

## K-rich Basalt in the Bukit Mersing area, Third Division, Sarawak

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**Abstract:** The basalts exposed near Bukit Mersing, Sarawak are early Eocene in age, and lie conformably over the highly folded, imbricated metasediments of the Rajang Group. Initially thought to be ophiolite, it lies close to the "Tatau-Bukit Mersing Line", which was thought to be a major thrust fault or terrane suture, containing obducted ocean floor material. The one analysis published in 1957 showed a  $K_2O$  value of 2.82%, too high for ocean floor basalt produced at a spreading center. New analyses confirm that K contents in these rocks are high. The K is hosted in K-feldspar rims around plagioclase phenocrysts. Based on the chemistry, and on field relationships, the Tau Range basalt is not ophiolite, but is likely to be Oceanic Island basalt, developed over oceanic crust, caused by short-lived hot spot magmatism.

### INTRODUCTION

The basaltic lavas and tuffs near Bukit Mersing, in Sarawak's Third Division, form the Tau Range, the highest peak of which stands over 3000 meters above the Anap River flood plain. Geological surveys of the upper Rajang River basin carried out in the early 1950s (Wolfendon, 1960; Kirk 1957) included this area.

The presence of the basalts of the Tau Range, and the (mostly silicic) volcanics of the Usun Apau area, both of which lie close to a major regional geologic contact, gave rise to speculation that the contact (referred to as the Tatau-Bukit Mersing Line) was a major thrust fault zone (Hutchison, 1989) or terrane suture and that the Tau Range basalts represent obducted oceanic crust, in other words, ophiolite.

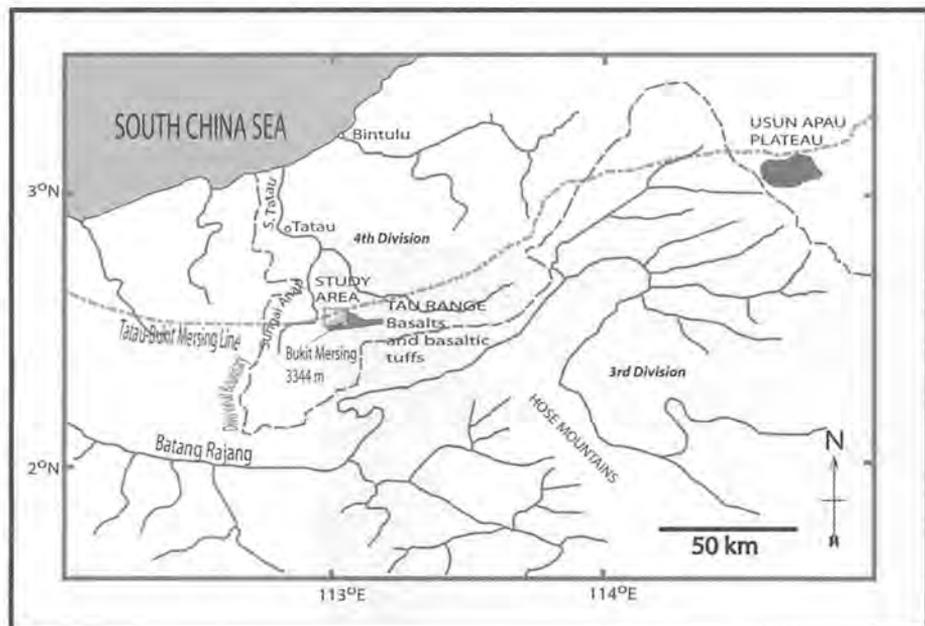
The unusual nature of the basalts was recognized early - initial field surveys reported the presence of nepheline-bearing alkali basalts, which was disproved by later sampling and study (Kirk, 1957). The one available chemical analysis (Table 1) published (Kirk, 1957, 1968) gave a  $K_2O$  value of 2.82%, much higher than what is found in most seafloor basalts.

The remoteness of this area has discouraged further study of the basalts until the present study, although the Sarawak Geological Survey

did collect stream sediments from the area, and a study of the unusual flora and fauna found in the uplands of the Tau Range was apparently conducted some years back (Ling Nan Ley and local residents, personal communications).

### GEOLOGIC SETTING

Based on field relationships (Kirk, 1957), the layers of basaltic lavas and pyroclastics which makes up the Tau Range belong to the uppermost stage of the Belaga



**Figure 1:** Map of the Tatau area, showing the location of the Tau Range and the major rivers (after Kirk, 1957).

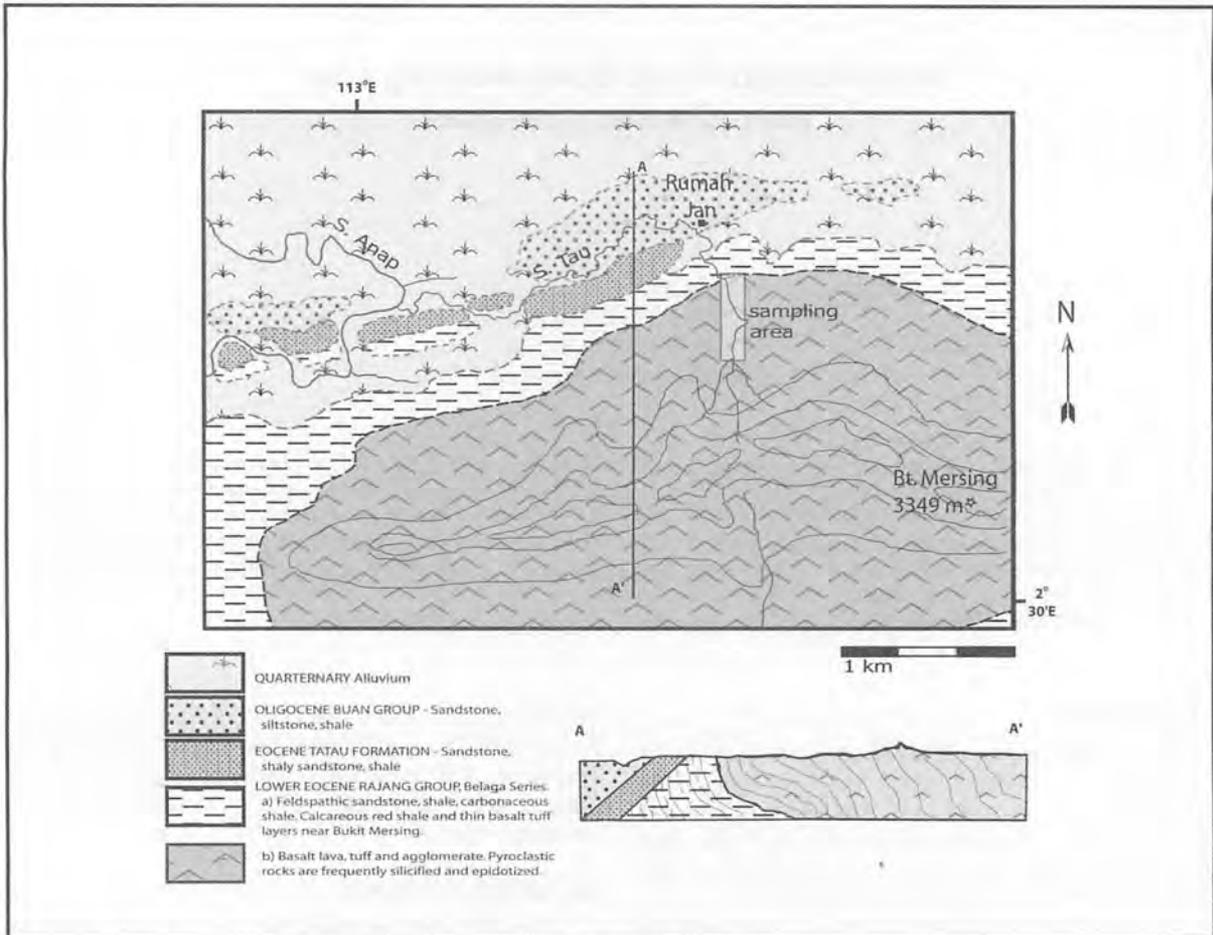


Figure 2: Geologic map of the Bukit Mersing area (after Kirk, 1957).

Formation. They lie conformably atop, and occasionally interbedded with, sand and shale units. The entire package dips almost vertically to the north (figure 2). The basalts are dated Upper Eocene, based on foraminifera found in associated shales.

The Belaga Formation is the uppermost part of the Rajang Group, which are deep marine deposits on oceanic crust, dated early Eocene based on microfossils (Kirk, 1957). The package has been highly compressed, resulting

in tight folds and imbrication as the result of subduction under continental crust to the south during the Miocene. The Tatau formation and units overlying it, and separated from it by a major unconformity, are shallow marine, deposited after the deformation.

Lava pillows exposed in the riverbed (Kirk, 1957, 1968) are evidence that at least some of the lavas were submarine. Columnar jointing was observed in one large river boulder (fig. 3), and this may be evidence (though not conclusive) of subaerial eruption. Tuffs are common, though it is not clear as to whether they are subaerial, submarine (hyaloclastic), or both.

#### SAMPLING, AND ANALYTICAL TECHNIQUES

The objective was to obtain a few samples to confirm the existence of K-rich basalts in the area, rather than to do a detailed geological study. With this in mind, the author sampled the lower reaches of Sungai Tau, up to an elevation of 650 meters. Sampling further upstream would have required setting up camp in the forest overnight, and an extended hike up the river. The Sungai Tau traverse was described in Kirk (1957, page 38). Kirk also described a traverse of Sungai Meniong, a location which was too far to sample, given time constraints, but might be the target for future trips to the area. Access to the general area was difficult, due to the remoteness – four hours by express



Figure 3: Large, columnar jointed basalt boulder in the streambed. Sg. Tau.

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**Table 1:** List of compositions. S3-S10 – Tau Range basalts analyzed for this study. (a) Tau Range basalt analysis published by Kirk (1957,1968). (b) from Bryan and Moore (1971). (c) Average composition from September 1971 eruption of Kilauea, corrected to 13% MgO by addition of olivine (Wright, 1971; quoted in Flower, 1991). (d) Low totals due to water content, samples not analyzed for LOI.

	S3	S4	S5	S6	S7	S8	S9	S10	S 3474 (a)	519-4-1 (N-MORB) (b)	Kilauea parent melt (OIB) (c)
<b>Major Elements (Weight Percent)</b>											
SiO <sub>2</sub>	48.90	48.15	47.65	47.05	52.64	45.43	47.87	49.06	46.57	49.07	48.93
TiO <sub>2</sub>	2.68	3.21	2.72	3.07	2.79	3.56	2.71	3.66	3.03	0.74	2.11
Al <sub>2</sub> O <sub>3</sub>	14.60	13.92	13.87	13.31	13.64	15.92	13.71	15.40	13.08	16.44	11.86
FeO*	12.54	13.40	12.92	14.56	13.97	14.66	13.78	16.36	17.06	8.86	11.49
MnO	0.19	0.20	0.18	0.22	0.16	0.26	0.22	0.20	0.03	0.16	0.18
MgO	5.50	4.56	6.17	5.11	3.59	3.02	5.37	2.60	5.07	10.15	13.20
CaO	10.21	7.28	9.40	9.75	4.70	6.44	9.28	3.88	8.33	11.65	9.67
Na <sub>2</sub> O	0.60	4.45	3.56	2.41	4.74	5.26	3.53	0.59	2.68	2.13	1.96
K <sub>2</sub> O	0.32	1.00	0.62	1.69	0.32	0.25	0.55	3.18	2.82	0.07	0.41
P <sub>2</sub> O <sub>5</sub>	0.35	0.77	0.34	0.40	0.55	1.90	0.40	0.09	0.61	---	0.22
<b>Total (d)</b>	<b>95.88</b>	<b>96.94</b>	<b>97.43</b>	<b>97.58</b>	<b>97.11</b>	<b>96.70</b>	<b>97.43</b>	<b>95.00</b>	<b>99.28</b>	<b>99.27</b>	<b>100.03</b>
Mg Number	0.44	0.38	0.46	0.38	0.31	0.27	0.41	0.22	0.35	0.67	0.67
CaO/Al <sub>2</sub> O <sub>3</sub>	0.70	0.52	0.68	0.73	0.34	0.40	0.68	0.25	0.64	0.71	0.82
Al <sub>2</sub> O <sub>3</sub> /TiO <sub>2</sub>	5.44	4.34	5.10	4.33	4.88	4.47	5.05	4.21	4.32	22.22	5.62
CaO/Na <sub>2</sub> O	17.14	1.63	2.64	4.05	0.99	1.22	2.63	6.62	3.11	5.47	4.93
<b>CIPW norms (weight)</b>											
Qtz	13.78	---	---	---	6.53	---	---	16.44	---	---	---
Plg	41.24	52.64	50.09	40.72	55.1	63.56	49.77	23.65	37.82	53.04	38.86
Or	1.96	6.05	3.81	10.35	1.89	1.55	3.32	19.01	16.68	0.56	2.57
Cor	---	---	---	---	---	---	---	4.11	---	---	---
Diop	9.94	13.2	19.88	20.88	3.92	0.4	19.27	---	18.19	18.23	19.33
Hy	17.43	4.84	4.8	12.01	16.79	4.05	10.12	17.33	5.72	15.68	23.27
OI	---	6.32	7.11	0.37	---	9.38	2.68	---	1.53	6.39	6.34
Ilm	5.09	6.1	5.17	5.83	5.3	6.76	5.15	6.95	5.78	1.41	4.01
Magt	6.06	6.48	6.25	7.03	6.76	7.09	6.67	7.9	11.37	4.28	5.55
Apt	0.81	1.78	0.79	0.93	1.27	4.4	0.93	0.21	1.34	---	0.51
<b>Total</b>	<b>96.31</b>	<b>97.41</b>	<b>97.9</b>	<b>98.12</b>	<b>97.56</b>	<b>97.19</b>	<b>97.91</b>	<b>95.6</b>	<b>98.43</b>	<b>99.59</b>	<b>100.44</b>
<b>Trace Elements (ppm)</b>											
Ni	51	8	66	51	41	43	31	67	---	---	---
Cr	116	35	97	42	88	48	56	87	---	---	---
Sc	32	22	36	37	34	44	39	43	---	---	---
V	336	230	340	381	389	429	420	304	---	1	---
Ba	64	184	208	486	43	65	117	233	---	4	---
Rb	7	20	9	25	6	8	9	88	---	---	---
Sr	305	236	340	195	254	223	331	109	---	---	---
Zr	253	332	196	212	206	291	185	309	---	---	---
Y	50	51	34	38	46	83	37	43	---	---	---
Nb	32.6	48.0	22.9	25.8	19.3	25.3	20.7	26.2	---	---	---
Ga	21	22	20	22	18	26	19	23	---	---	---
Cu	136	30	181	194	69	211	176	245	---	---	---
Zn	122	146	119	134	155	159	128	178	---	---	---
Pb	4	5	2	1	2	3	1	1	---	60	60
La	31	45	25	24	20	36	17	20	---	---	---
Ce	70	92	46	53	53	70	52	63	---	50	135
Th	3	5	2	2	2	1	1	2	---	---	---
Nd	38	55	29	31	33	48	32	32	---	---	---

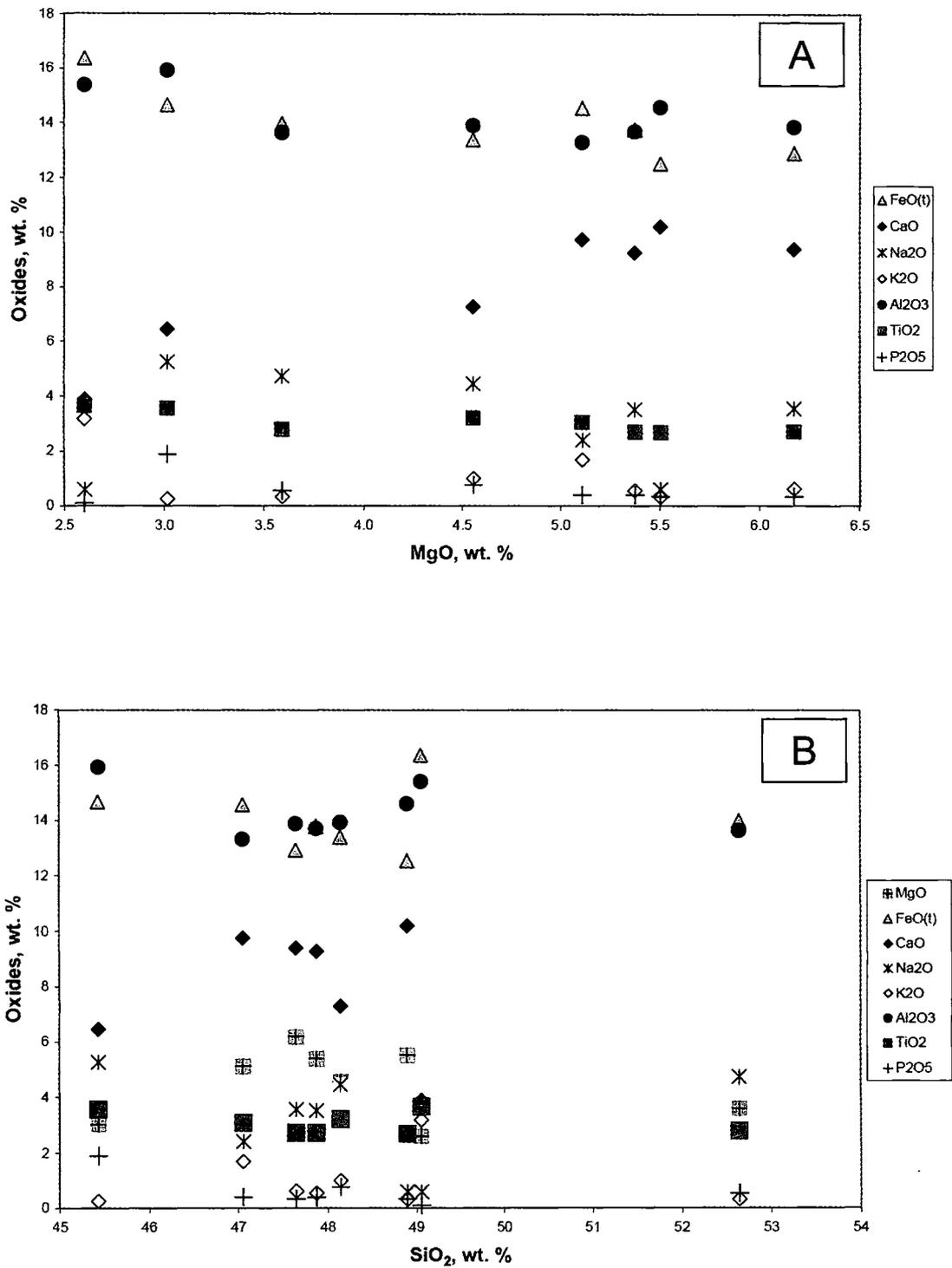
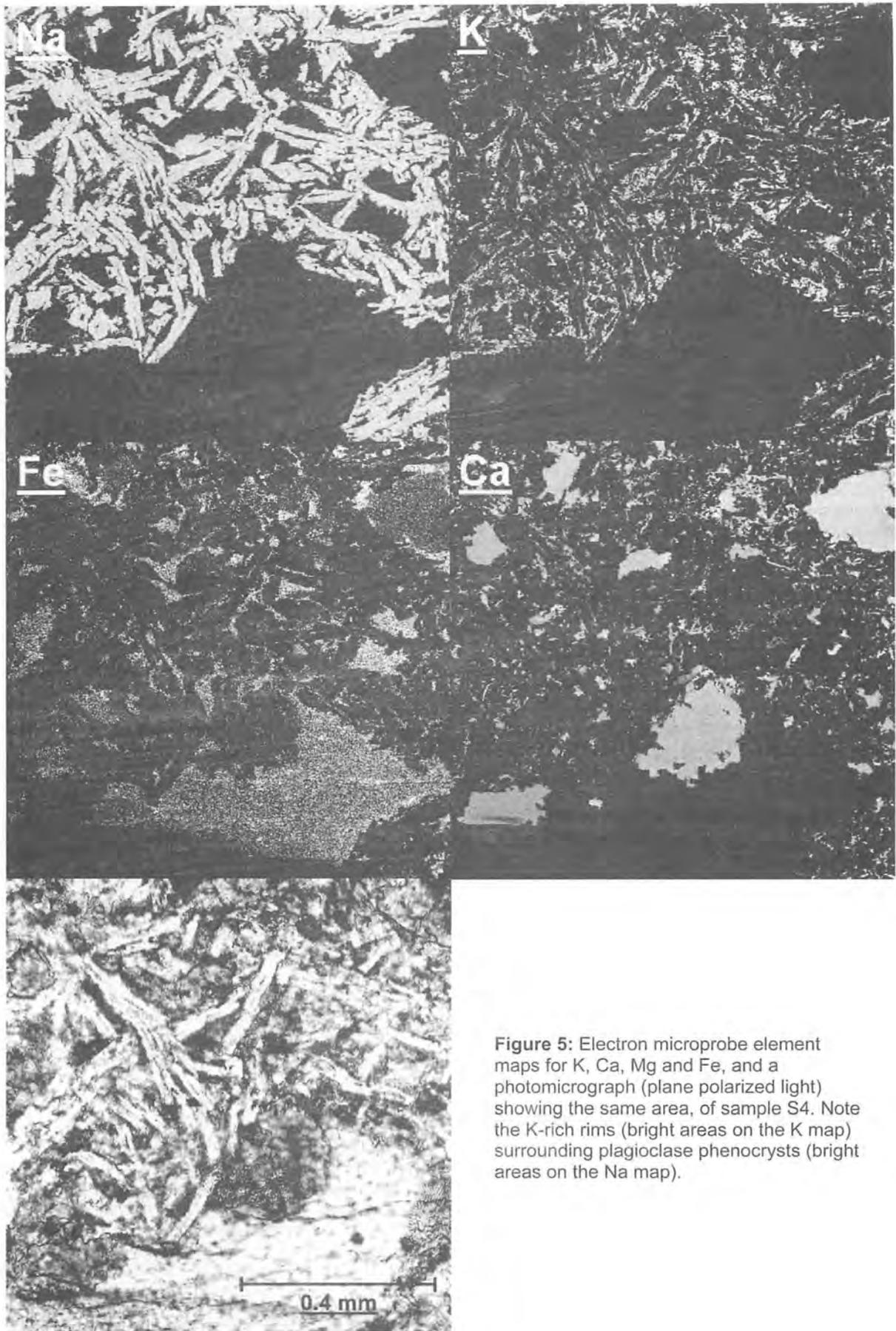
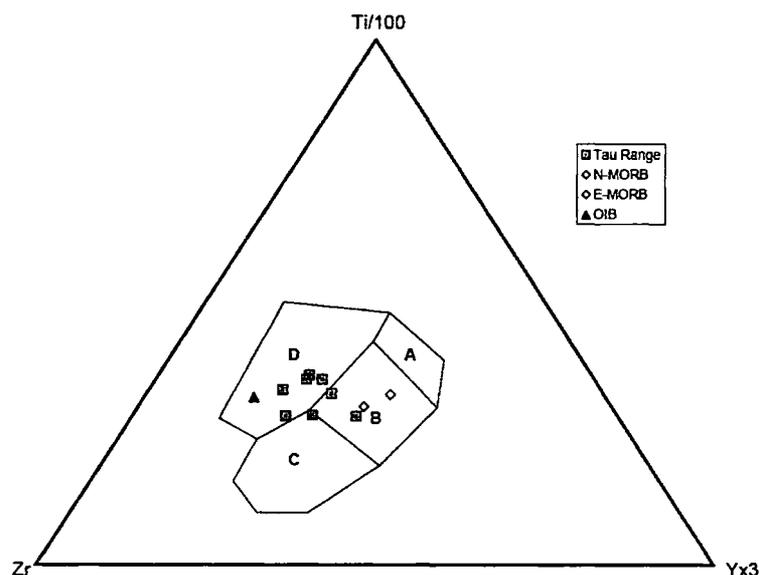


Figure 4: Chemical variation diagrams, vs. MgO (a) and SiO<sub>2</sub> (b)



**Figure 5:** Electron microprobe element maps for K, Ca, Mg and Fe, and a photomicrograph (plane polarized light) showing the same area, of sample S4. Note the K-rich rims (bright areas on the K map) surrounding plagioclase phenocrysts (bright areas on the Na map).



**Figure 6:** Ti-Zr-Y discrimination diagram, after Pearce and Cann, 1973. Fields are: A – island arc tholeiites. B – MORB, island arc tholeiites and calc-alkali basalts. C – calc-alkali basalts. D – intra-plate basalts. N-MORB, E-MORB and OIB values are those given in Sun and McDonough (1989) and compiled in Floyd (1991).

boat from Tatau Bazaar up Sg. Tatau to Rumah Penghulu Jepun, and several hours by longboat to Nanga Tau. From Nanga Tau, it was another hour overland to Rumah Jan, where we stayed for three days during the sampling, which took us 500 meters above the Sg. Tau floodplain, skirting several sets of rapids and waterfalls.

Eight samples were powdered in a tungsten carbide ring-and-puck mill, and were sent to the GeoAnalytical Laboratory at Washington State University for major and trace element analysis, using XRF. Polished thin sections were prepared for petrographic examination, and were also examined using University of Malaya's Cameca SX100 electron microprobe.

## SAMPLE DESCRIPTIONS

All of the samples collected were nominally basalts, containing plagioclase and augite phenocrysts of varying size. Two samples contained sulfides. All of the samples have been altered to varying degrees, with the devitrified groundmass partially altered to chlorite, and some of the mafic minerals to serpentine. S9 was collected from a several meter long, columnar jointed boulder in the river, and was the freshest. S10 was a tuff.

## MAJOR AND TRACE ELEMENT GEOCHEMISTRY

Major and trace element values, as well as CIPW norms, are presented in Table 1. Low major element oxide totals are the result of high water content, with samples not analyzed for Loss On Ignition (LOI) or for water. Before launching into a discussion of chemistry, it should be pointed out that whole rock analyses are generally not considered good representatives of parent magma compositions, since redistribution and sorting of cumulate crystals might have occurred during magma ascent and

during eruption. In addition, these rocks bear all the signs of hydrothermal alteration to various degrees, be it submarine or otherwise. The best samples to use as melt compositions are fresh volcanic glass. In cases where glass is not to be found, however, the use of whole rock data is unavoidable. S10 should be regarded with particular caution, since it is a tuff, tuffs are accidental conglomerations of volcanic clasts, and the chemistry is similarly accidental. In addition, the porous nature of tuffs exposes them to a greater degree of alteration, especially by seawater immediately after deposition.

Variation diagrams vs. MgO and SiO<sub>2</sub> are presented in figs. 4a and 4b. Compared to N-MORB, the Bukit Mersing samples are more "evolved", with SiO<sub>2</sub> contents varying between 45.4 to 52.6%, Al<sub>2</sub>O<sub>3</sub> varying between 13.1 and 15.9% (less than N-MORB). Mg numbers are between 0.22 and 0.46 (compared to 0.67 for N-MORB), and quartz appears in the norm for three samples (one of them, S10, a tuff), while the rest are olivine-normative.

K<sub>2</sub>O is unevenly distributed, ranging between 0.25 and 3.18% (compared to 0.17% for N-MORB). The highest value encountered is in a tuff (sample S10). This should be sufficient to confirm the presence, though not the ubiquity, of high-K basalt compositions like the one published by Kirk (1957).

K is hosted in K-feldspar rims around plagioclase phenocrysts (fig. 5). In basalts, K feldspar is a late-crystallizing phase, and crystallization had not proceeded very far before eruption took place, so the K-rich rims are probably due to post-eruption crystallization, or other processes.

## DISCUSSION

There are several possible explanations for higher than normal concentrations of K in basalts. One is that the parent melts were themselves K-rich. Another is that the rock gains K from seawater over time, as a result of metasomatism. Yet another is that the K is mobile, and has been redistributed through the rock by the circulation of convecting seawater, giving rise to inhomogeneous K content, and high K values in some samples. There may also be a combination of reasons.

Pillow interiors and crusts on the ocean floor do gain K with time – in over 60 million years, pillow interiors can reach up to 1.6% K<sub>2</sub>O (from less than 0.5% initially), while losing much of their Fe. In pillow crusts, this change takes place much more rapidly, reaching 2.5% K<sub>2</sub>O in less than 10 million years (Thompson, 1983). Where deep circulation of oxygenated seawater exists, this effect can extend deep into the subsurface, as observed in DSDP drill hole 417D (Donnelly et al. 1979). Where such circulation does not take place, basalts are relatively unaltered and K values remain low.

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The high K contents of the Tau Range basalts fall within the higher range of values encountered in Oceanic Island Basalts (compiled in Floyd, 1991). OIBs are erupted over oceanic crust, and exhibit a much wider range of compositions than do Mid Ocean Ridge basalts (MORBs). Basalts and alkali basalts from the more potassic island groups (Jan Mayen, Tristan da Cunha, Gough, Heard, Society Islands, and Samoa) show values of up to 4% for rocks containing 2-6% MgO (Gunn, 2006; Georoc, 2006). More evolved members of these oceanic island volcanic suites (trachytes, rather than basalts) can reach 8% K<sub>2</sub>O.

While the samples appear to be altered, they are not altered to the degree to which they have lost a great proportion of their Fe, nor have the plagioclase phenocrysts been altered to much of a degree to clay minerals, which is what one expects if the K<sub>2</sub>O values were entirely metasomatic in origin. In addition, alteration to this degree would have oxidized the sulfides present in some of the samples. This being the case, the overall high K nature of the basalts is probably primary, although redistribution of K by circulating fluids might have occurred, and some of the K may indeed be from seawater. S10, being a tuff, also has the highest K content, and this may be due to its proximity to the surface, as well as its very high initial porosity, and small particle size.

By all indications, the Tau Range basalts do not appear to be the upper part of an obducted ophiolite suite, nor is the Tatau-Bukit Mersing Line a terrane suture. That the basalts are conformable with the underlying Belaga Formation metasediments means that they were deposited on top of the sediments covering the oceanic basement, rather than being themselves part of that basement. The Belaga Formation continues below the Tatau formation, and is exposed as the Tatau "Horst", to the north (Hutchison, 2005). If they are not spreading center basalts which make up the oceanic basement, then they are most likely Oceanic Island Basalts, and their eruption was caused by a short-lived hot spot underlying the then-undeformed oceanic crust and its overlying sediments in the early Eocene. A Zr-Ti-Y discriminant diagram (fig. 6; Pearce and Cann, 1973) puts most of the Tau Range samples squarely in the intraplate basalt field.

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