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The Nan River mafic-ultramafic belt, northern Thailand: Geochemistry and tectonic significance

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Abstract: Reconnaissance mapping of the largest body of the Nan River mafic-ultramafic belt in northern Thailand shows that it consists mainly of metabasalt and metabasaltic andesite flows and tuffs overlying metagabbro transitional into epidote amphibolite. Ultramafic rocks along the southeast side of the body include metahornblendite, metapyroxenite and serpentite lenses within garnet amphibolite. Geochemical studies suggest that the mafic rocks closely resemble calc-alkali basalts formed in a volcanic arc, rather than in an oceanic environment. Lacking oceanic affinities, several essential components, and the systematic stratigraphy of a typical ophiolite suite, this group of mafic-ultramafic rocks, together with other occurrences farther to the southwest, should probably be termed a volcanic arc suite with associated fault-emplaced ultramafic bodies. If this belt does mark the suture between the Shan-Thai and Indosinian cratonic blocks then there was apparently no significant obduction of an intervening oceanic basin onto the Shan-Thai block.

INTRODUCTION

Geological mapping in northern Thailand (Baum *et al*, 1970; German Geological Mission, 1972) defined two belts of mafic and related ultramafic rocks of Late Carboniferous—Early Permian(?) age which were informally described as ophiolites (Baum *et al*, 1970). The western belt in the Chiang Rai—Chiang Mai area, which was subsequently referred to as uncertain ophiolite by Hutchison (1975), is probably a volcanic arc assemblage of basaltic lavas, agglomerates, and tuffs with related pyroxenite and peridotite inclusions and intrusions (Macdonald and Barr, 1978). The eastern belt, exposed in the vicinity of the Nan River between Uttaradit and Nan (Fig. 1), has been more widely accepted as ophiolite, presumably because of more abundant occurrences of ultramafic rocks (with associated chromite and asbestos) and has been referred to as a collision suture in several tectonic analyses (Hutchison, 1975; Mitchell, 1977; Bunopas and Vella, 1978). However, there are very few details available as to the internal geology and petrology of the eastern belt. Occurrences of chromite in peridotite have been described by Suwanasing (undated report) from the northeast side of what is now the Pha Som reservoir behind the Sirikit Dam (Fig. 1), whereas the ultramafic rocks themselves and the country rocks in the same area have been described in a general way by Bunopas (1970). That part of the belt which extends north-northeast from the Pha Som reservoir toward Nan was delineated by the German Geological Mission to Thailand and shown on maps at scales of 1:M (1972) and 1:250,000 (1975) whereas the part extending southwest from the reservoir toward Uttaradit was mapped by the Thai Department of Mineral Resources (Piyasin, 1974). More recent mapping within the latter area has also been done (Thanasuthipitak, 1978), as well as detailed mapping and sampling of the ultramafic bodies on both sides of the Pha Som reservoir (T.Nakpin, 1976, pers. comm.).

This paper reports on reconnaissance mapping and sampling in 1977 of the largest body of the eastern belt exposed along the Nan River above the Pha Som reservoir

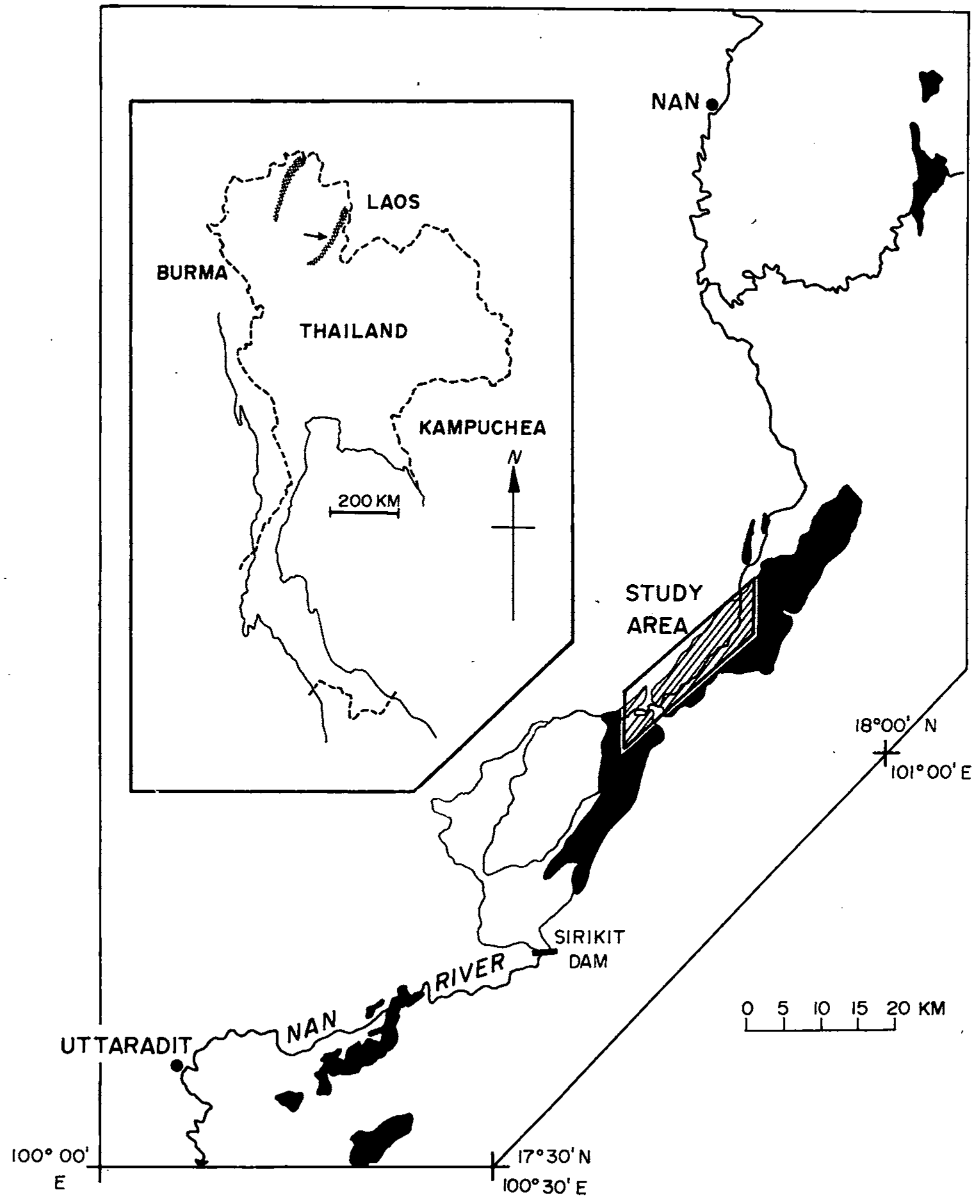


Fig. 1. Distribution of the Nan River mafic-ultramafic belt in northern Thailand, compiled from 1:250,000 map sheets of Uttaradit (Piyasin, 1974) and Nan (German Geological Mission, 1975). Inset map of Thailand shows locations of Nan River belt (arrowed) and of Chiang Rai—Chiang Mai belt farther to the west.

(Fig. 1) and presents the results and implications of petrological and geochemical studies which may contribute to understanding the internal geology of the belt and assist in future tectonic analyses of the region.

FIELD RELATIONS

Rocks of the Nan River belt are exposed intermittently along the core of what appears to be a major anticlinal structure extending approximately 100 km in a northeast-trending arc, essentially sandwiched between Late Paleozoic and Mesozoic basins to the west and east respectively (Fig. 1). It is not clear what contribution faulting makes to the distribution of the belt; faults trending northeast and north-northeast are shown on the 1:250,000 map (German Geological Mission, 1975) but none is shown as a major bounding fault. However, Bunopas (1970) did report faulted contacts between ultramafic rocks and adjacent phyllite and greenschist.

The large mafic-ultramafic body examined in this study is unconformably overlain on both northwest and southeast sides by limestone, followed conformably by a sequence of phyllite shales, sandstone, and minor conglomerate. This sedimentary sequence is assumed to be of Permo-Carboniferous(?) age, as shown on the 1:250,000 Nan map sheet (German Geological Mission, 1975). Other younger Mesozoic clastic rocks are shown on the same map to overstep both the mafic-ultramafic body and the late Paleozoic cover but these rocks were not examined as part of this study. The only rocks of sedimentary origin identified within the mafic-ultramafic body itself are dark grey, banded phyllites and black slaty argillites occurring locally along the southeast margin in close (faulted?) contact with ultramafic units.

The bulk of the body consists of mafic meta-igneous rocks, including metagabbro, amphibolite, and metabasaltic flows, tuffs and dykes, together with minor amounts of ultramafic meta-igneous rocks such as serpentinite, metahornblendite and metapyroxenite. Due to the reconnaissance nature of this study, only the broad distribution pattern of these various rock types was established (Fig. 2).

Massive metagabbro grading into foliated amphibolite forms the core of the body which is apparently overlain to the northeast and southwest by the mafic metavolcanic rocks; no contacts between these units were observed. However, metabasaltic dykes, which are petrographically and chemically indistinguishable from the mafic metavolcanic rocks, cut metagabbro and amphibolite implying that the metavolcanic rocks are, at least in part, younger than the metagabbro-amphibolite infrastructure. The ultramafic rocks were observed at two localities only, both on the southeast margin of the body, forming possibly fault-bounded silvers or pods. This overall distribution of the various units within the mafic-ultramafic body could be explained as a doubly-plunging anticlinal structure, faulted along its overturned southeastern side (see cross-sections on Fig. 2). All of the rocks have been moderately to strongly deformed, with compositional banding and foliation everywhere striking northeast and dipping moderately to steeply northwest, and the common occurrence of the assemblage albite-hornblende-epidote-chlorite in all of the mafic rock units (see below) indicates that they have also undergone greenschist facies metamorphism.

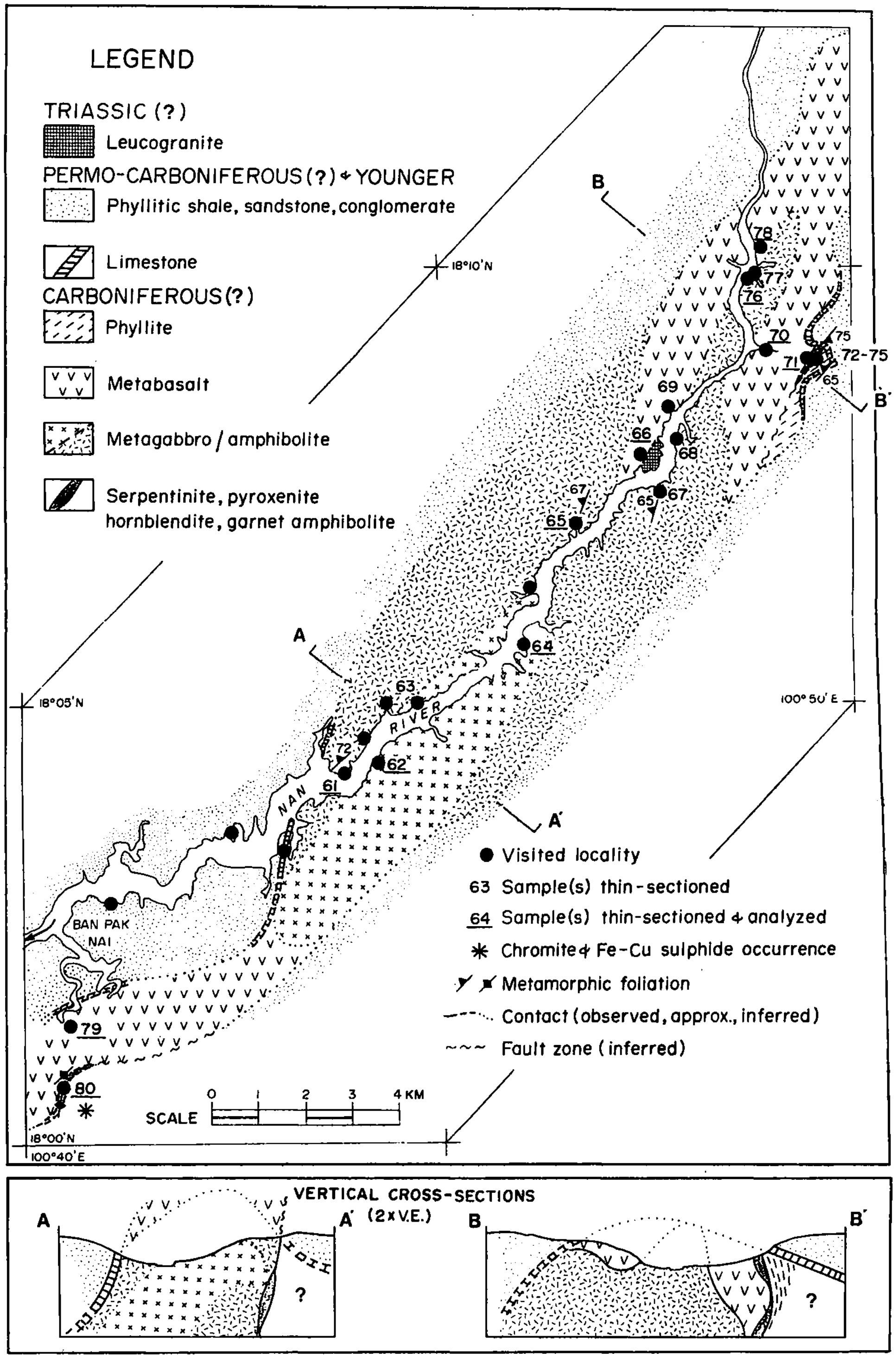


Fig. 2. Geological map and cross-sections of Ban Pak Nai area of the Nan River mafic-ultramafic belt.

PETROGRAPHY

Metagabbros

Metagabbros are associated both with epidote amphibolites and locally with the ultramafic rocks on the southeast side of the body. The metagabbros associated with epidote amphibolites are relatively uniform, massive medium- to coarse-grained grey-green rocks possessing weak inhomogeneously developed foliation and local thin shear zones. Although the original igneous textures largely survive, there is extensive alteration of the primary minerals: (i) the cores of plagioclases are intensely altered to sericite + epidote ± chlorite, whereas the rims are formed of clear albitic plagioclase; (ii) clinopyroxenes are usually rimmed by amphibole. Interstitial to these altered primary minerals are fresh subhedral albitic plagioclase, amphibole, epidote, chlorite and quartz, plus accessory opaque phase(s) and apatite. Shear zones are marked by development of sericite with lesser quartz and calcite. Electron microprobe study (Table 1) of the clinopyroxene and amphibole showed them to be diopsidic augite and ferro-tschermakitic hornblende (Leake, 1978) respectively.

Contrasting with these metagabbros is a hornblende metagabbro which is associated with the ultramafic rocks of the body. This is a very coarse-grained, highly deformed and altered gabbro whose primary mineralogy appears to have been plagioclase and amphibole; the former now extremely turbid and the latter veined and rimmed by chlorite, and the whole cut across by veinlets of calcite and chert. It closely resembles the metahornblendite (described below) and probably represents a minor facies of that ultramafic unit.

Epidote Amphibolites

The epidote amphibolites are typically medium-grained, grey-green banded and(or) foliated inhomogeneous rocks. Textures, in fact, range from fine- to coarse-grained and composition too, particularly in the more banded varieties, varies from ultramafic through to intermediate. Adding to the inhomogeneous character are local occurrences of very coarse pegmatoid amphibolite and of medium-grained epidosite.

The typical epidote amphibolites consist of subhedral to granoblastic amphibole, turbid or sericitized plagioclase, epidote, chlorite, quartz together with accessory sphene, apatite and oxidized opaque phases(s). They are commonly cut by thin shear zones with sericite and calcite, and by late veinlets of quartz and(or) calcite. Electron microprobe study (Table 1) showed the amphibole to be magnesio-hornblende (Leake, 1978).

Although there is believed to be a transition from pyroxene metagabbro into epidote amphibolite, this could nowhere be observed on the scale of a single outcrop.

Metabasalt flows, tuffs and dykes

The metabasaltic rocks which cut and apparently overlie the metagabbroic-amphibolitic core of the body are mineralogically relatively uniform, although obviously texturally varied. Extrusive representatives make up the bulk of these rocks and include flows, lithic tuffs and rare volcaniclastic(?) breccias. The dykes were recognized only locally intruded into both metagabbro and epidote amphibolite.

TABLE 1

REPRESENTATIVE MINERAL ANALYSES FROM NAN RIVER MAFIC AND ULTRAMAFIC ROCKS.

	PYROXENE					AMPHIBOLE				PLAGIOCLASE		GARNET
Sample #	62–1	64	70	79	80–7	62–1	64	65–1	71–1	64	79	71–1
	Metagabbro		Metabasaltic Rocks		Pyroxenite	Metagabbro		Epidote Amphibolite	Garnet Amphibolite	Metagabbro	Metabasalt	Garnet Amphibolite
SiO_2	50.75	50.11	51.50	52.85	50.64	42.01	43.03	46.55	49.12	66.56	65.73	39.49
TiO_2	0.43	0.38	0.44	0.51	0.21	1.52	1.35	0.62	0.59	0.00	0.09	0.00
Al_2O_3	3.48	3.62	4.20	2.62	3.16	11.39	10.76	10.41	9.99	21.18	20.12	22.15
Cr_2O_3	0.10	0.15	0.21	0.95	1.04	0.00	0.00	0.00	0.09	0.00	0.00	0.06
FeO	8.80	11.22	8.04	6.60	5.02	20.53	19.83	15.07	12.07	0.06	2.08	24.23
MnO	0.25	0.27	0.20	0.18	0.11	0.39	0.28	0.30	0.06	0.00	0.00	1.31
MgO	14.30	14.24	15.24	16.75	16.85	8.77	9.23	11.84	13.98	0.00	0.38	7.89
CaO	21.85	19.66	21.16	21.00	22.21	10.27	10.85	12.27	12.37	2.12	1.64	6.30
Na_2O	0.13	0.17	0.13	0.34	0.00	2.02	1.96	0.98	0.76	10.51	10.60	0.00
K_2O	0.00	0.00	0.00	0.00	0.00	0.95	0.91	0.00	0.00	0.32	0.18	0.00
H_2O	0.00	0.00	0.00	0.00	0.00	1.96	1.98	2.05	2.11	0.00	0.00	0.00
Total	100.09	99.82	101.12	101.80	99.24	99.81	100.18	100.09	101.14	100.70	100.82	101.43
0	6	6	6	6	6	24	24	24	24	32	32	24
Si_{IV}	1.893	1.886	1.887	1.914	1.880	6.417	6.520	6.818	6.979	11.621	11.581	5.997
AL_{VI}	0.107	0.114	0.113	0.086	0.120	1.583	1.480	1.182	1.021	4.357	4.177	3.966
AL	0.046	10.046	0.068	0.026	0.018	0.467	0.441	0.614	0.652	0.000	0.000	0.000
Ti	0.012	0.011	0.012	0.014	0.006	0.175	0.154	0.068	0.063	0.000	0.000	0.000
Cr	0.003	0.004	0.006	0.027	0.031	0.000	0.000	0.000	0.010	0.000	0.000	0.000
Fe	0.275	0.353	0.246	0.200	0.156	1.997	2.084	2.585	2.961	0.009	0.306	3.077
Mn	0.008	0.009	0.006	0.006	0.003	2.622	2.513	1.846	1.434	0.000	0.000	0.169
Mg	0.795	0.799	0.832	0.904	0.932	0.050	0.036	0.037	0.007	0.000	0.100	1.786
Ca	0.873	0.793	0.831	0.815	0.883	1.681	1.761	1.925	1.883	0.397	0.310	1.025
Na	0.009	0.012	0.009	0.024	0.000	0,598	0.576	0.278	0.209	3.558	3.621	0.000
K	0.000	0.000	0.000	0.000	0.000	0.185	0.176	0.000	0.000	0.071	0.040	0.000
	Wo 44.9	40.8	43.5	42.5	44.8					Or 1.8	1.0	Alm 50.8
	En 40.9	41.1	43.6	47.1	47.3	$\frac{Mg}{(Fe+Mg)}$ 0.42	0.46	0.58	0.67	Ab 88.4	91.2	Spess 2.8
	Fs 14.2	18.1	12.9	10.4	7.9					An 9.8	7.8	Pyr 29.5
												Gross 16.9

Primary igneous textures largely survive in most of the samples with both porphyritic and non-porphyritic intersertal to intergranular textures being most common, although flow-aligned laths and vesicles/amygdales can still be recognized within some lapilli of the lithic tuffs. In the porphyritic varieties, the phenocrysts are of (i) plagioclase, either strongly saussuritized or fresh albitic, and (ii) less abundant augite more-or-less altered to amphibole and(or) epidote. The groundmass of these rocks, and the non-porphyritic varieties as a whole consist of plagioclase, amphibole, epidote, chlorite, and calcite, with or without quartz and zoisite, usually in modified intersertal to intergranular arrangements, or less commonly in recrystallized granoblastic textures (although in these cases porphyritic textures are not obliterated).

Ultramafic Rocks

The ultramafic rocks found along the southeast side of the body consist of metahornblendite and metapyroxenite occurring as bands and lenses within more abundant serpentinite and garnet amphibolite. All are highly deformed and display cataclastic textures superimposed upon both the primary and secondary (metamorphic) minerals.

The metahornblendite and metapyroxenite are both very coarse-grained greenish rocks: (i) the former consisting of coarse, strained amphibole with interstitial chlorite, sericite and quartz together with accessory sphene and opaque phase(s), and (ii) the latter consisting of coarse strained diopside (Table 1) with interstitial serpentine.

The serpentinites vary from foliated serpentine-talc-calcite to serpentine-amphibole-epidote-talc assemblages which locally contain minor concentrations of asbestos veinlets and disseminated chromite. South of Ban Pak Nai (Fig. 2), chromite-rich and sulphide-rich float samples were collected in the vicinity of serpentinite outcrops. One sample of metapyroxenite (#80–7), collected from outcrop in this area, was found to contain 2700 ppm Cr. The sulphide float material when polished was seen to consist of a foliated mass of highly elongate to granoblastic pyrrhotite containing abundant augen and vein-like masses of chalcopyrite, and fractured irregular masses and grains of magnetite (commonly with "emulsion" blebs of chalcopyrite). Pyrite is limited to occasional small grains within chalcopyrite and rims on pyrrhotite where in contact with magnetite.

Garnet amphibolite, which hosts metahornblendite and serpentinite bands and lenses in the more northeasterly of the ultramafic occurrences, is a distinctive porphyroblastic gneissic rock containing large garnets (± 1 cm) set in a crudely foliated matrix of amphibole, chlorite, and highly altered plagioclase(?). Electron imcroprobe study (Table 1) showed the garnet to be almandine, and the amphibole to be magnesio-hornblende (Leake, 1978).

GEOCHEMISTRY

The results of chemical analyses of 14 samples of mafic and ultramatic rocks are presented in Table 2, grouped according to rock type. Although some degree of alteration is reflected in the variable ferric: ferrous iron ratios and in the relatively high losses-on-ignition, the alkali values largely fall within the range for unaltered igneous rocks (Fig. 3).

TABLE 2

WHOLE-ROCK CHEMICAL ANALYSIES* OF NAN RIVER MAFIC AND ULTRAMAFIC ROCKS.

Sample #	Metabasaltic Rocks					Metagabbro			Epitode Amphibolite			Garnet Amphibolite	Hornblendite	Pyroxenite
	66	70	76–1	78	79	62–1	63–1	64	65–1	61–3	61–5	71–1	71–2	80–7
SiO_2	49.89	48.96	48.72	52.85	48.38	48.90	48.78	47.93	46.63	48.29	48.32	44.88	51.49	47.94
TiO_2	1.43	0.64	0.65	0.89	2.03	0.76	0.81	0.93	0.46	0.65	0.67	0.68	0.48	0.19
Al_20_{3T}	14.58	17.74	19.16	13.47	16.03	18.65	18.19	17.19	18.10	17.46	22.51	19.45	7.86	3.95
Fe_2O_3	10.90	10.00	10.13	11.56	12.97	11.10	11.26	12.40	11.64	11.04	3.62	10.74	12.21	7.09
FeO	7.12	7.35	6.96	6.81	9.29	5.92	6.63	7.42	8.14	6.63	2.13	7.71	8.96	4.88
MgO	5.66	6.31	6.32	3.46	5.43	4.06	4.18	4.58	7.42	5.54	3.91	7.62	15.77	20.54
MnO	0.19	0.15	0.19	0.21	0.18	0.18	0.19	0.19	0.22	0.21	0.11	0.19	0.21	0.14
CaO	11.71	10.07	9.42	8.53	6.55	10.34	11.11	11.39	11.73	11.36	16.60	13.05	9.89	17.42
Na_2O	1.99	1.77	2.98	2.84	4.26	2.74	2.43	2.20	1.95	2.84	2.16	1.43	0.50	0.07
K_2O	0.06	0.36	0.64	0.07	0.46	1.02	0.97	1.14	0.14	0.15	0.10	0.05	0.04	0.01
P_2O_5	0.18	0.06	0.07	0.15	0.24	0.27	0.25	0.25	0.04	0.08	0.03	0.03	0.03	0.00
LOI	3.18	3.53	1.75	4.74	3.48	2.20	2.18	1.94	2.07	2.74	2.71	1.95	1.59	3.55
Total	99.77	99.59	99.91	98.77	100.01	100.22	100.35	100.14	100.40	100.36	100.64	100.07	99.98	100.90
Trace Element Data (ppm)														
Rb	4	10	18	7	23	25	25	30	9	8	8	7	2	2
Sr	381	292	318	423	579	687	618	649	356	360	484	502	64	18
Nb	8	5	5	6	13	7	7	7	5	5	5	5	4	4
Y	48	48	18	20	22	31	16	23	18	14	18	25	18	10
Zr	114	44	34	81	160	77	78	76	23	25	30	31	7	4
Ni	47	37	34	10	102	25	20	20	10	21	14	45	110	195
Pb	11	8	5	9	9	8	9	7	9	9	10	7	4	4
Zn	88	72	46	109	161	83	84	84	80	82	24	67	81	30
Co	41	44	49	35	51	55	44	44	44	43	21	43	75	60
Cr	56	30	39	23	100	14	10	17	20	15	22	83	340	2700
Cu	72	59	15	204	56	266	266	305	54	131	10	53	170	258

*Major element and Cu, Pb, Zn analyses done by atomic absorption spectrometry at Acadia University by J. Cabilio. Other elements analysed commercially by CLIM Laboratories, Halifax, N.S.l

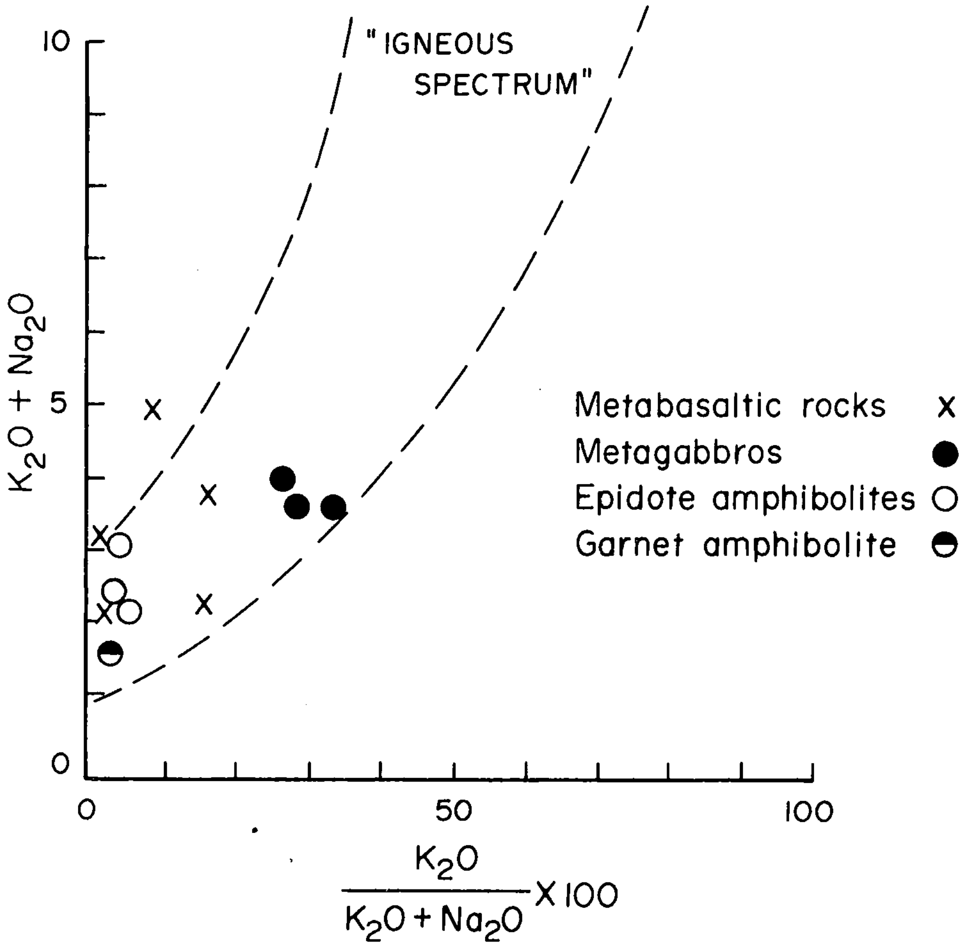


Fig. 3. Plot of alkalic parameters for mafic rocks from Nan River. Boundaries of "igneous spectrum" from Hughes (1972).

When silica values are recalculated on a volatile-free basis, the total range is found to be 46–57 % SiO_2 with most samples having 49–50 % SiO_2. Of the mafic rocks, the basaltic flows, tuffs and dykes show the widest range of silica contents and chemically at least appear to be basalts and basaltic andesites, whereas the gabbros and amphibolites are more compositionally restricted. In terms of their overall major element chemistry, the basaltic rocks closely resemble the gabbros but the amphibolites have distinctly lower TiO_2, K_2O and P_2O_5 values, in spite of field and petrographic evidence which suggest that gabbro was the protolith for the amphibolites.

The tectonic setting or environment in which these rocks were generated can perhaps best be determined from the abundances of those elements, such as Ti, Cr, Zr, Y, Sr, and Nb, which are considered to be relatively immobile during alteration and

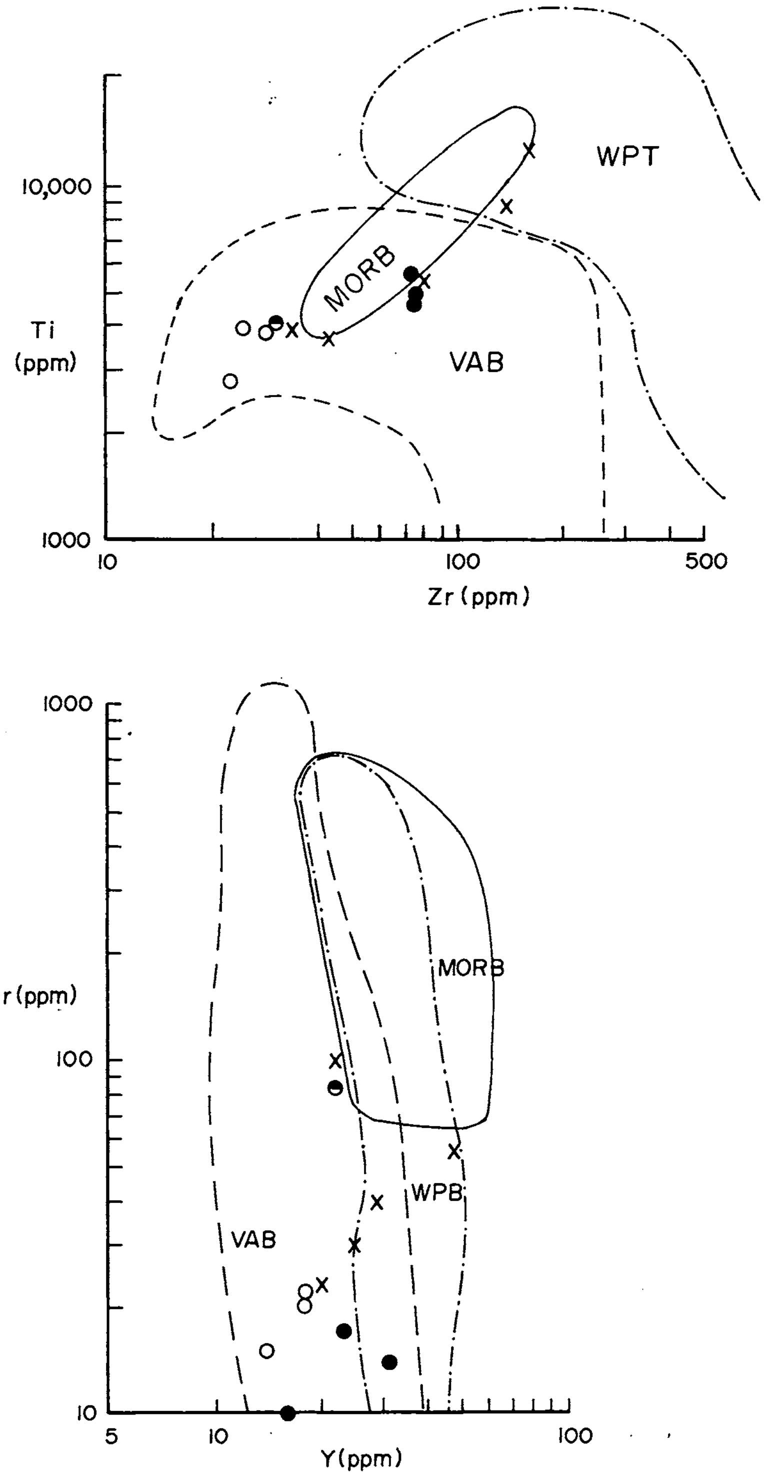
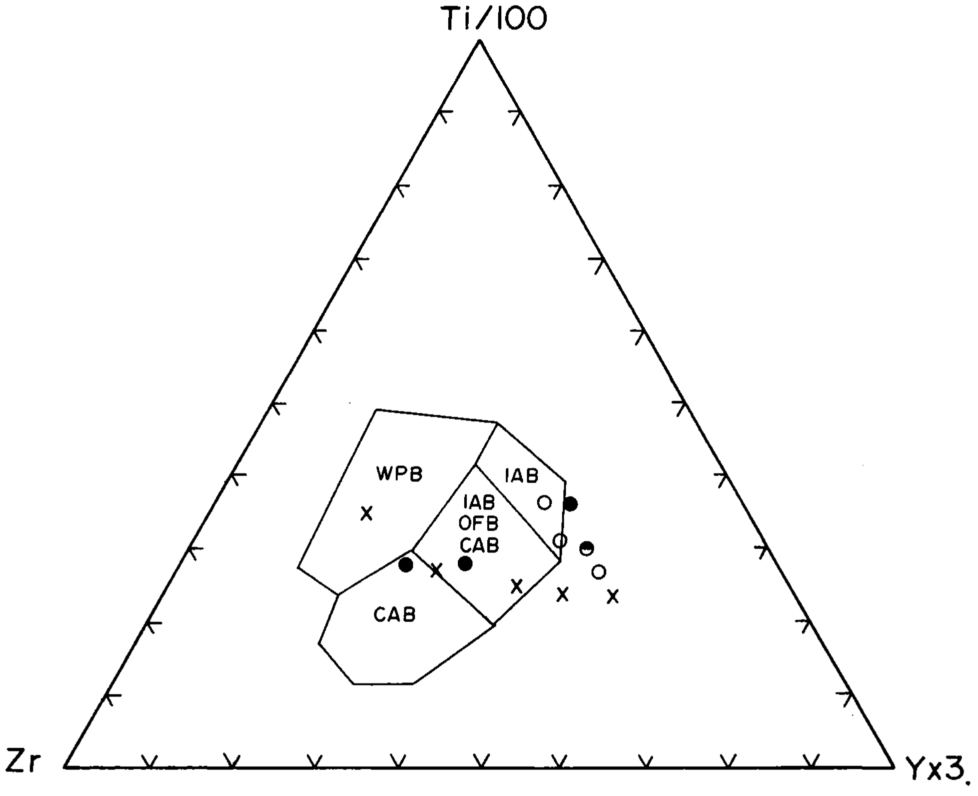


Fig. 4. Mafic rocks from Nan River plotted on (a) Ti-Zr and (b) Cr-Y discrimination diagrams (Pearce, 1982). Symbols as in Figure 3.



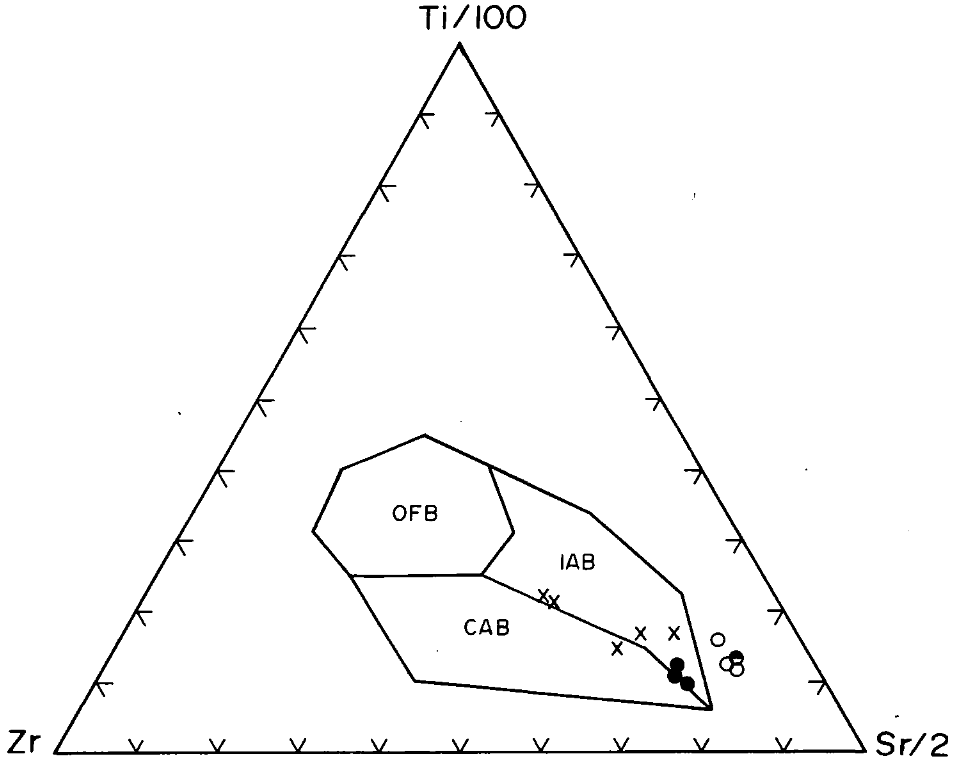


Fig. 5. Mafic rocks from Nan River plotted on (a) Ti-Zr-Y and (b) Ti-Zr-Sr discrimination diagrams (Pearce and Cann, 1973). Symbols as in Figure 3.

metamorphism (e.g. Pearce and Cann, 1973). On Ti-Zr and Cr-Y plots (Pearce, 1982), most of the mafic rocks fall in the field for volcanic arc basalts (Figs. 4a, 4b). The ternary plot Ti-Zr-Y (Fig. 5a) is less convincing due to overlapping fields and a wide scatter of sample points apparently caused by the relatively wide range of Y values (minimized on the Cr-Y plot which uses log scales). However, on a Ti-Zr-Sr plot (Fig. 5b) the mafic rocks all plot close to the boundary between island arc tholeiites and calc-alkaline basalts; the strongly linear distribution of sample points suggests that significant Sr enrichment has occurred, presumably with increasing metamorphic grade, but there is nothing to suggest that these rocks were ever ocean-floor basalts. Some inconclusive evidence for origin in a volcanic arc is also provided by pyroxene compositions from these rocks (Table 1), with 4 out of 5 analyzed samples plotting in the overlapping area between the fields for volcanic arc basalts and ocean-floor basalts (Fig. 6).

When the average trace element abundances for each group of mafic rocks are normalized and plotted against mid-ocean ridge basalt (Pearce, 1982) the patterns clearly show that these rocks have no oceanic affinities; they plot very close to patterns for volcanic arc basalts (Fig. 7). The metabasalts and metagabbros plot closest to average calc-alkali basalt, while the amphibolites although somewhat similar appear to

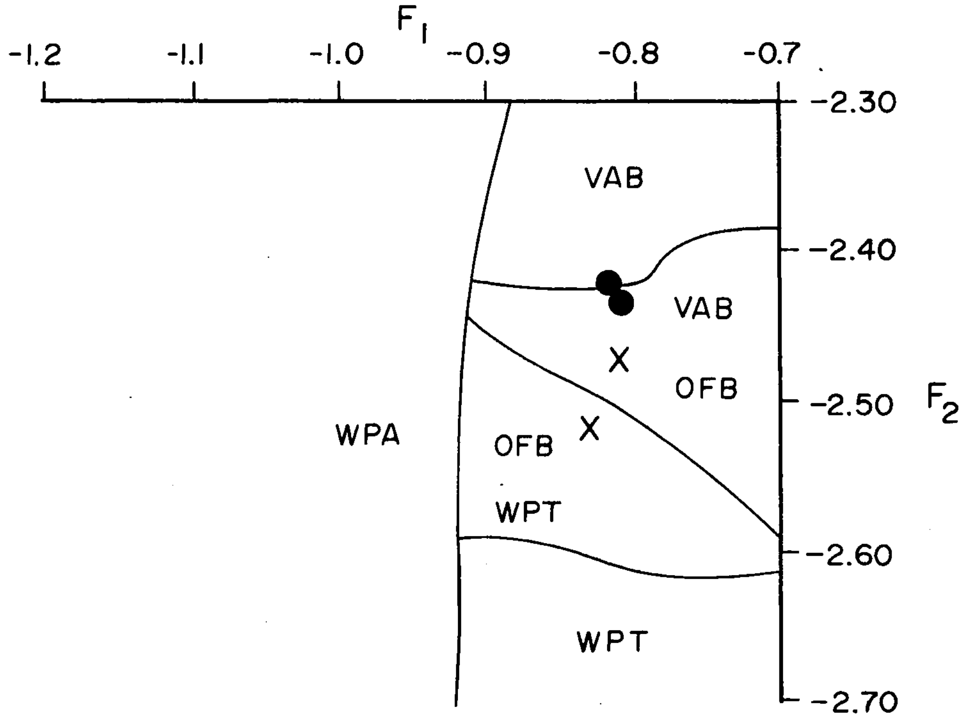


Fig. 6. Pyroxene compositions from selected mafic rocks (symbols as in Figure 3) plotted on the discriminant function diagram of Nisbet and Pearce (1977).

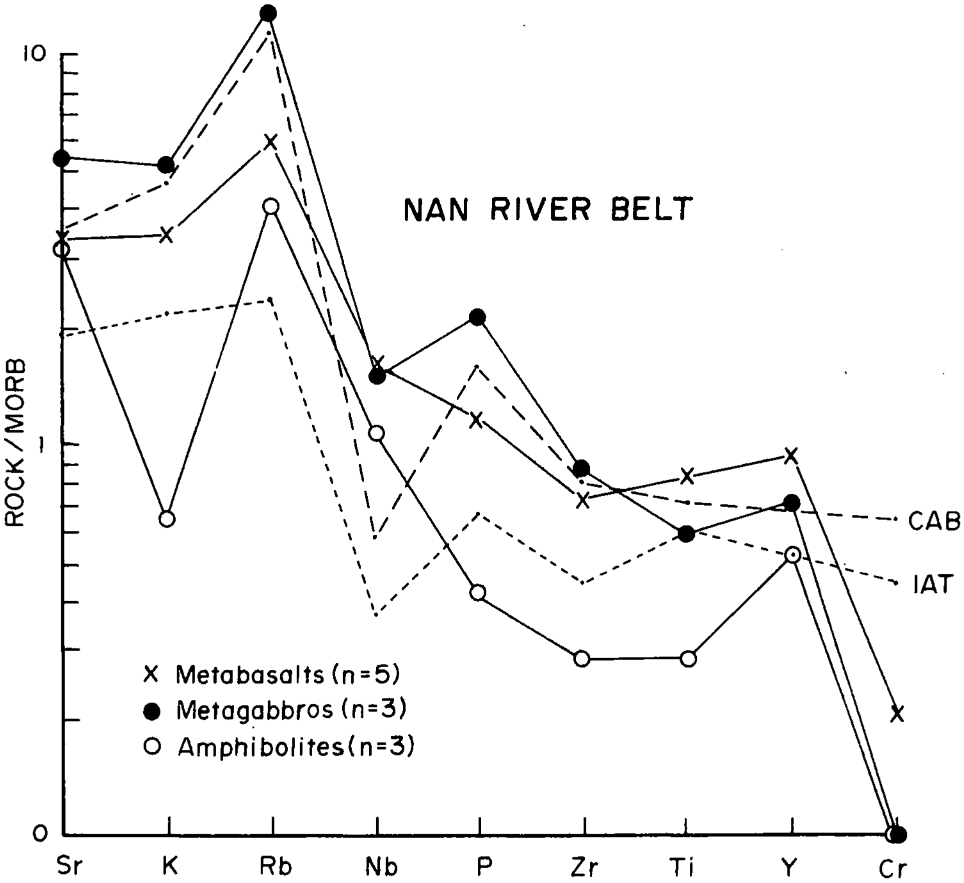


Fig. 7. Average trace element abundances of mafic rocks from Nan River normalized against mid-ocean ridge basalt and compared to calc-alkali basalt and island arc tholeiite (Pearce, 1982).

be depleted in K, P, Zr and Ti. All three groups of mafic rocks are also apparently depleted in Cr.

DISCUSSION

That part of the Nan River belt examined in this study consists mainly of a metamorphosed sequence of basalts and basaltic andesites overlying a gabbroic infrastructure (the protolith of the metagabbro-epidote amphibolite package). Ultramafic units are present but they are apparently restricted to the southeast side of the belt where serpentinites together with metapyroxenite and metahornblendite are associated with garnet amphibolite; their distribution is probably fault controlled.

Typical ophiolite sequences are generally considered to consist of basal peridotite overlain successively by cumulate ultarmafites and gabbro, sheeted sill/dyke complex, pillow basalts and oceanic sedimentary rocks (Penrose Conference, 1972). Metamorphic units commonly underlie the tectonized bases of such ophiolites and are postulated to have developed during overthrusting (obduction) by the ophiolite slab (e.g. Malpas, 1979). While this part of the Nan River belt does contain a number of these components, the apparent absence of sheeted sill/dyke complex and pillowed basalts, and of any systematic stratigraphic relationship between the mafic and ultramafic components, suggest that the belt is dismembered and(or) atypical. In particular, the ultramafic rocks which occur in small lenses or silvers have more of the form of fault-controlled, ultramafic bodies than of an infrastructure to the mafic rocks (Fig. 2).

Outside of the study area, the same general situation appears to exist: northeast of the Sirikit Dam, small chromite-bearing dunite bodies and locally asbestiform serpentinite lenses occur within epidote amphibolites (Bunopas, 1970; pers. obs. by authors, 1976), whereas to the southwest of the dam, the belt consists of pyroxenite and serpentinite associated with amphibolites and (meta) andesites (Thanasuthipitak, 1978).

Petrochemically, the mafic rocks appear to have closer affinities with a volcanic arc setting than with ocean-floor as might be anticipated for a typical ophiolite sequence and as previously proposed for this belt (Hutchison, 1975; Bunopas and Vella, 1978; Thanasuthipitak, 1978). They most closely resemble calc-alkali basalts, although the epidote amphibolites in particular are depleted in K, P, Zr, and Ti.

In general character, the Nan River belt resembles its counterpart some 90 km farther to the west, the Chiang Rai—Chiang Mai belt (Fig. 1), except that the latter (i) has more tuffaceous and agglomeratic units, (ii) lacks occurrences of dunite and serpentinite, and (iii) has not been so strongly metamorphosed (Macdonald and Barr, 1978). The mafic rocks from that belt were considered to be volcanic arc basalts, basaltic andesites and their intrusive equivalents, probably tholeiitic in composition rather than calc-alkaline (Macdonald and Barr, 1978). However, closer inspection of trace and minor element data suggests that these rocks are relatively enriched in Nb, Zr, Ti, Ce and Ti (but not in K) over normal volcanic arc basalts (Fig. 8), and so they are possible transitional toward more alkaline rocks. Presumably the Chiang Rai—Chiang Mai belt represents more distal activity in relation to the Permo-Carboniferous volcanic arc-trench complex than does the Nan River belt. This would agree with the generally accepted model of subduction westward under the Shan-Thai cratonic block (e.g. Bunopas and Vella, 1978).

The lack of any detectable oceanic character in the mafic rocks of the Nan River belt and of typical ophiolitic features does not prelude this belt from marking the suture between the Shan-Thai and Indosinian cratonic blocks (Hutchison, 1975; Bunopas and Vella, 1978) but it does imply that significant obduction was not involved and hence perhaps that convergence between these blocks was oblique. Alternatively, the suture could be located farther east beneath the cover of Mesozoic rocks. In either case, there is no direct record, yet proven, of the ocean basin which presumably existed between these cratonic blocks.

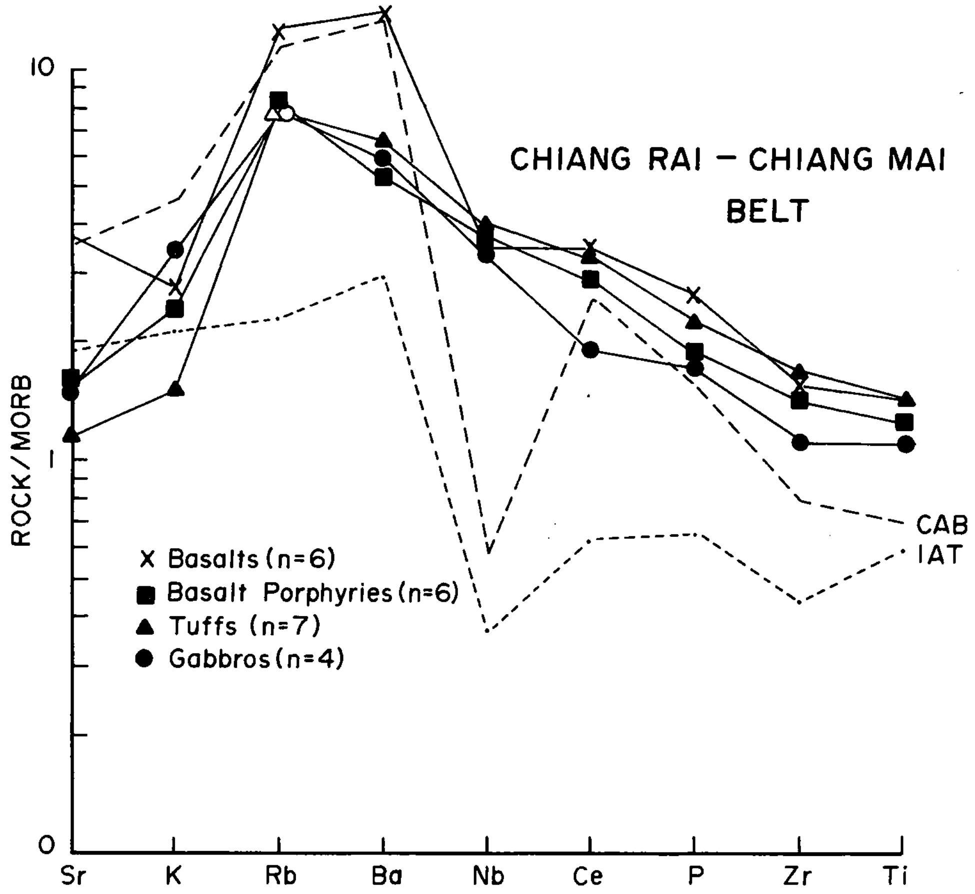


Fig. 8. Average trace element abundances of mafic rocks from Chiang Rai—Chiang Mai belt normalized against mid-ocean ridge basalt and compared to calc-alkali basalt and island arc tholeiite (Pearce, 1982).

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