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How Geochemical Data Substantiate Findings in Lithostratigraphy with Specific Reference to Characterizing Lithodemes

HAMZAH MOHAMAD

Program Geologi, Fakulti Sains dan Teknologi
Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia

Abstract

There are three main factors which hinder accurate characterisation and correlation of a metamorphic complex, supersuite, suite or a lithodeme. The factors are related to the direct dependence of type and nature of metamorphic rocks (i.e. mineral composition, texture and microstructure) on (1) The specific type of metamorphism affecting the area, (2) The intensity of the metamorphism, and (3) The initial composition of the protoliths. Before using mineral composition, texture and microstructure as prime rock characters, detailed understanding about the relation between the three factors and the metamorphic rocks is very important in order to avoid, amongst others: (1) Mixing up of lithostratigraphic and lithodemic nomenclature, (2) Giving more than one name to a single lithodeme, and (3) Mixing up of ranks in lithodemic units, i.e. complex, supersuite, suite and lithodeme. The proven isochemical nature of regional metamorphism of metapelites, except for H_2O and CO_2, has enabled the bulk chemical composition to be treated as an additional rock character in characterising lithodemic units. In this study the chemical character is represented by Niggli numbers si, al, alk, and fm. Four correlations based on the these Niggli numbers and their derivatives have been formulated to discriminate lithodemic units, as follows: (1) si vs. al - alk, (2) si vs. alk, (3) si vs. fm, and (4) si vs. [fm / (fm + alk)]. The correlations have been applied to the Scottish Highlands metapelites near Angus District, and three formal and informal lithodemes in Semenanjung Malaysia, i.e. Kenny Hill formation, Taku Schist, and the East-West Highway metapelites. All lithodemic units portray common trends of slopes in all correlations, but any individual lithodeme is distinguishable from the others by the si ranges, as well as the gradients of curves. The strongest discriminating correlation is si vs. al -alk.

Bagaimana Data Geokimia Membuktikan Penemuan Litostratigrafi dengan Rujukan Spesifik ke Atas Pencirian Litodem

Abstrak

Terdapat tiga faktor utama yang menghalang ketepatan pencirian dan korelasi kompleks metamorf supersuit, suit ataupun satu litodem. Faktor ini berkait daripada pengaruh terus jenis dan keadaan semulajadi batuan metamorf (contohnya komposisi kimia, tekstur dan mikrostruktur) dalam (1) Jenis metamorfisme yang dialami oleh kawasan, (2) Kekuatan metamorfisme, dan (3) Komposisi asal protolith. Sebelum menggunakan komposisi mineral, tekstur dan mikrostruktur sebagai asas pengelasan batuan, pengetahuan lengkap mengenai perhubungan antara ketiga-tiga faktor dengan batuan metamorf adalah penting untuk mengelakkan, antaranya: (1) Pencampuran penamaan litostratigrafi dan litodemik, (2) Penamaan lebih daripada satu nama kepada litodem tunggal, dan (3) Pencampuran kedudukan unit litodemik, contohnya kompleks, supersuit, suit dan litodem. Dibuktikan keadaan semulajadi isokimia metamorfisme rantau metapelit, kecuali H_2O dan CO_2, membolehkan komposisi kimia pukal diuji sebagai tambahan kepada sifat batuan dalam pengelasan unit litodemik. Dalam kajian ini, sifat kimia diwakili oleh nombor Niggli si, al, alk dan fm. Empat korelasi berdasarkan nombor Niggli ini dan terbitannya telah diformulakan untuk menyingkirkan unit litodemik seperti berikut: (1) si lawan al-alk, (2) si lawan alk, (3) si lawan fm, dan (4) si lawan [fm / (fm + alk)]. Korelasi ini telah diaplikasikan di metapelit Pergunungan Scottish berdekatan Daerah Augus, dan tiga litodem rasmi dan tidak rasmi di Semenanjung Malaysia, contohnya formasi Kenny Hill, Syis Taku dan metapelit Lebuhraya Timur-Barat. Semua unit litodemik menunjukkan tren umum cerun dalam semua korelasi tetapi setiap litodem tunggal boleh dibezakan daripada yang lain menggunakan julat si serta kecerunan lengkuk. Diskriminasi paling jelas dalam korelasi ialah si lawan al-alk.

INTRODUCTION

Malaysian Stratigraphic Nomenclature Committee (1997) categorised nine problems faced by geologists working in Malaysia when dealing with its stratigraphic nomenclatures. Two of these problems are related to metamorphic complexes. The first problem is "...different names are being used by different geologists for the same rock unit in adjacent areas". To illustrate this situation two popular lithodemic units were quoted: Dinding schist in Kuala Lumpur area (Gobbett, 1964) and Jelebu schist in the Kuala Kelawang area, Negeri Sembilan (Shu, 1989). Also quoted were Semantan Formation in Temerloh area (Jaafar Ahmad, 1976) and Gemas Formation in the Segamat area (Loganathan, 1977). The second problem, which is closely related to the first one is "...highly metamorphosed rocks (e.g. Hawthornden Schist) and highly tectonised rocks (e.g. Lubok Antu Melange) have been classified as lithostratigraphic units instead of lithodemic units".

According to widely accepted definition (e.g. ISSC, 1994), a lithostratigraphic unit is "...a defined body of sedimentary, metasedimentary, volcanic or metavolcanic strata which is distinguished and delimited on the basis of lithologic characteristic and stratigraphic position." A lithodemic unit is also a rock body defined by its lithologic character, but it is restricted to "...predominantly intrusive, highly deformed, and / or highly metamorphosed rock". A lithodemic unit lacks primary stratification (e.g. bedding, lamination) and does not conform to the Law of Superposition.

This paper focuses strictly on lithodemic units of metamorphic origin, more precisely clastic metasediments. A brief treatment on the possible reasons of discrepancies in stratigraphic nomenclature, as illustrated by the case of Dinding schist versus Jelebu schist above, is given. In doing so, the nature and behaviour of regional metamorphism and their implications on the nature of the resulting metamorphic rocks are also discussed. An attempt is made to utilise bulk chemical composition of rock as an additional "rock character" in order to characterise and differentiate a lithodemic unit. Three lithodemic units of clastic sedimentary origin in Semenanjung Malaysia with sufficient chemical data are taken as examples. The widely studied Scottish Highlands metapelitic unit in Angus District is taken as a comparison.

BEHAVIOR OF CLASTIC SEDIMENTARY ROCK DURING REGIONAL METAMORPHISM: ARBITRARY BOUNDARY BETWEEN BIOSTRATIGRAPHIC, LITHOSTRATIGRAPHIC AND LITHODEMIC UNITS

Destruction of Sedimentary Features

It is fairly common that some of the important depositional features such as bedding, lamination, cross bedding, graded bedding, current ripple and bioturbation structure are preserved in low grade metamorphic rocks, particularly slates. A detail microscopic study will reveal the presence of both foliation and bedding planes in such low grade rocks (see for example a comprehensive treatment by Frey, 1987). Most argillaceous metasediments of Kenny Hill formation display foliation, as well as the original bedding (Hamzah Mohamad *et al.*, 1986). Traces of primary structures are rarely observable in phyllite and are absent in schist and gneiss. The author would like to suggest that the practical boundary for lithostratigraphic-lithodemics units lies somewhere at the transition of phyllite into schist.

Destruction of Fossils

Due to notable continuous differential stress, fossils are deformed at the onset of regional metamorphism. However it is not uncommon to observe deformed, yet fairly well preserved fossils in slates and probably some low grade phyllites. Weist slates, for example, contains deformed trilobites (*Angelina*) (Gillen, 1982). Rather well preserved ammonoids (*Agathiceras sp.*) have been reported from Sepang, Selangor (Abdullah Sani Hashim, 1982). The Permian fossil occurs in argillaceous rocks of the Kenny Hill formation, which is of low grade metamorphics in nature with occurrences of slates and even phyllites in the areas closer to Kuala Lumpur (Hamzah Mohamad *et al.*, 1986). It seems reasonable to take the lower part of grenschist facies (i.e. chlorite zone) as the upper limit for fossils to survive metamorphism; thus such low grade rock body can be considered as a lithostratigraphic, or even a biostratigraphic unit, rather than a lithodeme.

Mineralogical Changes

For low and medium - *P/T* regional metamorphism of Miyashiro (1994), the most common clastic metasedimentary rocks (metapelites) in the greenschist facies are made up of chlorite + phengitic muscovite + quartz in the chlorite zone, and chlorite + phengitic muscovite + quartz + biotite in the biotite zone. These major minerals are normally accompanied by one or more of the following minerals in small amount: albite, tourmaline, graphite, hematite, magnetite, ilmenite, sphene, rutile, and calcite. Chloritoid, pyrophyllite and paragonite may occur in highly aluminous rocks, usually in association with chlorite and muscovite (Zen, 1960; Tobschall, 1969). If the original sediment is of greywacky type, as shown by some parts of the Kenny Hill formation, the most common mineral assemblage in the resulting metagreywacke is muscovite + chlorite + epidote + albite + quartz, with or without biotite. Microcline and tourmaline may accompany the above assemblage. As the metamorphism progresses to epidote-amphibolite facies, garnet normally occurs and modify the common metapelites assemblage to garnet + biotite + muscovite + quartz, with or without chlorite. The authors inclined to suggest that clastic metasediments containing garnet and higher index minerals - staurolite, kyanite and sillimanite should be considered as components of a lithodeme.

Textural Changes

As a general rule, the average grain size of a clastic metasedimentary rock increases as the regional metamorphism progresses. Slaty cleavage will appear at the lowest part of the greenschist facies, characterising slates and some phyllites. At higher metamorphic grade, more or less equivalent to the epidote-amphibolite facies, strong schistocity develops in highly micaceous rock. Both types of foliations, however, are either absent or weakly developed in psammites (metamorphosed quartzo-felsphatic rocks).

Gneissic bending characterises the higher grade rocks, within the amphibolite facies. Texturally, the lithodemic numenclature should be used in schistose and gneissic rocks.

Bulk Chemical Changes

Various reactions have taken place in the process of changing the mineral composition of metapelites within the greenschist, epidote-amphibolite and amphibolite facies. Of prime importance is the dehydration reactions, which release H_2O from break-up of hydrous minerals such as muscovite, chlorite and biotite in the course of forming new, less hydrous higher grade minerals, such as garnet, staurolite, kyanite and sillimanite. Some clastic sedimentary rocks and low grade metapelites may also contain some calcite, which disappear by reaction with associated minerals, evolving CO_2 – a decarbonation reaction. It has been generally accepted that H_2O and CO_2 are significantly mobile during regional metamorphism.

Shaw (1956) statistically studied the bulk chemical compositions of 185 clays, shale, slate, phyllite, schist and gneiss and suggested that apart from H_2O and CO_2, regional metamorphism did not alter the bulk rock compositions in terms of major elements. Most of the following works on this subject up to 1980 support Shaw's finding, i.e. metamorphism in metapelites can be considered as isochemical in nature (see a concise discussion on this subject by Hamzah Mohamad, 1984). The findings lead to possible inference of mineralogy of protoliths from the chemistry of the equivalent metamorphic rocks.

LITHOSTRATIGRAPHIC AND LITHODEMIC CORRELATION: COMMON OBSTACLES

If the present accepted definition is strictly followed, a group of medium to high grade metapelites readily meet the criteria of a lithodeme because "...the rock body has lost its primary stratification and does not conform to the Law of Superposition". In practical mapping, however, the case is not that straight forward. For the purpose of establishing a stratigraphic correlation (e.g. aerial distribution), rock characters cannot be defined solely on the basis of mineral composition, texture and microstructure. This is so because the nature of metamorphic rocks which form a lithodeme depends so much on the three following factors: (1) The specific type of metamorphism effecting the protolith, (2) The intensity of the metamorphism, and (3) The initial composition of the protolith. For a relatively small terrain, it is always true that a single type of regional metamorphism has taken place, thus factor (1) is not so crucial. On the other hand, the intensity of metamorphism has a strong potential of creating confusions. Lets examine the following extreme case as an example. A terrain of metamorphic rock consists of two mappable rock types — predominant mica schist and quartz-mica schist and lesser amount of quartz schist and metaquarzite; no carbonate layers were found. This unit has been assigned A schist (A is a geographic name), i.e. a lithodeme.

In an adjacent area, separated by younger granitic body, an extensive and mappable rock unit was assigned B formation (B is a geographic name). The rocks are predominantly mudstone and shale, with lesser amount of greywacky type sandstone and aranitic sandstone. Carbonate layers were not found. Judging from the lithologic character there is a strong possibility that B formation is an extension of A schist, or vice versa. Why? Because all types of rocks in A schist are the metamorphic equivalent of those from B formation. Mudstone and shale, when highly metamorphosed, will be transformed into mica schist and quartz-mica schist, respectively. Accordingly greywacky type sandstone and aranitic sandstone will form weaker schistosity and be transformed into quartz schist and metaquarzite, respectively. It is now clear that other character, such as bulk chemical composition, is very wanting in accurate characterisation and differentiation of B formation and A schist.

Factor (3), the initial composition of the protolith may also create confusion. It has been proven by Mather (1970) and other workers that the formation of biotite through reaction involving chlorite and phengitic muscovite may be delayed in highly aluminous rocks, thus in such rocks biotite occurs at garnet zone of more "normal" rocks. In the same study Mather (1970) found that original clastic sediments containing chlorite, phengitic muscovite and microcline will react at far lower temperature than the chlorite + phengitic muscovite assemblage to form biotite. Hamzah Mohamad *et al.* (1986) pointed out that most rocks of Dinding schist contain biotite in association with microcline, while biotite does not occur in most, if not all, rocks of Kenny Hill formation. Structural and textural features, such as the type and degree of perfection of foliation are about comparable in both formations, suggesting a comparable grade of metamorphism. In short, characterising metamorphic rocks using mineral assemblage and texture alone may lead to some serious error, as far as metamorphic grade is concerned.

BULK CHEMICAL COMPOSITION AS A ROCK CHARACTER TO SUBSTANTIATE LITHOSTRATIGRAPHIC AND LITHODEMIC CORELATION

The Basic Assumption

In the following section, bulk chemical composition will be treated as a rock character for clastic sedimentary rocks, as well as metapelites, their metamorphic equivalent. Regional metamorphism is considered isochemical in nature, except for H_2O, CO_2 and a few other less important volatile components.

The Niggli Numbers as Rock Character

In this study, the chemical rock character is represented by Niggli numbers (Niggli, 1954); a series of molecular proportions of major and minor oxides in the rock. These numbers allow more flexibility in interpretation of rocks based on their chemical compositions because each number was formulated from a specific group of oxides, which represents a mineral, or a group of minerals. Niggli numbers have been widely used in the study of igneous rocks, as well as sedimentary and metamorphic rocks (Cox *et al.*, 1979). For example, the chemical trends of clastic sedimentary rocks have been observed in their medium grade metamorphic equivalents (Senior and Leake, 1978; Hamzah Mohamad, 1984; Rohayu Che Omar, 1995).

For the purpose of characterising a "lithodeme", four of the Niggli numbers are recommended to be put into practical usage: si, al, alk, and fm. In addition, two derivative parameters are also suggested: *al - alk* (read as al minus alk), and [fm / (fm + alk)]. Ultimately, four geochemical correlation curves are recommended to be adopted as discrimination diagrams. A brief summary for the individual Niggli numbers, the two derivative parameters and the four correlation curves are as follows:

si: This number represents the relative amount of quartz (100% SiO_2), as well as potassic feldspar (65% SiO_2). Arenaceous clastic sediments (e.g. arenites, arkoses) and quartzo-feldsphatic schist and gneiss normally show high values of si, in contrast to the obvious lower values in argillaceous sediments and mica schist.

al: This number represents the relative amount of feldspar and other Al-rich minerals, such as andalusite, kyanite and sillimanite.

alk: This number approximates the relative amount of feldspar and to a lesser extent potassic micas, due to the fact that both minerals contain considerable amount of Na_2O and K_2O.

fm: fm represents the relative amount of chlorite, iron oxides and some clay minerals.

al - alk: This derivative parameter represents the relative amount of hydrous aluminium silicates, i.e. clay minerals, as a whole, in clastic sediments. In metamorphic equivalents, it approximates the relative amount of muscovite (see the full descriptions of *al - alk* in Hamzah Mohamad, 1980, 1984; Hamzah Mohamad *et al.*, 1991).

[fm/(fm + alk)]: This parameter gives insight into the relative amount of chlorite, iron oxides and some clay minerals to feldspar in clastic sediments; it may also be used to show the relative amount of chlorite, biotite, and almandine garnet to feldspar in metasediments.

si vs. *al - alk*: Represents the correlation between clay minerals and quartz in clastic sediments, or micas and quartz in the metamorphic equivalent; normally a negative correlation.

si vs. alk: Reflects the correlation between potassic feldspar and quartz — a positive correlation.

si vs. fm: Typically a negative correlation; infers the correlation between chlorite, iron oxides and some clay minerals to quartz in clastic sediments; chlorite, biotite, iron oxides and almandine garnet to quartz in the metamorphic equivalent.

si vs. [fm / (fm + alk)]: To infer the correlation, normally negative, between chlorite, iron oxides and some clay minerals to feldspar in clastic sediments as the amount of quartz increases. In the equivalent metasediments, this correlation reflects the relation between chlorite, biotite, iron oxides and almandine garnet to feldspars, with increasing quartz content.

The Scottish Highland Pelitic-Psammitic Schists as a Standard

Metapelites, semipelites and psammites in Angus District, Scotland were derived from turbidite detrital sediments of Carbon - Precambrian age, which were metamorphosed several times during the Caledonian orogeny, with the climax during Ordovician time (Johnstone, 1966). The bulk chemistry of eighty samples from chlorite, biotite, garnet, staurolite, kyanite and sillimanite zones of Barrow (1893, 1912) in terms of the four geochemical correlations mentioned above are shown in Figure 1. Negative correlations are shown by si vs. *al - alk*, si vs. fm, and si vs. [fm / (fm + alk)]; si vs. alk shows a positive trend.

EXAMPLES OF BULK CHEMICAL CHARACTER OF SOME MALAYSIAN LITHODEMES

The Kenny Hill Formation

The chemical character of low grade metamorphic rocks of Kenny Hill formation (Yin, 1976) of probably Permian age (Abdullah Sani Hashim, 1982) in Kuala Lumpur area, based on eleven representative samples is shown in Figure 2. The character resembles Angus clastic metasediments: negative correlations for si vs. *al - alk*, si vs. fm and si vs. [fm / (fm + alk)], and a positive correlation for si vs. alk.

Palaeozoic Rocks of East-West Highway

The Grik - Jeli stretch exposes low to rather high grade clastic metasediments, tuffaceous in some places, ranging in metamorphic facies from greenschist to amphibolite, with mappable metamorphic zones of chlorite, biotite, garnet, staurolite and sillimanite (Rohayu Che Omar, 1995). The pre-metamorphic rocks are believed to be the Baling Group (Burton, 1970; Jones, 1970) in the west, the Bentong Group in the middle, and the Gua Musang Formation in the eastern part of the stretch. A total of 61 samples of non-tuffaceous metapelites have been chemically analysed. Figure 3 shows the four Niggli numbers' geochemical correlations. The geochemical trends are similar to the

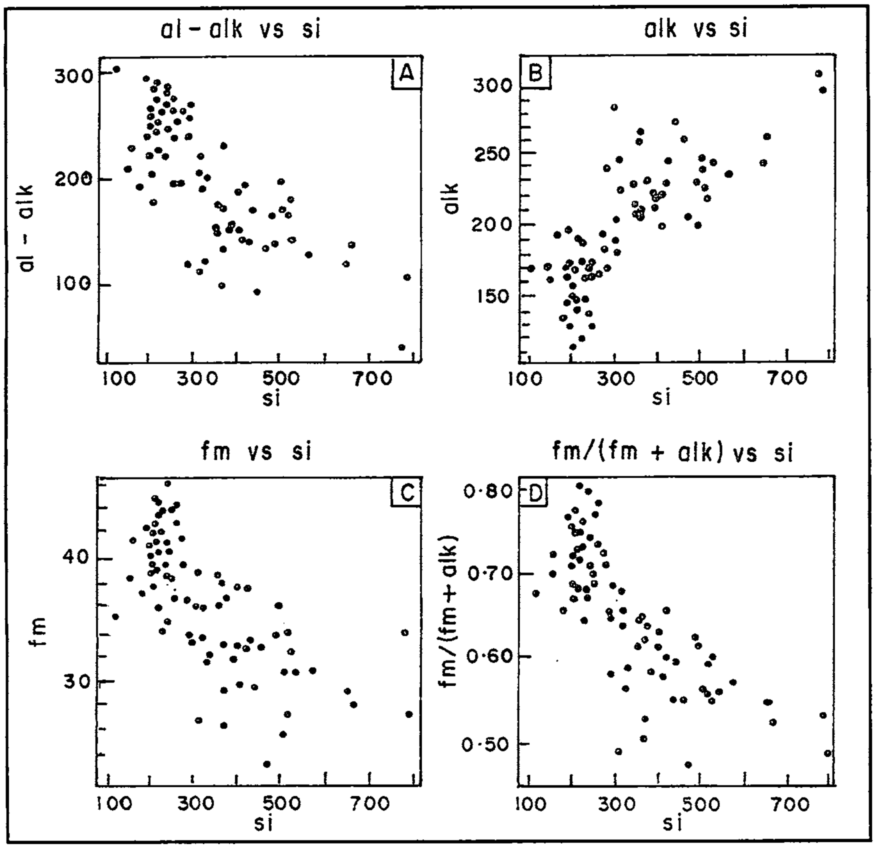

Figure 1: Negative correlation between si and *al - alk*, fm, and [fm / (fm + alk)]; postive correlation between si and alk (Clastic metasediments, Angus District, Scotland).

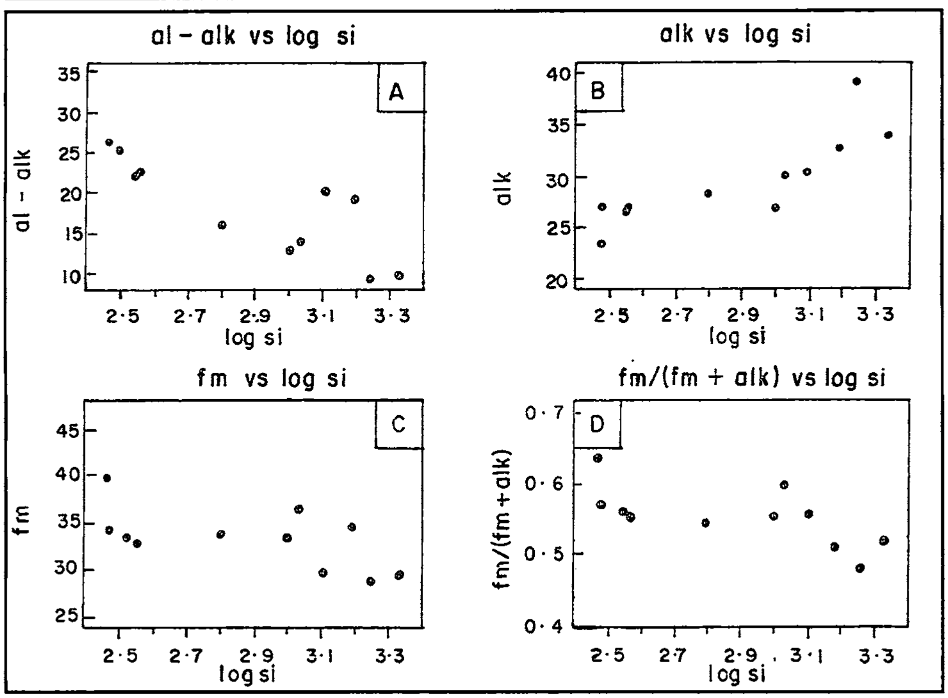

Figure 2: Negative correlation between si and *al - alk*, fm, and [fm / (fm + alk)]; postive correlation between si and alk (Clastic metasediments, Kenny Hill formation, Kuala Lumpur).

Angus rocks (Fig. 1) and the rocks of Kenny Hill formation (Fig. 2).

Taku Schist

The protolith of the well defined metapelitic body in the northern part of Kelantan, although not exposed (Hutchison, 1973) is believed to be slightly tuffaceous clastic sediments of Permo-Triassic age (Khoo & Lim, 1983). The metamorphism took place, as shown by radiometric dating of muscovite and biotite, during Middle Triassic or Lower Triassic (MacDonald, 1968; Hutchison, 1973), or Upper Triassic (Bignell & Snelling, 1977). Except for limited occurrences of amphibolite schist, serpentinite and granite gneiss, Taku Schist is dominated by metapelites; quartz-mica schist, quartz schist, garnet-quartz-mica schist and mica schist in descending order of abundance, with metamorphic facies ranging from lower greenschist to amphibolite facies (Hamzah Mohamad, 1993).

Figure 4 depicts the chemical correlations of 20 Taku Schist metapelites. Although larger scatter of points was observed, the general patterns are still maintained, i.e. three correlations show negative trend (si vs. *al - alk*, si vs. fm and si vs. [fm / (fm + alk)]), and a positive trend for al vs. alk.

Comparison Between Lithodemes

In order to portray differences in chemical character among the three "lithodemes" described above, straight line curves representing their average compositions have been plotted together, along with the average composition of the Angus rocks (Fig. 5, Fig. 6, Fig. 7 and Fig. 8). The figures show three interesting features as follows:

1) The range of si differs from terrain to terrain; Taku Schist shows the widest and East-West Highway rocks being the narrowest. Assuming representative sampling, the magnitude of si range may reflect the dominance of rock types. In this particular case, the pre-metamorphic sediments of Taku Schist seem to be wider in composition, argillaceous to arenaceous in nature, compared to the narrower, argillaceous nature of the East-West Highway rocks. Kenny Hill metasediments fit in between.
2) In each correlation, the four curves share the same trend (i.e. positive or negative). However there are significant differences in their gradients. In general, there are strong indications of resemblance between Taku Schist and the East-West Highway rocks (especially in Fig. 5 and Fig. 8). The Kenny Hill rocks seem to behave differently.
3) All correlations show notable discriminating abilities, but of different degree. The strongest is shown by si vs. *al - alk*, followed by, in descending degree, si vs. alk, si vs. fm, and si vs. [fm/(fm + alk)].

CONCLUSION

As long as the isochemical nature of metamorphism of metapelites is maintained true, this study has shown that bulk chemical composition, represented by Niggli numbers and their derivatives can be used as an additional and supporting rock character for lithodemic units of metamorphic origin. The usage of the additional rock character along with traditional mineralogical, textural and structural characters will minimise some discrepancies in lithostratigraphic and lithodemic correlations.

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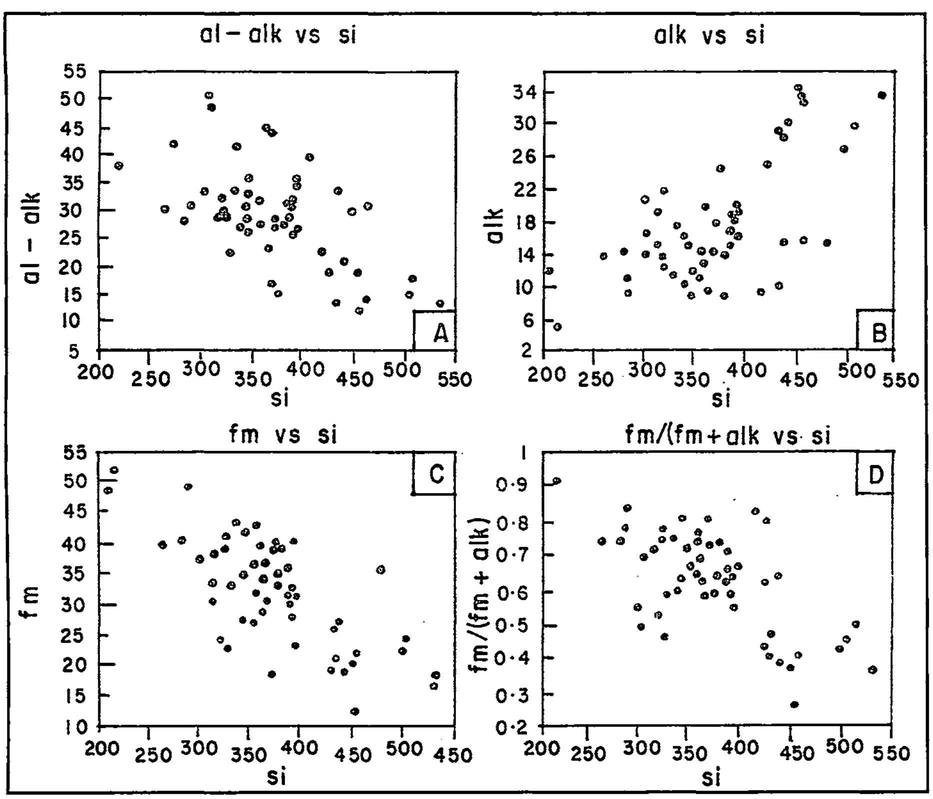

Figure 3: Negative correlation between si and *al - alk*, fm, and [fm/(fm+alk)]; postive correlation between si and alk (Clastic meta-sediments, East-West Highway, Perak - Kelantan).

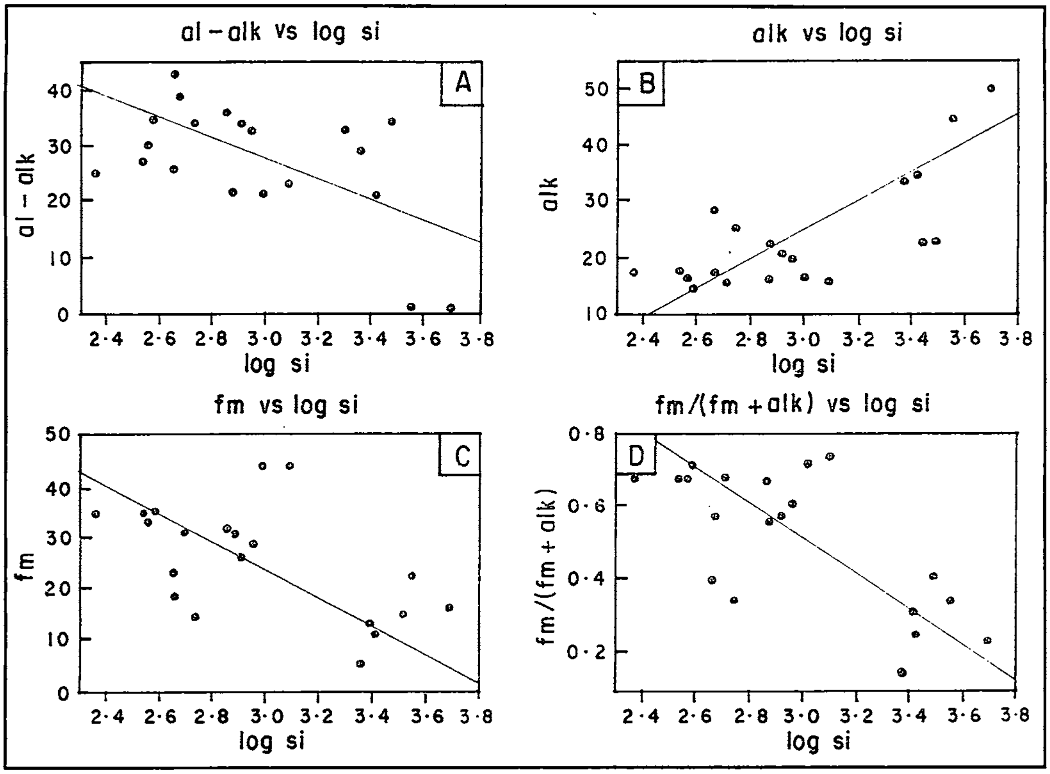

Figure 4: Negative correlation between si and *al - alk*, fm, and [fm / (fm + alk)]; postive correlation between si and alk (Clastic metasediments, Taku Schist, Kelantan).

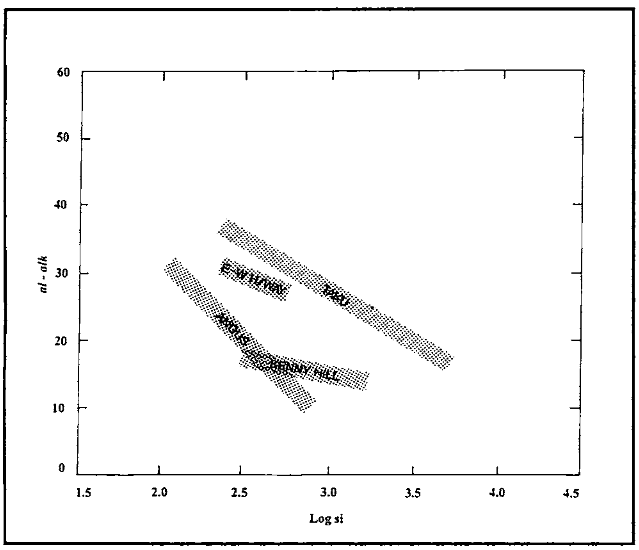

Figure 5: Negative correlation between si and *al - alk* for all lithodemes.

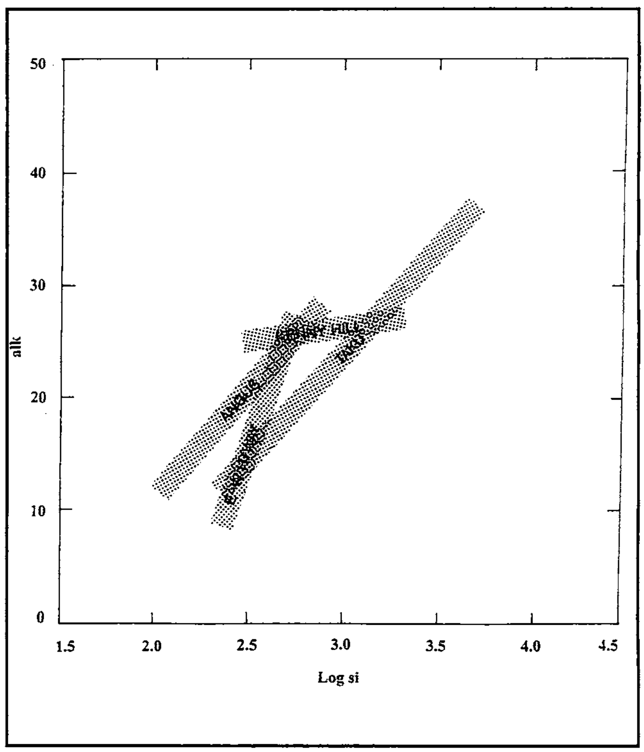

Figure 6: Positive correlation between si and alk all lithodemes.

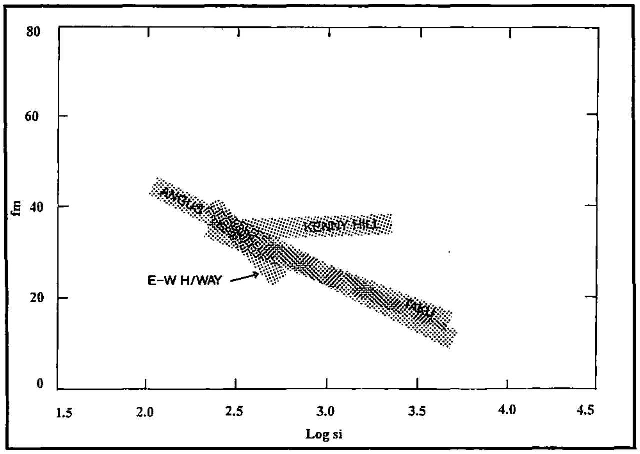

Figure 7: Negative correlation between si and fm for all lithodemes, except Kenny Hill formation.

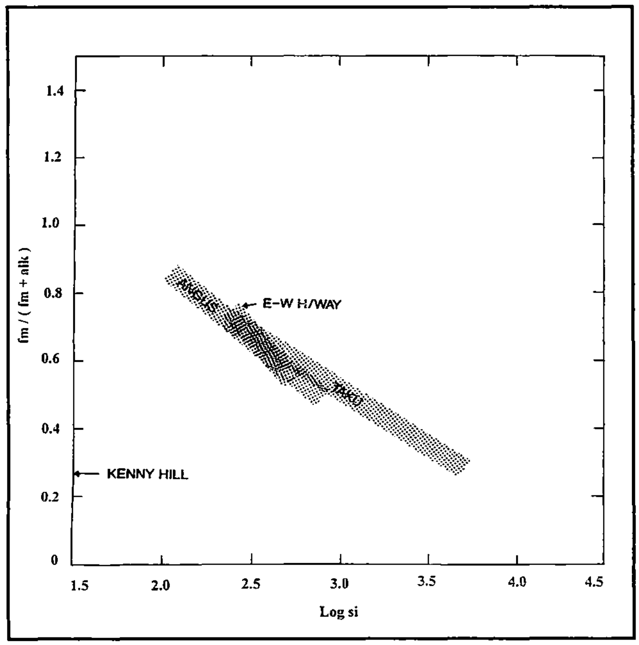

Figure 8: Negative correlation between si and [fm / (fm + alk)] for all lithodemes, except Kenny Hill formation.

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