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# Sempah Volcanic Complex, Pahang

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**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), and Sempah Conglomerate (Permian), which were collectively known as the Bentong Group (Alexander 1968). The complex consists of two main rock types namely orthopyroxene-lacking rhyodacite (OLR) and orthopyroxene - bearing rhyodacite (OBR). Geochemical evidence indicates that the OLR and OBR are not related by simple fractional crystallization. The difference is indicated by a compositional gap at 69.1 to 70.7% $SiO_2$, different ACNK values, different ACNK trends with increasing $SiO_2$ and contrasting behaviour for the major and trace elements, particularly $K_2O$ and Ba. This is supported by major element modelling where both OBR and OLR have different mineral extract proportions.

## Kompleks Volkanik Sempah, Pahang

**Abstrak**

Kompleks Volkanik Sempah terletak di kawasan tengah hingga ke batolit Banjaran Besar ke Barat Kuala Lumpur. Kompleks ini merejah Syis Selut (Pre - Devon), Chert Gombak (Devon Akhir - Kapur Awal), Konglomerat Sempah (Perm) yang dikenali sebagai Kumpulan Bentong (Alexander 1968). Kompleks ini terdiri daripada dua batuan utama yang dinamakan ortopiroksen kurang riodasit (OLR) dan ortopiroksen beriodasit (OBR). Bukti geokimia menunjukkan OLR dan OBR tidak hanya berkaitrapat melalui pecahan ringkas pengkristalan. Perbezaan ini ditunjukkan melalui jurang komposisi diantara 69.1 hingga 70.7% $SiO_2$, perbezaan nilai ACNK, corak perbezaan nilai ACNK yang bertambah dengan $SiO_2$ dan menunjukkan sifat yang berbeza berbanding unsur utama dan surih terutamanya $K_2O$ dan Ba. Keadaan ini disokong oleh model unsur utama di mana OBR dan OLR menghasilkan jumlah mineral yang berbeza.

## INTRODUCTION

Associated volcanic or subvolcanic rocks that are contemporaneous with granitic bodies are not uncommon (e.g. Atherton *et al.*, 1979; Norman *et al.*, 1992). 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 texture and composition of the phenocrysts can be used to establish the early crystallization history of magma and the composition of the liquid (Atherton *et al.*,1992). 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 (Liew 1983; Chakraborty 1995). These rocks were known as rhyolite and as porphyritic pyroxene microgranodiorite respectively by previous workers (Haile, 1970; Liew, 1977; Liew, 1983). The rocks have been well studied and documented by many workers since the beginning of the century (Scrivenor 1931; Alexander 1968; Shu, 1968; Hutchison 1973; Haile 1970; Liew 1977 ; Chakraborty 1995). Many of the discussions of the workers centered on the relation of this complex to the Main Range granite. Hutchison (1973) 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 (1977) stated in his thesis, 'The undeniably pyroclastic nature of the rhyolitic rocks (OLR in this paper) seems to make it clear that they are unlikely to represent a marginal modification of the Main Range granite'. Bignell (1972) dated (Rb/Sr whole rock method) the rhyolite (OLR) as Carboniferous-Permian and the granodiorite (OBR) as late Silurian – late Devonian. Liew (1977) 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. We will retain the nomenclature used by Chakraborthy (1995) on the two main rock types in the complex that is orthopyroxene lacking rhyodacite (OLR) and orthopyroxene bearing rhyodacite (OBR). 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 (Alexander 1968). Alexander (1968) 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 (Fig 1). It is overlain by the Gombak Chert along a major fault; which is represented by a zone of sheared rocks (Lee, 1976). 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 (Chow *et al.*, 1995). 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 (1977) mentioned the occurrence of several types of enclaves such as spinel-corundum-sericite-biotite-plagioclase-cordierite, surmicaceous, quartz epidote hornfelsic and hyperstene-quartz-plagioclase-biotite enclaves. Aplite dykes, calcite veins and minor quartz veins are common features present throughout the complex.

## PETROLOGY

Megascopically, both the OLR and OBR are medium grained bluish grey rocks. In weathered samples, the OLR is easily recognized from the OBR as the feldspar phenocrysts in the rock appear to be whitish. Apart from the presence of hypersthene and labradorite in the OBR, both rocks show many similarities in thin section. We will describe the petrography of both rocks in the same section. A summary of the mineral phases present in both rocks is presented in Table 1.

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 quartzo-feldsphatic groundmass. Accessory minerals include magnetite, apatite and zircon. The groundmass of the OLR is slightly finer grained (tuffaceous) than the groundmass of the OBR; which averages from 0.01 to 0.02 mm. Most phenocryst phases are commonly fragmented with resorbtion 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 $An_{38}$ – $An_{50}$ (Liew, 1983). 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 exists both as discrete phenocrysts, and also as glomeroporphyritic aggregates. Inclusions of plagioclase were also observed in hypersthene phenocrysts of the OBR.

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 OLR, 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 OBR is characterized by high relief, low birefringence in sections of normal thickness and parallel extinction. Liew (1977) presented the range as $En_{60}Fs_{40}$. Schillerized grains with alligned iron oxides, reaction rims consisting of biotite, and Fe – Ti oxides were also observed. Glomeroporphyritic clots of hypersthene in the OBR 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 (Liew, 1977). Microperthite varies in size from 1 – 4 mm typically displaying embayment structures with various inclusions of accessory minerals and occasional biotite and apatite. Mymerkite is extensively developed where microperthite is in contact with plagioclase.

## GEOCHEMISTRY

In general the OBR is more basic compared to the OLR 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 OLR also contains 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 OBR (CaO:

Table 1: Summary of the mineral phases present in the OLR and OBR.

| Rock Type | Phenocrysts | Groundmass |
|---|---|---|
| Orthopyroxene Lacking Rhyodacite (OLR) | (euhedral - subhedral < 7mm) Quartz (embayed) Microperthite Plagioclase (andesine) Biotite plates (kinked) | (a) microcrystalline quartz and feldspar (b) minor biotite (c) accessory zircon, apatite and opaque minerals |
| Orthopyroxene Bearing Rhyodacite (OBR) | (euhedral – subhedral < 7 mm) Quartz (embayed) Microperthite Plagioclase (labradorite cores) Biotite plates Hypersthene | (a) fine grained (slightly coarser grained than the OLR) (b) aggregates of quartz, subhedral plagioclase (c) lesser alkali feldspar (d) accessory zircon, magnetite and apatite |

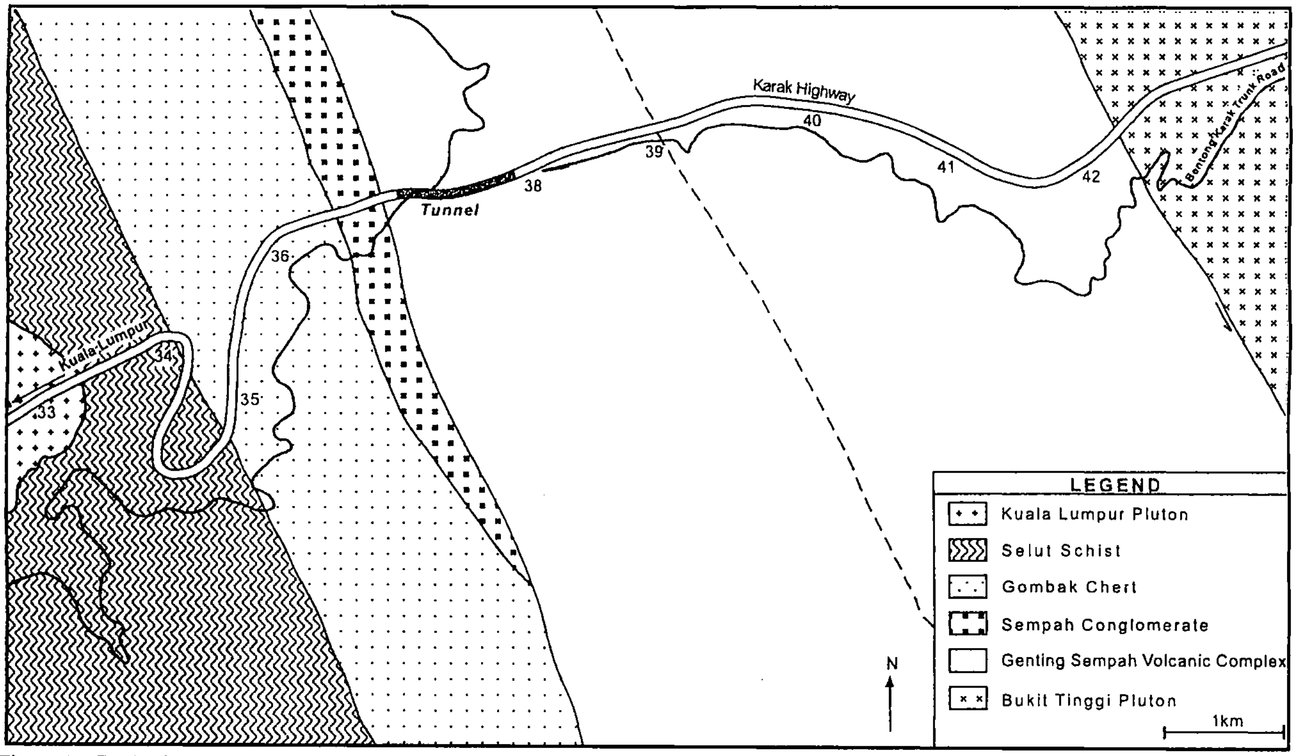


Figure 1 : Geological map of the Genting Sempah area, showing the relationship between the volcanic complex, and the adjacent Paleozoic metamorphic rocks with the Late Triassic granitoids. Dashed lines represent inferred fault zones, while heavy lines are lithological contacts. The contacts of Selut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

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) (Fig 2). All OLR samples are peraluminous (Fig 3) with ACNK values ranging from 1 to 1.36. On the other hand the OBR has lower ACNK values. The rocks straddle at ACNK = 1 with the lowest value of 0.96 and the highest is 1.03. Another significant difference between these two units is that they behave differently with $SiO_2$. Thus the OLR samples show an increase in ACNK values whereas the OBR decreases with increasing $SiO_2$.

On a $K_2O$ vs $SiO_2$ plot (Fig 4), all samples (except a sample from OLR) plot in the high-K calc-alkali field. Again in this diagram, the rocks from both units have different trends, thus the OLR decreases whereas the OBR increases with increasing $SiO_2$. Samples from the OLR seem to have been evolved from shoshonite to high-K calc-alkali fields. Roberts and Clemens (1993) 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 OLR and OBR are not related by simple fractional crystallization. This is evident from 1/Sr vs 87Sr/86Sr plot (Fig 5) (Isotope data from Bignell 1972 and Liew 1983). In this diagram, fractionation generates an igneous suite that will be plotted as or on a horizontal line (Myers *et al.*, 1984). The trends produced by both OBR and OLR are not horizontal and thus preclude fractionation as the main evolution process between the two units. The plot suggests that the OLR and OBR may be related by other

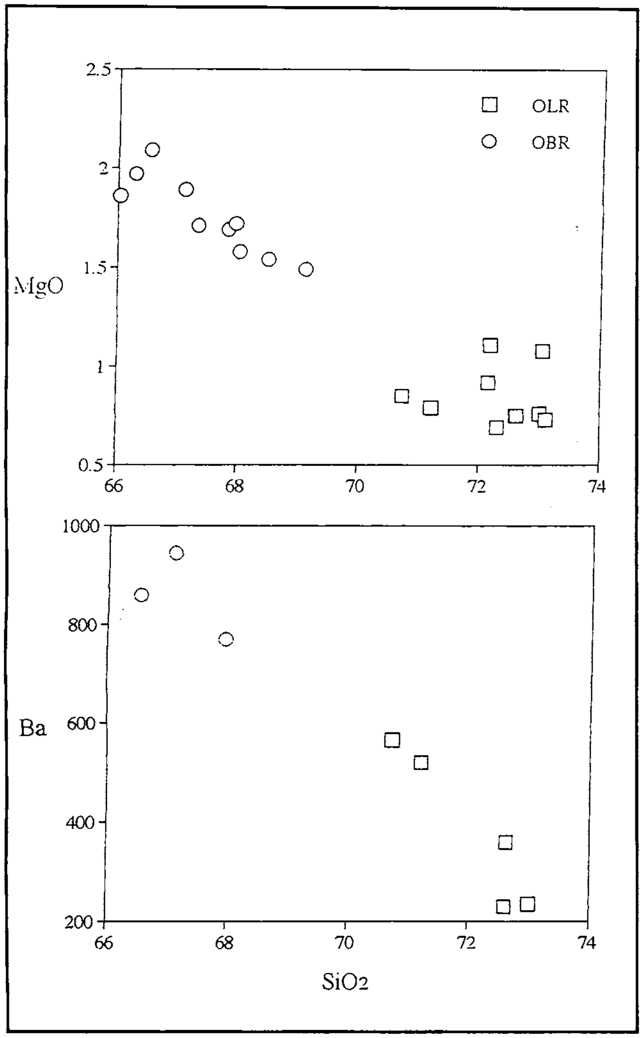


Figure 2: Selected Harker variation diagrams for the Genting Sempah Volcanic Complex. Both MgO and Ba (in ppm) decrease with increasing $SiO_2$ (in wt %). Note the hiatus between the OLR and OBR between approximately 69 – 70 wt % $SiO_2$.

processes such as assimilation. However, within the magma, crystal fractionation may play an important role, particularly in the OLR.

## CONCLUDING REMARKS

According to Cox *et al.* (1979), 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 OLR and OBR 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 OBR resemble clots of mafic 'noritic' micro-inclusions. There is a possibility that the OBR is a hybrid – as proposed by Liew (1977) – developed by mixing of, and limited reaction between solid norite and a low melting silicic liquid. The arrested nature of the 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 OBR 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.*, (1977).

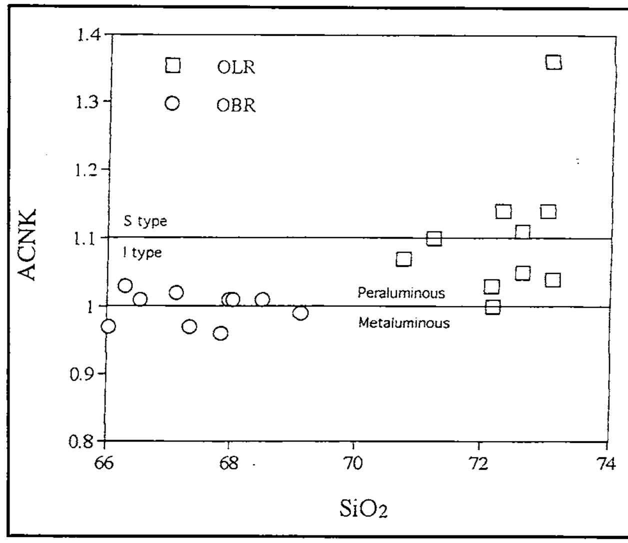


Figure 3 : Molar $Al_2O_3$ / CaO + $Na_2O$ + $K_2O$ vs $SiO_2$ (in wt %) diagram for the Genting Sempah Volcanic Complex. A significant observation is the two completely different trends present for both the OLR and OBR. The values for the OBR seem to straddle close the the peraluminous – metaluminous boundary; whereas there is a notable increase in ACNK values with increasing $SiO_2$ for the OLR.

Chemical data show that both OLR and OBR are not related by simple fractionation. Another process that may be important is simple assimilation. However, crystal fractionation may be important within the OLR magma as vector diagrams indicate that biotite, plagioclase and K-feldspar are important fractionation minerals. Both OLR and OBR also show some different chemical characteristics such as a compositional gap at 69.1 to 70.7% $SiO_2$, different ACNK values, different ACNK trends with increasing $SiO_2$ and contrasting behaviour for the major and trace elements, particularly $K_2O$ and Ba. This is supported by major element modelling where both OBR and OLR have different mineral

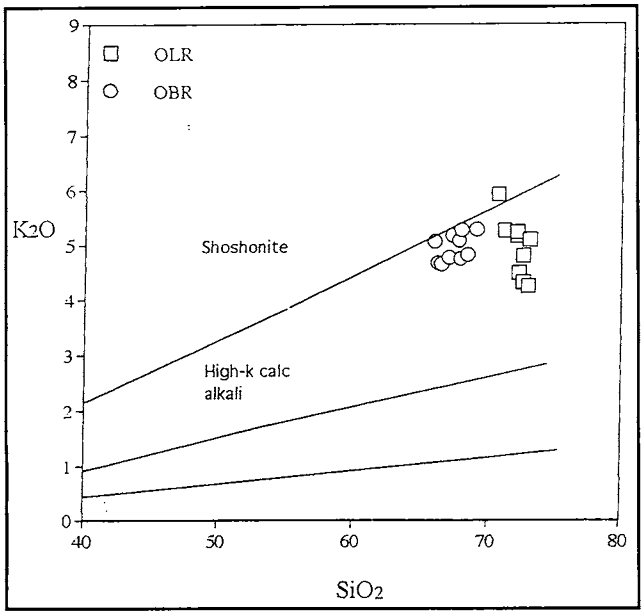


Figure 4: Subdivision of the Genting Sempah Volcanic Complex using the $K_2O$ (in wt %) vs silica (in wt%) diagram. There is an increase of $K_2O$ with increasing $SiO_2$ values within the high – K calc alkali field for the OBR, as opposed to decreasing $K_2O$ values with increasing $SiO_2$ observed for the OLR. This is another case where there are two different trends present. The evolution of the OLR 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.

extract proportions (Table 2). The strong enrichment of Ba and Sr in OBR is probably related to transfer of enriched (hydrous ?) fluids from the mantle into the lower crust and possibly initiated melting to form the rocks (Stephens and Halliday 1984 ; Tarney and Jones 1994).

## FUTURE WORK

(1) A detailed study on the composition of the enclaves that occur in the volcanic complex should be conducted for a more thorough understanding of the magmatic evolution of the complex.

(2) Radiogenic isotopes – particularly Sr, Nd, Sm and Pb – are crucial in determining the source region and the importance of other processes such as mixing and high – level interaction. It is imperative to obtain more isotope data for this complex, especially in the middle portion of the complex.

(3) Petrogenetic modelling based on REE data is also required for a more comprehensive understanding of the individual fractionation processes operating within the OLR and OBR.

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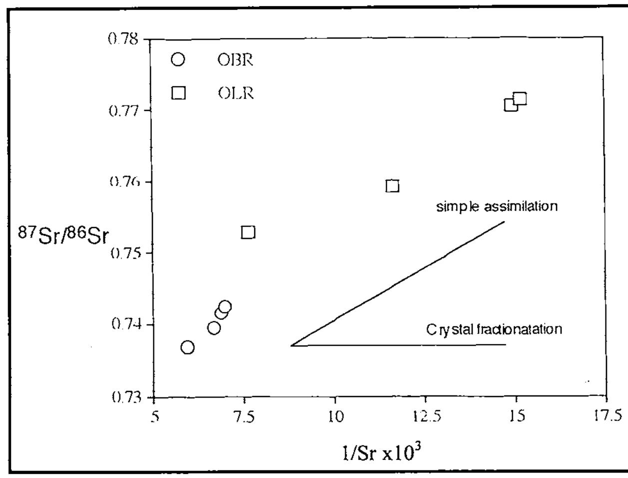


Figure 5: $^{87}Sr/^{86}Sr$ vs 1/Sr x $10^3$ plot for the Genting Sempah Volcanic Complex. Generally a horizontal trend is an indication of crystal fractionation, whereas a sub – horizontal trend represents simple assimilation (Myers *et al.*, 1984). The trends produced by both the OLR and OBR are not horizontal and thus preclude fractionation as the main evolution process between the two units.

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Table 2: Major element modelling of the OLR and OBR. Note that the mineral proportions for both rocks are different. Composition of samples MAL78, Liew(9), MAL76 and MAL73 from Liew (1983).

| Major element modelling for the OBR | | | |
|---|---|---|---|
| | Start Composition MAL78 | Liquid Composition at 25% fractionation | Target Composition Liew(9) |
| $SiO_2$ | 66.53 | 69.38 | 69.11 |
| $TiO_2$ | 0.77 | 0.75 | 0.71 |
| $Al_2O_3$ | 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 |
| $Na_2O$ | 2.42 | 1.95 | 2.06 |
| $K_2O$ | 4.65 | 4.08 | 5.28 |
| Mineral extract proportion — Bi : 25%; Ksp : 25%; Opx : 5%; Pl : 40%; Qu : 5% | | | |

| Major element modelling for the OLR | | | |
|---|---|---|---|
| | Start Composition MAL76 | Liquid Composition at 35% fractionation | Target Composition MAL73 |
| $SiO_2$ | 70.73 | 73.06 | 73.00 |
| $TiO_2$ | 0.45 | 0.40 | 0.35 |
| $Al_2O_3$ | 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 |
| $Na_2O$ | 2.18 | 2.39 | 2.67 |
| $K_2O$ | 5.92 | 4.09 | 4.25 |
| Mineral extract proportion — Bi : 17%; Ksp : 50%; Pl : 14%; Qu : 19% | | | |

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