, whereas values for the rhyodacite range from 1.00-1.36. On the ACNK diagram (Figure 3),

most orthopyroxene rhyodacite samples straddle at the peraluminous-metaluminous boundary. For the rhyolite, there is an increase of ACNK values with increasing SiO_2 . All rhyodacite samples plot in the peraluminous zone and six samples plot in the I-type field of Chappell and White [15] compared to four fall into the S-type area. Although there are some samples that appear to be in the I-type domain for the orthopyroxene rhyodacite, most of the samples seem to overlap very close to $ACNK=1$.

On the K_2O vs. Na_2O diagram proposed by Chappell and White [16], the majority of both rock types fall into the S-type category (with the exception of a single rhyodacite sample and three orthopyroxene rhyodacite samples). It can be inferred that the rhyodacite and orthopyroxene rhyodacite display S-type affinities. The separate trends for both units also suggest that they are not co-magmatic. On a K_2O vs SiO_2 plot (Figure 4), all samples (except a sample from rhyodacite) plot in the high-K calc alkali field. Again in this diagram, the rocks from both units have different trends, thus the rhyodacite decreases whereas the orthopyroxene rhyodacite increases with increasing SiO_2 . Samples from the rhyodacite seem to have been evolved from shoshonite to high-K calc alkali fields. Roberts and Clemens [17] showed that a parent magma with a given K_2O and SiO_2 content will evolve within the particular field in the diagram. For magma to evolve into an adjacent field some process other than crystal-liquid separation must operate. This clearly is an indication that the rhyodacite and orthopyroxene rhyodacite are not related by simple fractional crystallization. This is evident from $1/Sr$ vs $^{87}Sr/^{86}Sr$ plot (Figure 5) [7], [12]. In this diagram, fractionation generates an igneous suite that will be plotted as or on a horizontal line [18]. The trends produced by both rhyodacite and orthopyroxene rhyodacite are not horizontal and thus preclude fractionation as the main evolution process between the two units. The plot suggests that the rhyodacite and orthopyroxene rhyodacite may related by other processes such as assimilation. However, within the magma, crystal fractionation may play an important role, particularly in the rhyodacite.

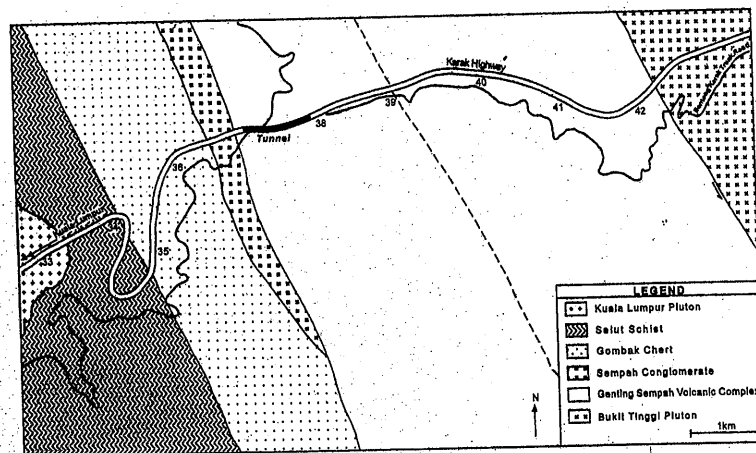


Figure 1. Regional geology map of the Genting Sempah area, showing the relationship between the volcanic complex, and the adjacent Paleozoic metamorphic rocks with the Late Triassic granitoids. Dashed lines represent inferred fault zones, while heavy lines are lithological contacts. Lithological contacts for the Selut Schist, Sempah Conglomerate and the Bukit Tinggi Pluton are also fault zones.

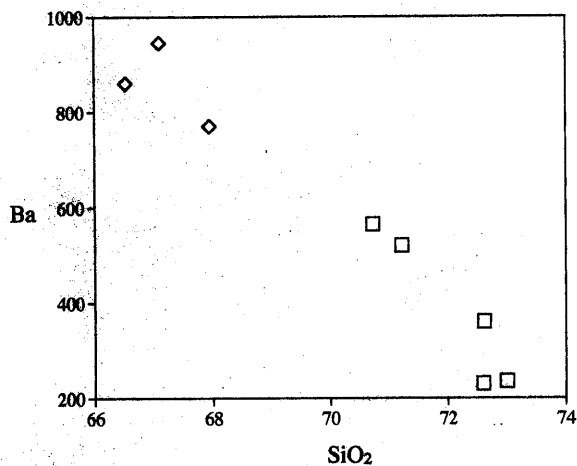
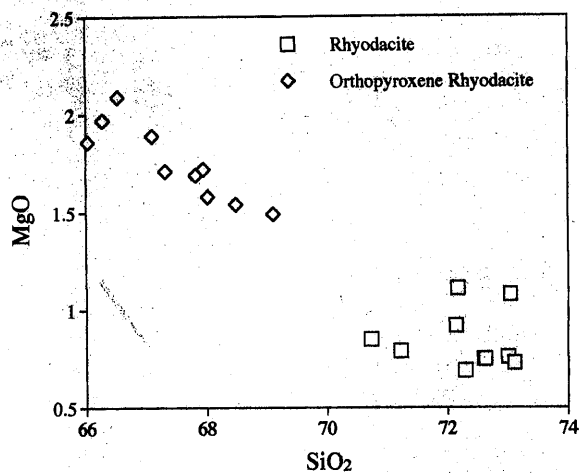


Figure 2. Selected Harker variation diagrams for the Genting Sempah Volcanic Complex. Both MgO and Ba decrease with increasing SiO₂. Note the hiatus between the rhyodacite and orthopyroxene rhyodacite between approximately 69 – 70 wt % SiO₂.

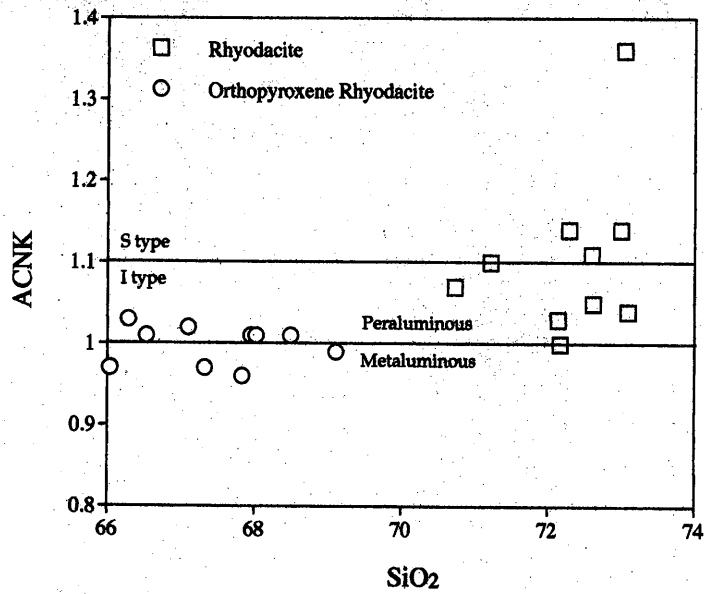


Figure 3. Molar $\text{Al}_2\text{O}_3 / \text{CaO} + \text{Na}_2\text{O} + \text{K}_2\text{O}$ vs SiO_2 (ACNK) diagram for the Genting Sempah Volcanic Complex. A significant observation is the two completely different trends present for both the rhyodacite and orthopyroxene rhyodacite. The values for the orthopyroxene rhyodacite seem to straddle close to the peraluminous – metaluminous boundary; whereas there is a notable increase in ACNK values with increasing SiO_2 for the rhyodacite.

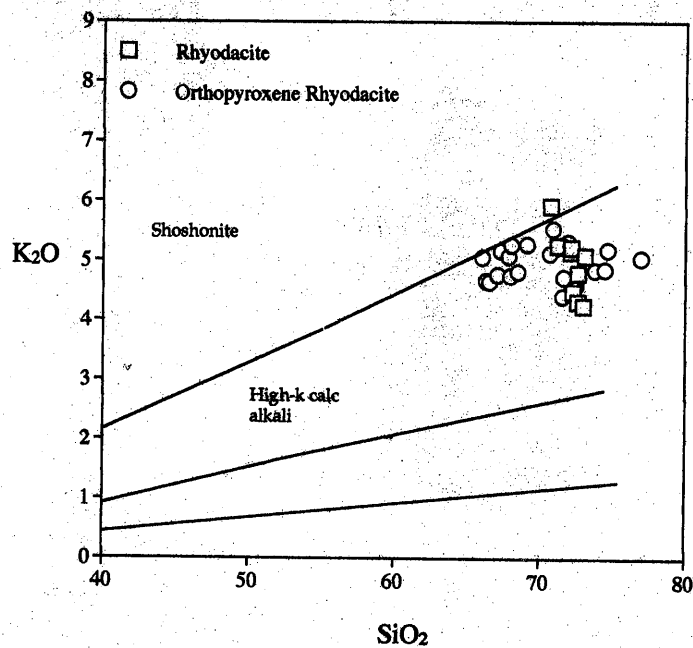


Figure 4. Subdivision of the Genting Sempah Volcanic Complex using the K_2O vs silica diagram. There is an increase of K_2O with increasing SiO_2 values within the high – K calc alkali field for the orthopyroxene rhyodacite, as opposed to decreasing K_2O values with increasing SiO_2 observed for the rhyodacite. This is another case where there are two different trends present. The evolution of the rhyodacite from the shoshonite field to the high – K calc alkali field is an indication that some process other than crystal – liquid separation is the cause for the chemical variation observed.

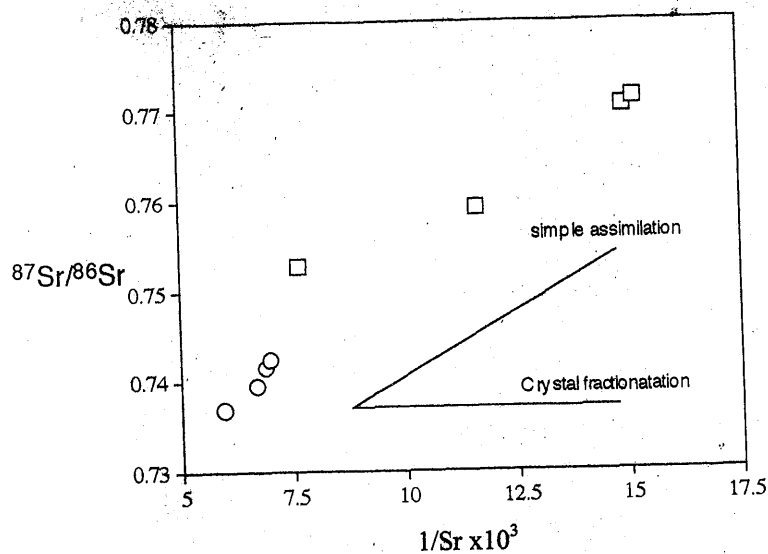


Figure 5. $^{87}\text{Sr}/^{86}\text{Sr}$ vs. $1/\text{Sr} \times 10^3$ plot for the Genting Sempah Volcanic Complex. Generally a horizontal trend is an indication of crystal fractionation, whereas a sub - horizontal trend represents simple assimilation. The trends produced by both the rhyodacite and orthopyroxene rhyodacite are not horizontal and thus preclude fractionation as the main evolution process between the two units.

DISCUSSION

According to Cox *et al.* [19], porphyritic texture in volcanic rocks is widely ascribed to the effects of a period of slow cooling during which the phenocrysts grew, followed by a period of rapid cooling during which the groundmass crystallized. Crystals growing at this earlier stage are referred to as intratelluric. Glomeroporphyritic aggregates and the occurrence of individual discrete phenocrysts in both the rhyodacite and orthopyroxene rhyodacite strongly suggest that the bulk of the phenocrysts is a result of slow cooling prior to rapid undercooling. This would imply a magmatic origin for the bulk of the phenocrysts

Aggregates of hypersthene and labradorite in the orthopyroxene rhyodacite resemble clots of mafic 'noritic' micro-inclusions. There is a possibility that the orthopyroxene rhyodacite is a hybrid - as proposed by Liew [7] - developed by mixing of, and limited reaction between solid norite and a low melting silicic liquid. The arrested nature of hybridization process possibly resulted from comparatively rapid and forceful intrusion to high levels, freezing following closely upon final emplacement (Flood *et al.*, 1977). The 'noritic' fraction reveals evidence of mineralogical dis-

equilibrium with glomeroporphyritic mafic aggregation, and the rimming of members of the discontinuous reaction series by lower members of the series, e.g. hypersthene rimmed by biotite. These reactions probably occurred prior to the injection of the low melting silicic fraction. The orthopyroxene rhyodacite itself may be a hybrid, developed by reaction between basic material and an acid liquid; based on the fact that cataclastic biotite fractions can be correlated with the widespread and intimate injection of the noritic parent by the quartzo - feldspathic liquid, perhaps in response to orogenic movements. These small aggregates of pyroxene and plagioclase are inferred to be either compositionally modified crystalline residuals (restite) from partial melting, or crystal cumulates, similar to that described by Flood *et al.*, [20].

Chemical data shows that both rhyodacite and orthopyroxene rhyodacite are not related by simple fractionation. Another process that may be important is simple assimilation. However, crystal fractionation may be important within the rhyodacite magma as vector diagrams indicate that biotite, plagioclase and K-feldspar are important fractionation minerals. Both rhyodacite and orthopyroxene rhyodacite also show some different chemical characteristics such as a

compositional gap at 69.1 to 70.7% SiO₂, different ACNK values, different ACNK trends with increasing SiO₂ and contrasting behaviour for the major and trace elements, particularly K₂O and Ba. This is supported by major element modelling where both rhyodacite and orthopyroxene rhyodacite have different mineral

extract proportions (Table 1). The strong enrichment of Ba and Sr in orthopyroxene rhyodacite is probably related to transfer of enriched (hydrous ?) fluids from the mantle into the lower crust and possibly initiated melting to form the rocks [21], [22].

Table 1. Major element modelling of the rhyodacite and orthopyroxene rhyodacite. Note that the mineral proportions for both rocks are different.

(A) Major element modeling for the Orthopyroxene Rhyodacite

	Start composition sample: MAL 78	Liquid composition at 25% fractionation	Target composition Sample: LIEW 9
SiO ₂	66.53	69.38	69.11
TiO ₂	0.77	0.75	0.71
Al ₂ O ₃	14.31	13.08	14.29
Fe ^{tot}	4.28	3.20	3.72
MgO	2.09	1.92	1.49
CaO	2.80	3.13	2.95
Na ₂ O	2.42	1.95	2.06
K ₂ O	4.65	4.08	5.28
Mineral extract proportion:			
Biotite:	25%		
K-Feldspar:	25%		
Plagioclase:	40%		
Quartz:	5%		
Orthopyroxene:	5%		

(B) Major element modeling for the Rhyodacite

	Start composition sample: MAL 76	Liquid composition at 35% fractionation	Target composition Sample: MAL 73
SiO ₂	70.73	73.06	73.00
TiO ₂	0.45	0.40	0.35
Al ₂ O ₃	13.65	12.79	13.60
Fe ^{tot}	2.87	2.27	2.12
MgO	0.85	0.59	0.76
CaO	1.52	2.00	1.61
Na ₂ O	2.18	2.39	2.67
K ₂ O	5.92	4.09	4.25
Mineral extract proportion:			
Biotite:	17%		
K-Feldspar:	50%		
Plagioclase:	14%		
Quartz:	19%		

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