

RELIC CLINOPYROXENES AND METAMORPHISM OF THE MOTTON SPILITE OF THE
LEVEN HILLS DISTRICT, TASMANIA

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(with one table, four text-figures and one plate)

ABSTRACT

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Electron probe analyses of the relic clinopyroxenes and bulk chemical compositions of the Motton Spilite greenstones both suggest that they have been derived from basaltic rocks similar to ocean floor tholeiites. The greenstones are considered to have been affected by low-grade metamorphism whose physical conditions corresponded to those of the lower grade part of the glaucophanitic facies.

INTRODUCTION

The Motton Spilite is a Cambrian volcanic formation in northwestern Tasmania. It consists mainly of basaltic rocks which have been affected by low-grade metamorphism and transformed into greenstones (e.g. Banks 1962; Burns 1964). About twenty specimens of the Motton Spilite in the Leven Hills district to the south of Ulverstone and a few of similar rocks in the Smithton and Kanunnah Bridge, Arthur River, areas were collected. The sample localities are shown in figure 1.

This paper deals briefly with the chemical composition of relic clinopyroxenes preserved in the greenstones and with the low-grade metamorphism by which the rocks have been affected.

ORIGINAL BASALTS

The original rocks of the Motton Spilite are considered to have been basalts, dolerites, trachybasalts and their pyroclastic equivalents, judging from their petrographic characteristics. They are all weakly metamorphosed, but the degree of recrystallization is generally so low that the igneous textures have been well preserved in most of the studied samples. Under the microscope, the rocks show various textures such as porphyritic, doleritic, intergranular, variolitic and amygdaloidal. Glassy mesostases, olivine, plagioclase and iron ore are completely or partly recrystallized into secondary minerals, whereas clinopyroxene has retained its original state.

Relic clinopyroxenes

The clinopyroxenes are pale purple in thin section and not infrequently show hour-glass extinction. The pyroxenes of the three selected samples were analysed by means of an electron-probe microanalyser, Hitachi XMA Model 5A, with three channel detecting system and 38° take-off angle. Accelerating voltage and specimen current were 15KV and 0.03 μ A, respectively. Synthetic periclase, corundum, quartz, wollastonite and rhodonite and natural albite, adularia, haematite and kaersutite were used as standards. The observed intensity ratios of unknown to standards were corrected by the alpha factor of Albee and Ray (1970). The results listed in table 1 and shown in figure 3 indicate that the analysed clinopyroxenes are augite slightly rich in TiO_2 and Al_2O_3 . In some greenstones pyroxenes are mantled at least partly with aegirine-augite (Plate 1(a)) the analysis of which is also given in table 1.

The aegirine-augite is apple green to yellowish green in thin section, while the host

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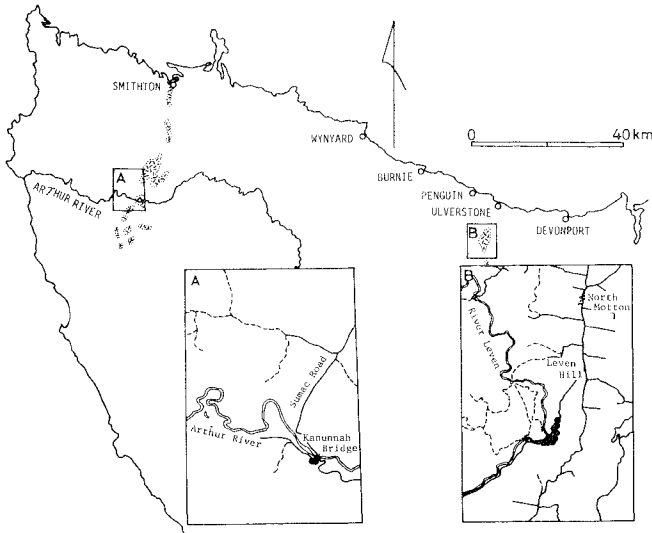


FIG. 1.- Sampling localities. The stippled pattern indicates Cambrian basic volcanic rocks (Williams, 1978). The sampling localities are shown by black dots.

augite is almost colourless or very pale brownish yellow. The angle $c^{\wedge}z$ of the augite is about 40° and $C^{\wedge}x$ of the aegirine-augite is about 38° . The latter pyroxene shows strong optical dispersion and does not entirely extinguish under the crossed nicols. Anomalous interference colours are observed at the rotation positions close to that of extinction. The aegirine-augite mantles of the pyroxenes are so small that further details of optical properties are difficult to determine.

Chemical compositions of augitic pyroxenes of basaltic rocks are considered to vary in relation with the rock series to which their hosts belong. Clinopyroxenes rich in Ti and Al are said to occur generally in rocks of the alkali basalt series, those rich in Si in the tholeiitic series rocks (Kushiro 1960; Le Bas 1962; Maruyama 1976). However Nisbet and Pearce (1977) stated that the chemistry of clinopyroxenes would give only rarely an unambiguous conclusion about their host.

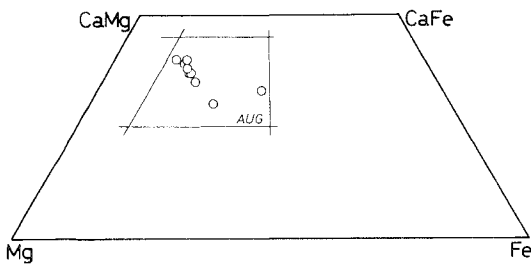


FIG. 2.- Ca/Mg/Fe ratios of relic augites of the Motton Spilite.

The Si - Al and Ti - Al relations in the analysed relic pyroxenes are illustrated respectively in figures 3a and 3b. All but one of the plots fall, in figure 3a, near the line representing $Si + Al = 2.0$ for $O = 6$, and the composition range extends over both fields of the tholeiitic and alkali basaltic clinopyroxenes given by Maruyama (1976). The Ti - Al diagram of figure 3b also shows that the pyroxene compositions of the studied greenstones are intermediate between those of the tholeiites and alkali basalts. Consequently, it is concluded from the relic clinopyroxene

chemistry that the original rocks of the Motton Spilite greenstones would have been intermediate basalts between tholeiites and alkali basalts. Furthermore, the composition field shown in figure 3b is in the midst of the larger field of the pyroxene analyses of tholeiitic deep-sea basalts given by Schweitzer *et al* (1979).

Bulk chemical composition

No new bulk chemical analysis was made for this study. A few greenstone analyses of the Motton Spilite and the correlatives, however, have been given by Scott (1951, 1952), Spry (1962) and Burns (1964). All the published analyses are basaltic, their SiO_2 contents varying from 47 to 53%. The $(Na_2O + K_2O) - SiO_2$ and $TiO_2 - P_2O_5$ plots are shown respectively in figures 4a and 4b. Most of the plots fall in the field of the alkali

TABLE 1

Electron-probe microanalyses and atomic ratios of relic clinopyroxenes of the Motton Spilite greenstones, Leven Hills, Tasmania

SiO ₂	51.70	50.21	50.88	51.34	50.57	50.79	50.72	50.41	51.20	50.43
TiO ₂	0.55	0.46	0.52	0.56	0.55	0.49	0.66	0.53	0.57	0.12
Al ₂ O ₃	1.81	2.61	2.48	2.60	3.54	2.13	2.18	1.38	2.33	0.36
FeO*	11.48	7.40	8.79	9.33	8.51	9.86	14.83	19.30	10.12	23.23
MnO	0.19	0.16	0.16	0.16	0.16	0.19	0.28	0.69	0.21	0.53
MgO	16.96	17.24	16.40	17.04	16.90	16.67	16.13	12.00	16.70	7.53
CaO	17.77	20.17	19.49	18.94	19.28	18.51	14.81	16.12	18.19	14.98
Na ₂ O	0.19	0.25	0.23	0.23	0.26	0.25	0.25	0.37	0.25	2.63
K ₂ O	0.01	0.02	0.01	0.01	0.01	0.01	0.00	0.02	0.00	0.04
Number of analyses averaged	1	2	2	2	3	2	1	1	2	2
Si	1.918	1.886	1.908	1.901	1.877	1.911	1.913	1.935	1.912	1.996
Al ^{IV}	0.079	0.114	0.092	0.099	0.123	0.089	0.087	0.063	0.088	0.004
Al ^{VI}	-	0.001	0.018	0.015	0.031	0.006	0.010	-	0.015	0.013
Ti	0.015	0.013	0.016	0.016	0.016	0.014	0.019	0.015	0.016	0.005
Fe	0.356	0.233	0.275	0.289	0.266	0.310	0.468	0.620	0.316	0.771
Mn	0.006	0.005	0.005	0.004	0.004	0.007	0.009	0.022	0.007	0.017
Mg	0.938	0.967	0.917	0.941	0.935	0.936	0.907	0.687	0.929	0.445
Ca	0.706	0.813	0.782	0.752	0.768	0.746	0.598	0.663	0.727	0.635
Na	0.013	0.018	0.016	0.016	0.018	0.018	0.019	0.027	0.018	0.202
K	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.001	0.000	0.002

*Total iron as FeO

1 - 9 : augites, 10 : aegirine-augite

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basalts in the former diagram (Macdonald and Katsura 1964). On the other hand, in the latter diagram TiO_2 contents are all less than 2.0% and P_2O_5 less than 0.3%. It is suggested, therefore, that the rocks may not be alkali basalts, but are ocean ridge basalts (Rhodes 1973). This discrepancy between the two conclusions taken respectively from the $(Na_2O + K_2O) - SiO_2$ and $TiO_2 - P_2O_5$ relations would result from a slight chemical change, particularly in the alkali contents, in the rocks after their formation.

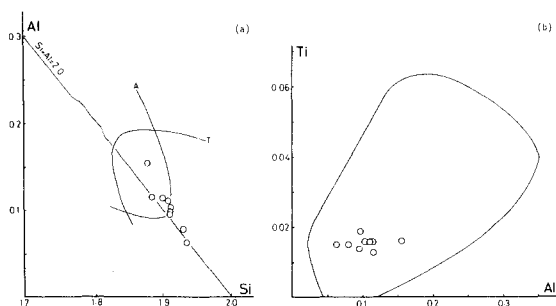


FIG. 3.- Si - Al and Ti - Al relations in relic clinopyroxenes of the Motton Spilite greenstones.

- a) Si - Al relation. Curves A and T given by Maruyama (1976) indicate respectively the fields of augitic pyroxenes in the alkali basaltic and tholeiitic rocks.
 b) Ti - Al relation. Curve encircles the composition field of most of clinopyroxenes from deep-sea tholeiites given by Schweitzer *et al.* (1979)

Scott (1951) also gave trace element analyses of four King Island Cambrian basalts. Their Ni contents range from 70 to 453 ppm, and Ti/Cr and Ba/Y ratios are respectively 2.3 - 219 and 0.5 - 33. According to Beccaluva *et al.* (1979), these values suggest that the analysed rocks are similar in trace element geochemistry to ocean floor tholeiites.

In conclusion, the electron-probe analyses of relic clinopyroxenes and the bulk chemical compositions of the Cambrian basaltic rocks in northwestern Tasmania and King Island indicate that the basalts may have been originally tholeiites similar to those of ocean floor. The possible origin as other kinds of tholeiite is, of course, not excluded.

METAMORPHISM

Various metamorphic minerals have been formed in the Motton Spilite greenstones due to the low-grade metamorphism which affected the rocks. They are pumpellyite, epidote, chlorite, albite,

quartz, sphene (leucosene), calcite and sericite.

Pumpellyite is found in various modes of occurrence. It not infrequently replaces relic plagioclase, being in association with albite and/or chlorite (Plate 1(b)). Pumpellyite occurs also in recrystallized mesostases of basalts and in veins and pools. The associated minerals in the veins and pools are chlorite, albite, quartz and epidote, although the last mineral is rather rare in the studied greenstones.

The metamorphic mineral assemblages observed in the Motton Spilite greenstones are thus summarized as follows:-

- (a) pumpellyite + chlorite + albite + quartz; (b) pumpellyite + chlorite + albite; (c) pumpellyite + chlorite + quartz; (d) pumpellyite + epidote + chlorite + albite + quartz; (e) pumpellyite + epidote + chlorite + albite; (f) pumpellyite + epidote + chlorite + quartz.

The former three are more common than the latter assemblages. All the assemblages are accompanied by sphene as an accessory. Calcite occurs alone or in association with other minerals in veins. Scattered minute flakes of sericite are often observed in relic plagioclase.

It is noticeable that actinolite occurs neither as a replacing mineral of clinopyroxene nor as an assemblage mineral of the matrix, though Scott (1951) reported its common occurrence in the King Island Cambrian spilites. Furthermore, no prehnite has been found in rocks during the present study.

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The metamorphic mineral assemblages described, in conjunction with the absence of actinolite and prehnite and scarcity of epidote, are quite similar to those observed in greenstones of the Chichibu terrain in western Shikoku, Japan. The metamorphic conditions of this terrain are considered to represent the lower grade part of the glaucophanitic Sambagawa belt of southwest Japan (Hashimoto and Kashima 1970; Hashimoto 1972a).

The mineral pumpellyite has rather wide stability range in rocks of basic composition. It is found in association with prehnite in some relatively low-pressure metamorphic rocks exemplified by Triassic volcanogenous rocks in the Tarringatura district, New Zealand (Coombs 1954; Coombs *et al.* 1959), by similar rocks of the Siluro-Ordovician formations in the Lyndhurst district, New South Wales (Smith 1962), and by Miocene volcanogenous rocks of the Tanzawa Mountains, Japan (Seki *et al.* 1969). On the other hand, the assemblage pumpellyite-actinolite is widely found in basic rocks of lower grade parts of metamorphic regions of the truly high-pressure or high-pressure intermediate types (Hashimoto 1966, 1972b; Miyashiro 1973; Nakajima *et al.* 1977). Furthermore, wide occurrence of pumpellyite-chlorite and pumpellyite-epidote-chlorite associated neither with prehnite nor with actinolite has been reported mostly from terrains which represent further lower grade parts of the high-pressure metamorphic regions such as the glaucophanitic Sambagawa and Sangun belts of southwest Japan (Hashimoto and Kashima 1970; Nishimura 1971; Hashimoto 1972b; Toriumi 1975).

As mentioned earlier, some relic clinopyroxenes in the greenstones are mantled by aegirine-augite (plate 1a and table 1). Similar aegirine-augitization of relic pyroxenes was reported in greenstones of the Chichibu terrain (Toriumi 1975) and is considered to have resulted from the low-temperature and relatively high-pressure metamorphism of the rocks.

Consequently, the metamorphism which affected the Motton Spilite greenstones may have been similar in physical conditions to that of the lower grade part of the Japanese Sambagawa high P/T belt.

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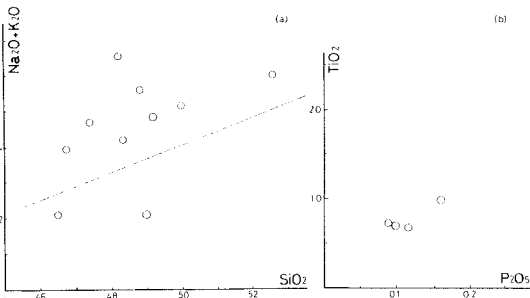
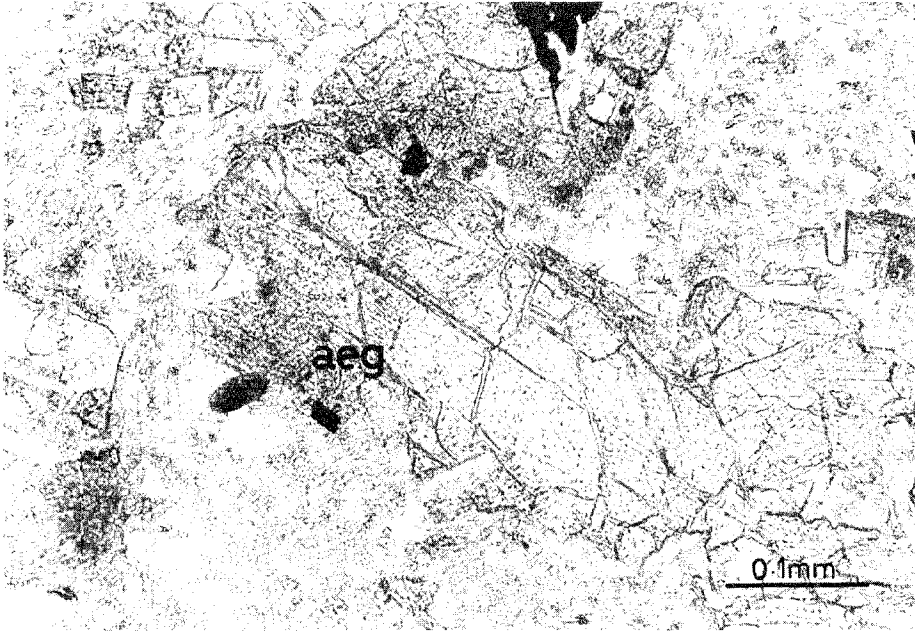


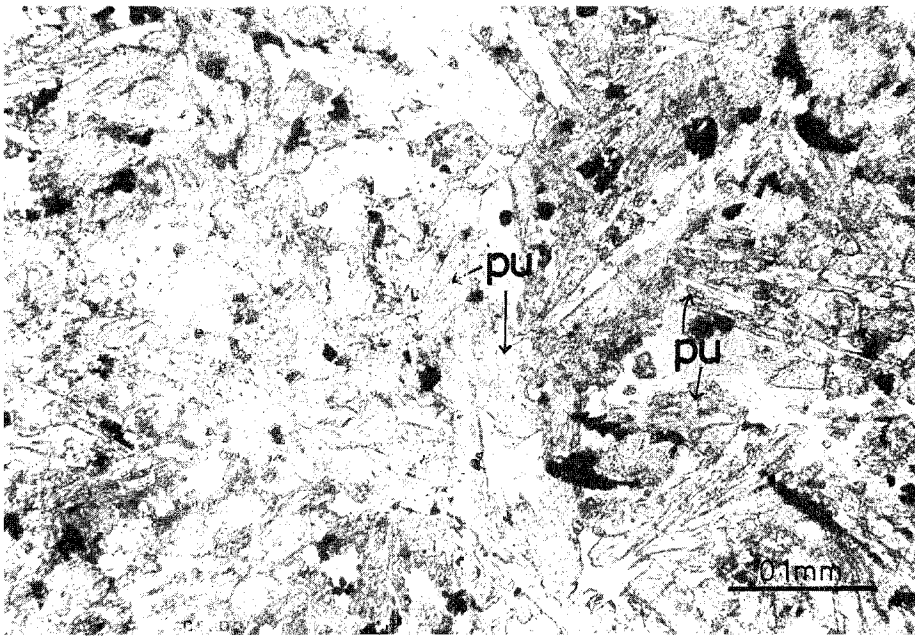
FIG. 4.- Bulk chemical compositions of the Motton Spilite greenstones and their correlatives.
(a) Total alkalis - silica relation. Broken line shows the boundary given by Macdonald and Katsura (1964) separating the fields of tholeiitic and alkali basaltic rocks.
(b) TiO_2 - P_2O_5 plots.

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A



B

PLATE 1(a).- Photomicrograph showing aegirine-augitization of relic clinopyroxene. aeg indicates the part of aegirine-augite composition.

PLATE 1(b).- Photomicrograph showing pumpellyite replacing plagioclase in a greenstone of the Motton Spillite.