

# HEAVY METALS COMPOSITION OF SOME SOILS DEVELOPED FROM BASIC AND ULTRABASIC ROCKS IN MALAYSIA

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**ABSTRACT.** Topsoil samples developed on basalt parent material are widely exposed in Segamat, Johor and Kuantan, Pahang, whereas topsoil samples developed from serpentinite parent material widely exposed in Telupid and Ranau, Sabah. The topsoil samples were analysed for Co, Cr, Cu, Pb, Ni and Zn content. The values were compared to the 'threshold concentrations' which indicate the permissible level of heavy metal concentration in soils. Serpentinite soils contain heavy metal concentrations which are significantly higher than the permissible level, whereas basalt soils contain heavy metal concentrations which are not significantly different from the permissible level. Based on the heavy metal contents it is suggested that serpentinite soil is generally unsuitable for agricultural activity whereas the basalt soil is marginally suitable.

## INTRODUCTION

Outcrops of basic igneous rock in Peninsula Malaysia can be found at Kuantan, Pahang; and at Segamat, Johor. Ultrabasic igneous rocks outcrop in many areas in Sabah, for example around Telupid and Ranau (Figs. 1, 2, 3 & 4). The weathering profile of the rocks consist of the subsoil and topsoil. Soil is the medium for any type of agricultural practice, and therefore it is imperative to know its mineral and chemical content. The objective are not only to assess its relative fertility but more important its potential toxicity to plants, animals and human beings.

### Ultrabasic and Basic Rocks Heavy Metal Composition

Basalt, a basic igneous rock is dark in colour, fine textured and can occur as lava flow, cone sheet, dyke or minor intrusion (Hatch, *et al.*, 1981). The main mineralogy consists of four groups viz. alkali and plagioclase feldspars, pyroxene and olivine. Minerals of ferrum oxide such as magnetite and ilmenite occur in small concentration of less than 5% in volume. Soils formed from basalt are brownish-yellow to greyish black in colour. Concretions are common in soil developed from basalt present in the Kuantan area and in the Segamat area.

Ultrabasic rock is usually softer compared to basalt. In Sabah the ultrabasic rock is represented largely by serpentinite rocks. Owing to serpentinization the rock is usually greenish black in colour. Rock-forming minerals are serpentinite, olivine, pyroxene and chlorite. Chromite, pyrrhotite, pentlandite and magnetite are present as accessory minerals (Fox and Tan, 1971). The serpentinite rocks generally contain high concentrations of Ni, Cr, Mg and Fe but low in Ca and Si. Poor plant growth on serpentinite soil has been attributed mainly to Ni toxicity rather than the relative large concentrations of Cr and Co (Alloway, 1990).

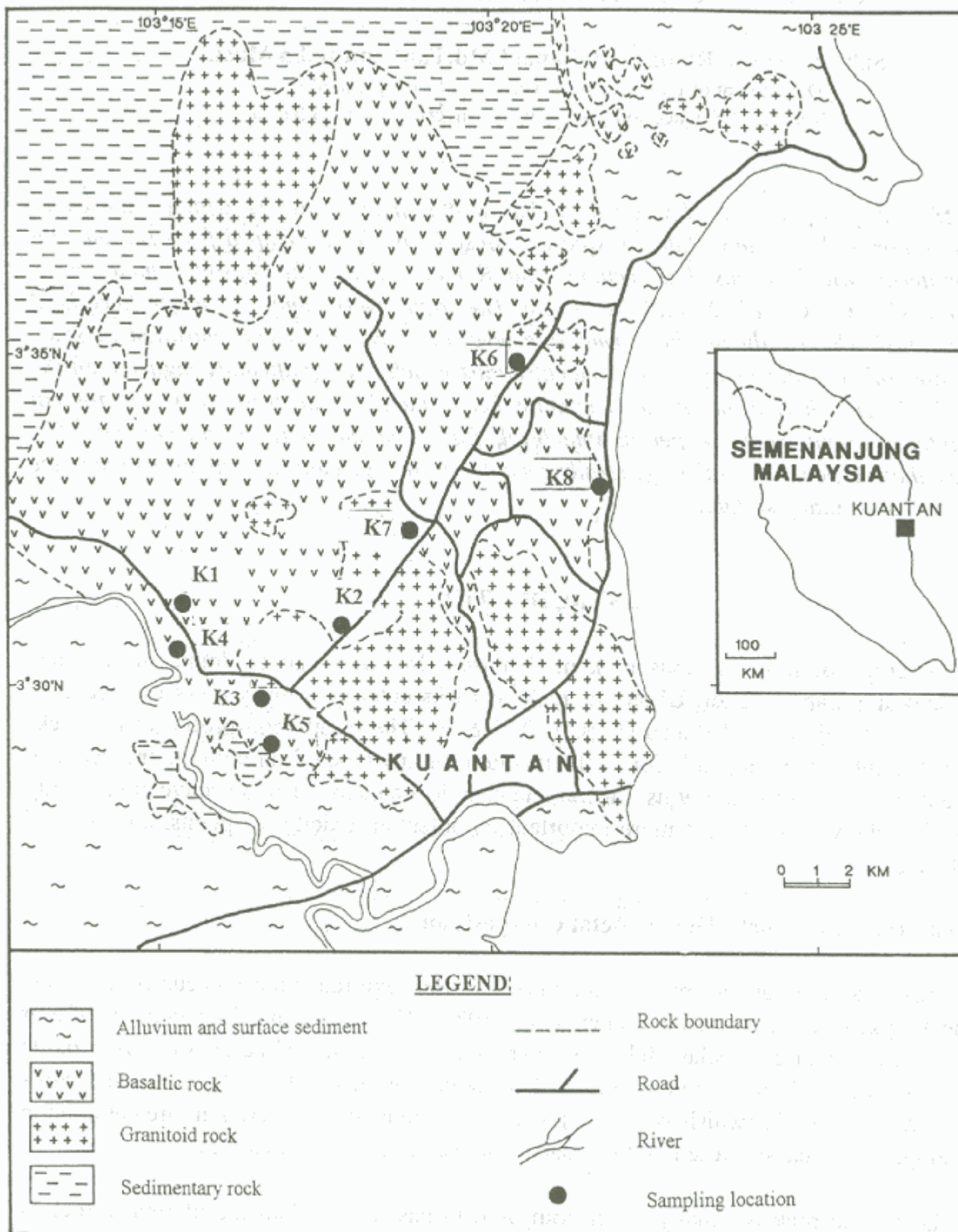


Figure 1: Map showing rock types distribution and sampling locations in Kuantan, Pahang (Modified from Haile, *et al.* 1983).



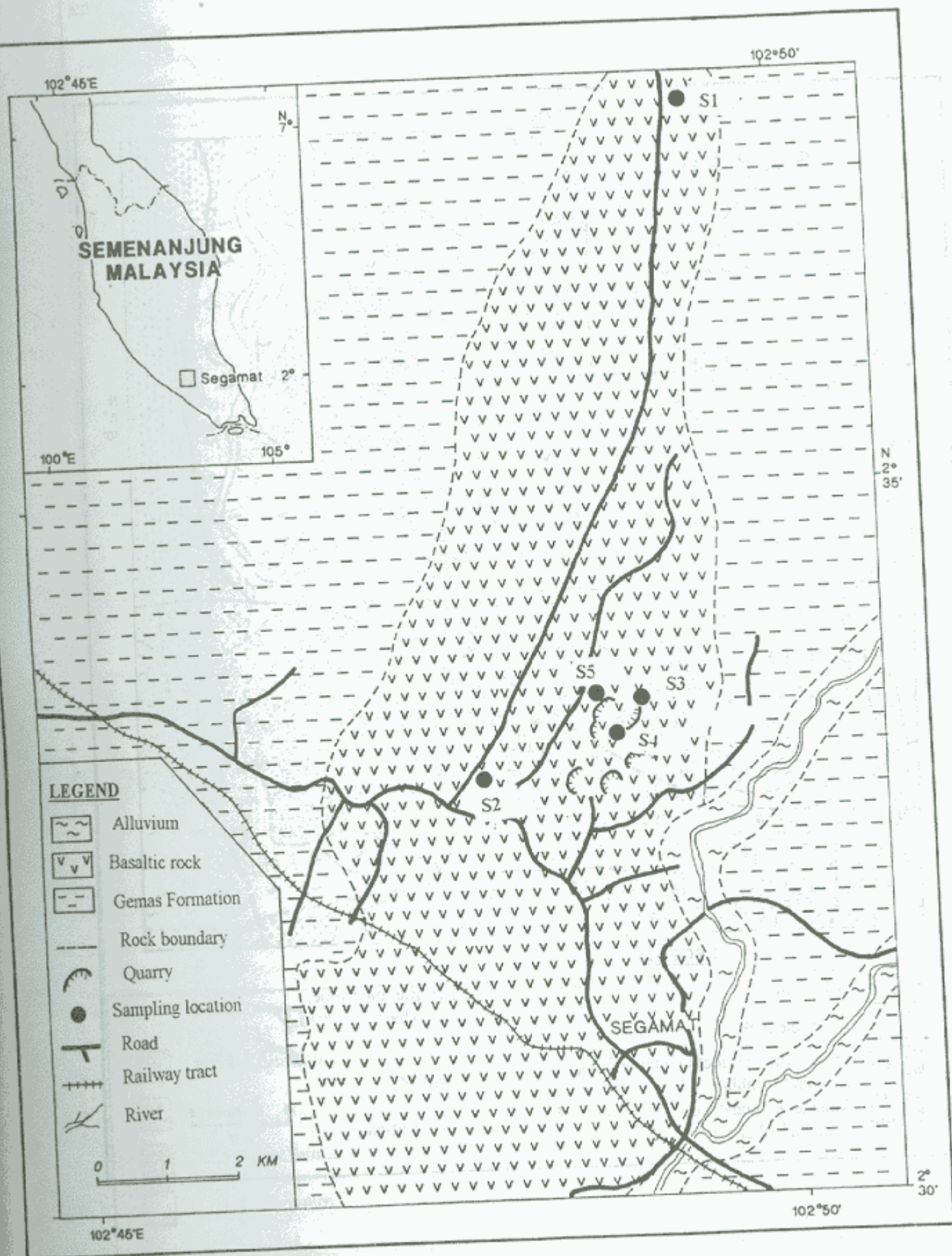


Figure 2: Map showing rock types distribution and sampling locations in Segamat, Johor (Modified from Loganathan 1979).

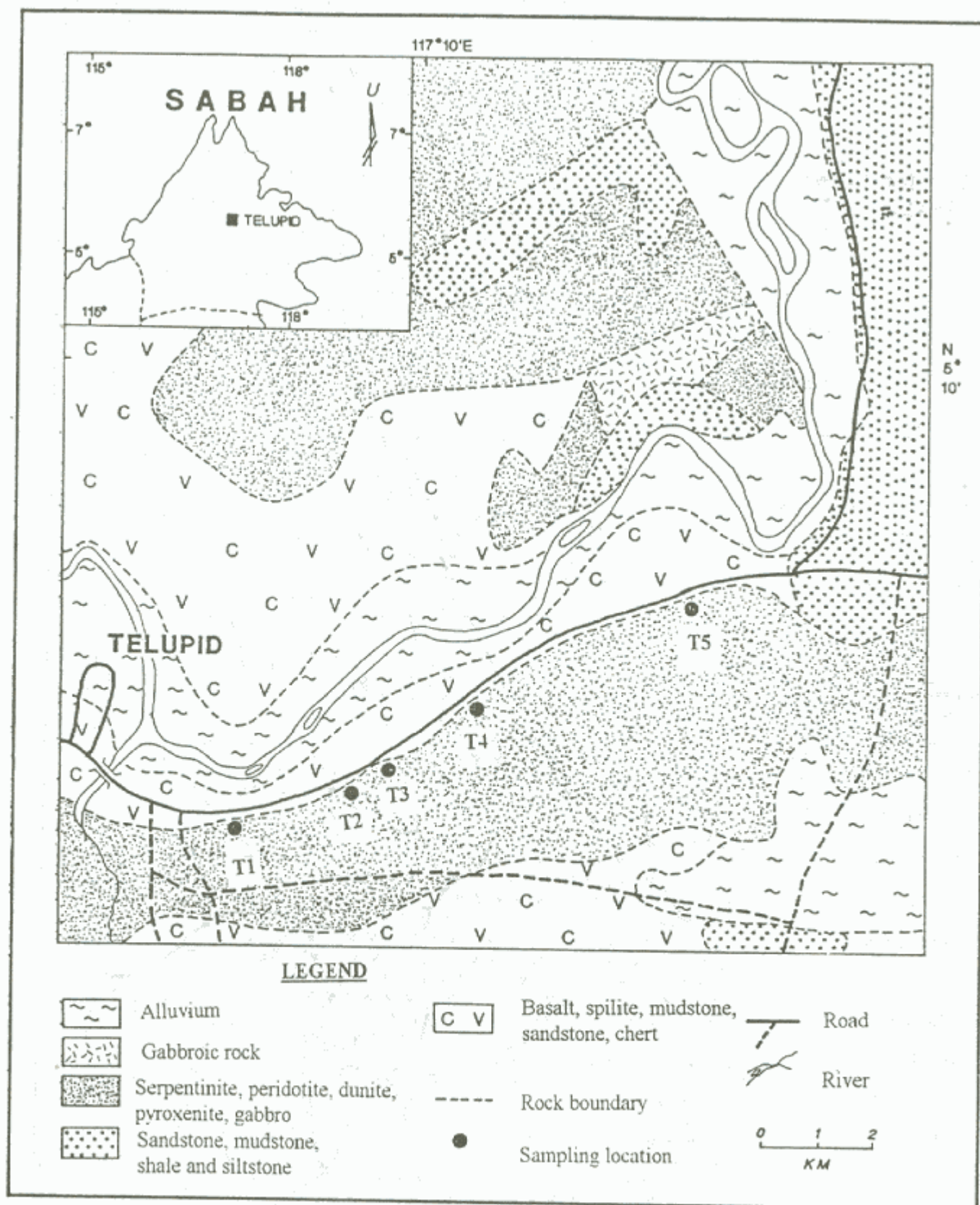


Figure 3: Map showing rock types distribution and sampling locations in Telupid, Sabah (Modified from Johnston and Walls 1974).



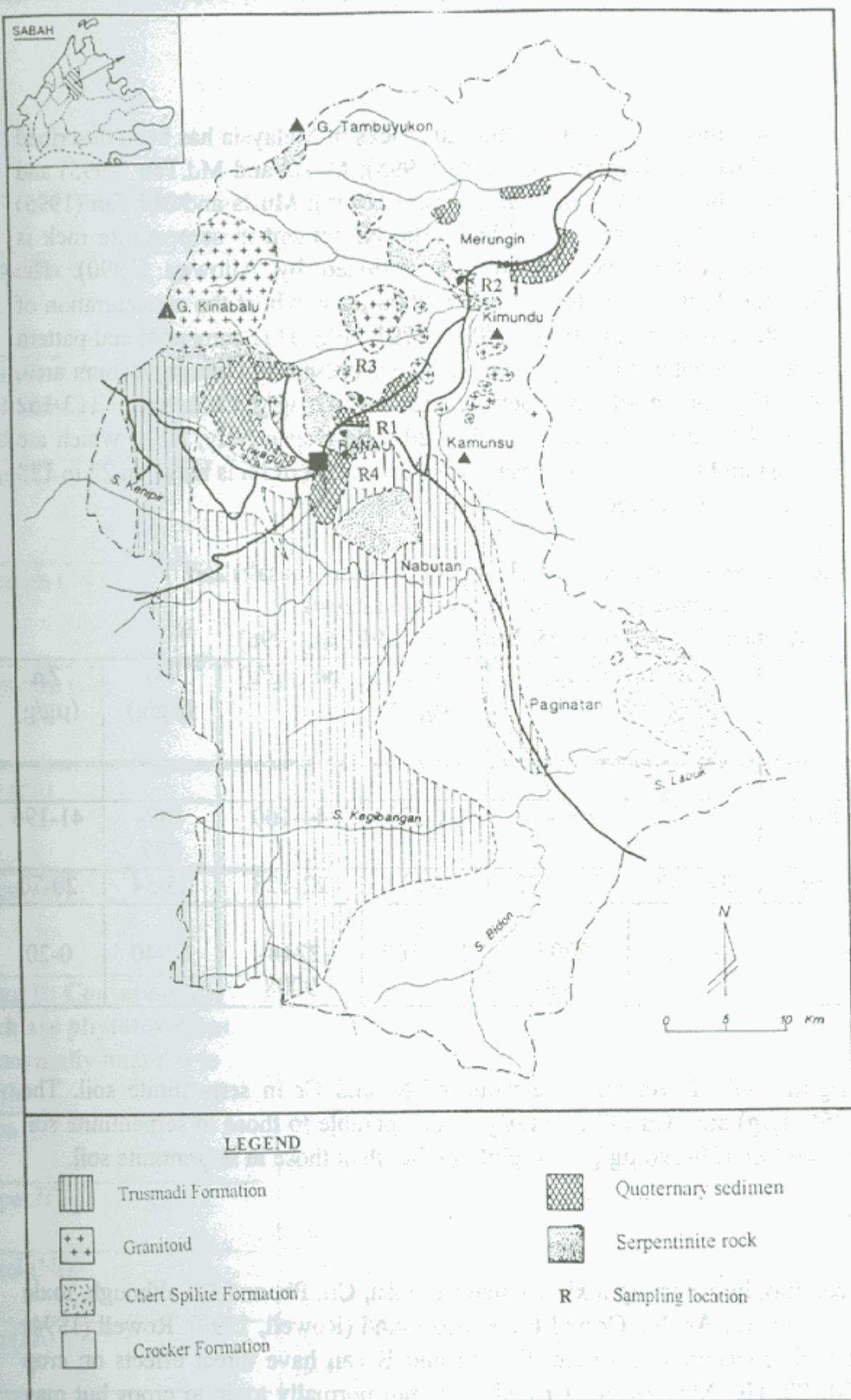


Figure 4: Map showing rock types distribution and sampling locations in Ranau, Sabah.

Heavy metal composition of basic and ultrabasic rocks in Malaysia has been described by many researchers, viz. Fox and Tan (1971); Musta (1995); Musta and Md.Tan (1995) and Musta and Md.Tan (1996). The extract of data from Musta (1995); Musta and Md.Tan (1995) and Musta and Md.Tan (1996) is shown in Table 1. The Ni content in serpentinite rock is within the range or even greater than the value mentioned by Alloway (1990). The concentration of Ni in serpentinite varies from 2244 to 9008  $\mu\text{g/g}$ , whilst the concentration of Cr is relatively lower with values varying from 2295 to 3791  $\mu\text{g/g}$ . This compositional pattern conforms with the Cr and Ni contents of serpentinite samples present in Gunung Danum area, Sabah (Brunotte, 1990). The content of Co is between 136 to 163  $\mu\text{g/g}$ , Cu between 113-162  $\mu\text{g/g}$ , Pb between 12 to 14  $\mu\text{g/g}$  and Zn between 0 to 20  $\mu\text{g/g}$  respectively, all of which are significantly lower than Cr and Ni content. In basalt soil, the content of Ni is between 22 to 128  $\mu\text{g/g}$  whereas Cr concentration is between 83 to 732  $\mu\text{g/g}$ .

Table 1: Example of heavy metal contents of basic (basalt) and ultrabasic (serpentinite) rocks in Malaysia  
(Musta and Md.Tan, 1995; Musta and Md.Tan, 1996)

metal Location	Heavy Co ( $\mu\text{g/g}$ )	Cr ( $\mu\text{g/g}$ )	Cu ( $\mu\text{g/g}$ )	Ni ( $\mu\text{g/g}$ )	Pb ( $\mu\text{g/g}$ )	Zn ( $\mu\text{g/g}$ )
Segamat (basalt)	77-256	83-454	54-279	44-100	147-989	41-196
Kuantan (basalt)	34-232	343-732	39-199	22-128	25-54	20-70
Telupid (serpentinite)	136-163	2295-3791	113-162	2244-9008	12-40	0-20

These values are significantly lower than the value of Ni and Cr in serpentinite soil. The content of Co (34-256  $\mu\text{g/g}$ ) and Cu (39-279  $\mu\text{g/g}$ ) is comparable to those in serpentinite soil but Pb (25-989  $\mu\text{g/g}$ ) and Zn (20-196  $\mu\text{g/g}$ ) is slightly higher than those in serpentinite soil.

### Heavy Metal Toxicity

The most commonly occurring toxic elements are Zn, Cu, Pb, and Cd although, toxic levels of others including Hg, As, Ni, Cr and F are also found (Rowell, 1994). Rowell (1994) has suggested that high concentration of Zn, Cu, Ni and B can have direct effects on crop growth, whereas Cd, Pb, Hg, Mo, As, Se, Cr and F are not normally toxic to crops but may affect animals feeding on crops grown on basic or ultrabasic soils. In other words, soils developed from serpentinite and basalt are the natural sources containing the unusually high concentrations of elements mentioned above.



Table 2: "Trigger Concentrations" for selected inorganic contaminants.  
(After ICRCL, 1987)

Contaminants	Planned uses	Trigger Concentrations ( $\mu\text{g/g}$ air-dried soil) Threshold
<b>Group A: Contaminants which may pose hazards to health</b>		
Arsenic (As)	Domestic gardens, allotments Parks, playing field, open space	10 40
Cadmium (Cd)	Domestic gardens, allotments Parks, playing field, open space	3 15
Chromium (Cr)	Domestic gardens, allotments Parks, playing field, open space	600 1,000
Lead (Pb)	Domestic gardens, allotments Parks, playing field, open space	500 2,000
Mercury (Hg)	Domestic gardens, allotments Parks, playing field, open space	1 20
<b>Group B: Contaminants which are phytotoxic but not normally hazards to health</b>		
Boron (B)	Any uses where plants are to be grown	3
Copper (Cu)	Any uses where plants are to be grown	130
Nickel (Ni)	Any uses where plants are to be grown	70
Zinc (Zn)	Any uses where plants are to be grown	300
Selenium (Se)	Domestic gardens, allotments Parks, playing field, open space	3 6

In United Kingdom the concept of "trigger concentrations" (ICRCL, 1987), which depend upon the intended use of the site, has been introduced to assist in determining the

significance of contamination. In Europe the concept of "threshold concentration" (Wild, 1993) which addresses similar problem has been introduced. Example of principle contaminants and their upper limit of permissible concentrations are given in Table 2.

For samples having concentration values below the lower trigger or threshold concentrations, it is reasonable to regard the sampling site as uncontaminated. For samples with concentrations exceeding the upper value of threshold concentrations, the sampling site should be considered as toxic particularly to agricultural practices and perhaps to animals and human beings. Some remedial action is therefore required if the toxic soils are to be used. Alternatively, a different use should be considered.

There are several ways in which the anomalous concentrations of potentially toxic elements can occur. Beside heavy metals that occur naturally at high concentrations in soils that develop from serpentinite and basalt, spoil heaps from metalliferous mining, industrial waste and sewage disposal can also contain anomalous high concentrations of potentially toxic elements (Alloway, 1990). Thus, soils in Malaysia have to be evaluated in order to identify the distribution and concentration of potentially toxic heavy metals for the purpose of avoiding toxic soils for agricultural purposes. Using the same threshold as practiced in the United Kingdom, the heavy metal content of soils developed from basic and ultrabasic rock in Malaysia is discussed below.

## Soil Types

Soil classification in the Peninsula is different from that used in Sabah. Soil classification in Peninsula followed the Soil Taxonomy (USDA, 1975) system, whereas soil classification in Sabah followed the FAO (1973) system. The soil type in the study area following the system of soil taxonomy is given in Table 3.

Table 3: Taxonomic classification of soil in the study area  
(After Yaacob and Jusop, 1982)

Order	Sub-Order	Group	Sub-Group	Series	Parent Material
Oxisol	Orthoks	Akrorthoks	Haplik Akrorthoks	Kuantan	Basalt
				Segamat	Basalt
				Sungai Mas	Serpentinite
				*Telupid	Serpentinite
				*Ranau	Serpentinite

\* using the soil taxonomy system, soils of Telupid and Ranau which developed from serpentinite is equivalent to Sungai Mas Series in Peninsula Malaysia.



## MATERIAL AND METHOD

### Soil Samples

Topsoil samples (0-15 cm) for the four sampling areas (Segamat, Johor; Kuantan, Pahang; Telupid and Ranau, Sabah) were collected using a Dutch auger. About 500 g soil samples were taken and kept in plastic bags for transportation to the laboratory. On reaching laboratory the samples were air dried, broken into smaller sizes using wooden mortar and then sieved through 2 mm sieve. This air-dried fine earth was kept for subsequent physical and chemical analyses.

### Heavy Metal Analysis

#### *Total heavy metal contents by wet analysis*

Total heavy metal content of the ultrabasic soil from Ranau area was determined using the method of Archer and Hodgson (1987). About 1.5 gram of air-dried fine earth was digested for 3-4 hours in 20 ml of concentrated nitric acid using 100 ml conical flask. After digestion the solution was made up to 50 ml, filtered with No. 5 Whatman filter paper. Various chemical elements from this aliquot were determined by atomic absorption spectrophotometer and expressed in  $\mu\text{g/ml}$ . The heavy metals determined were Cd, Co, Cr, Cu, Ni, Pb and Zn.

#### *XRF*

Heavy metals in the soil samples from Kuantan (Pahang), Segamat (Johor) and Telupid (Sabah) were analysed using XRF method. X-ray fluorescence (XRF) technique is used to analyse major and minor elements. Major elements were analysed using fused disc technique whereas minor elements were analysed using pressed pellets technique (Norish and Hutton, 1969). XRF technique uses Phillips PW 1480 X-ray Digital Instrument and the spectrometer is controlled by Digital Software X-44 Microcomputer. Graph calibration method is obtained by using Alpha On Line Program (De Jongh, 1973; 1979).

## RESULTS AND DISCUSSION

The sampling locations in the study area are shown in Figure 1 for Kuantan (Pahang), Figure 2 for Segamat (Johor) and Figure 3 and 4 for Telupid and Ranau area in Sabah respectively. Results of heavy metal content of topsoil samples collected from these study areas are presented in Table 4 (Kuantan), Table 5 (Segamat), Table 6 (Telupid) and Table 7 (Ranau).

As shown in Tables 6 and 7, serpentinite soils contain significantly higher Ni and Cr content compared with those in basalt soils. The Ni and Cr concentrations in serpentinite soils vary from 1183 to 3500  $\mu\text{g/g}$ , and from 233 to 17837  $\mu\text{g/g}$  respectively. The concentrations of Ni and Cr in basalt soils vary from 16 to 95  $\mu\text{g/g}$  and from 79 to 695  $\mu\text{g/g}$  respectively. The content of the other heavy metals viz. (Co, Cu, Pb and Zn) in serpentinite soils do not differ

significantly from those in the basalt soils. Nevertheless, the content of heavy metals in soils shows clear relationship with their parent materials.

High concentration of Cr and Ni contents in serpentinite soil is expected since the parent serpentinite rock usually contain high concentrations of Cr and Ni. In soil, their concentrations depend on their form and mobility. In Musta and Md. Tan (1996) it was shown that the Cr concentration in soil can become twice higher than the Cr concentration in rocks. This could be attributed to its high rate of release into soil environment through rapid process of decomposition and weathering. In basalt rock Ni and Cr content are not as high as those in serpentinite, and therefore basaltic soils also contain lower Ni and Cr content.

Table 4: Concentration (in  $\mu\text{g/g}$ ) of heavy metals in soil developed from basic rock (basalt) in Kuantan area

Elements Locality		Co	Cr	Cu	Ni	Pb	Zn
KKgP	K1	198	674	16	34	35	40
KKB	K2	213	622	131	25	35	35
35KSgL	K3	199	595	116	59	19	40
31.5KSgL	K4	221	657	110	16	35	28
KPPA	K5	14	469	95	28	48	7
201KKT	K6	142	371	123	55	66	37
206KKT	K7	160	501	166	86	46	45
KPBH	K8	209	395	160	64	68	81

Table 5: Concentration (in  $\mu\text{g/g}$ ) of heavy metals in soil developed from basic rock (basalt) in Segamat area.

Elements Locality		Co	Cr	Cu	Ni	Pb	Zn
18SKH	S1	241	79	46	bdl	91	37
6.5SKH	S2	132	275	137	43	493	54
SSQI	S3	142	431	165	95	345	102
SSQII	S4	83	147	204	82	329	117
SYFQ	S5	98	190	162	90	652	174

In evaluating the Ni and Cr concentrations in serpentinite soil for different kind of uses (see Table 2) Ni and Cr content in serpentinite soil are higher than the permissible threshold which is about 70 mg/kg for Ni and 600 mg/kg for Cr. Cu content is not significantly different from the threshold concentration whereas Pb and Zn content are significantly lower than the



permissible concentration level. In basalt soil, Cr and Pb content is not significantly different from the threshold concentration. The Ni, Zn and Cr content in basaltic soil are generally low.

Table 6: Concentration (in  $\mu\text{g/g}$ ) of heavy metals in soil developed from ultrabasic rock (serpentinite) in Telupid area.

Elements Locality		Co	Cr	Cu	Ni	Pb	Zn
2.5TS	T1	421	17837	112	1421	27	62
4.0TS	T2	577	16183	139	1850	6	34
4.5TS	T3	375	14300	123	1517	1	57
6.0TS	T4	553	17593	152	2514	16	65
11.0TS	T5	397	15033	103	1183	5	54

Table 7: Concentration (in  $\mu\text{g/g}$ ) of heavy metals in soil developed from ultrabasic rock (serpentinite) in Ranau area.

Elements Locality		Co	Cr	Cu	Ni	Pb	Zn
LSJ	R1	247	8000	70	2700	123	0
Garas	R2	43	310	72	257	93	3
Libang	R3	40	2333	45	1417	0	100
Mibang	R4	200	6067	70	3500	8	167

It can be deduced from the above discussion that soils developed from serpentinite is generally unsuitable for agricultural crops. Fox and Tan (1971) have suggested that the generally high soil porosity and tendency for high concentrations of elements such as nickel, cobalt, copper and lead in an ultrabasic soils would lead some toxicity problems in agriculture activities. High concentration of heavy metal contributes to heavy metal toxicity to crops which in turn may affect the grazing animals and human being. Besides, vegetations and crops do not grow normally (stunted growth) on this soil (Fox and Tan, 1971; Thomas, *et al.*, 1976). Plants growing on an ultrabasic soils can be divided into several groups according to their ability to tolerate the high content of Ni and Cr. There are types of hyperaccumulator plants such as *Ringora Bengalensis* (Violaceae) which thrive and accumulate heavy metal without limit in such soil (Magain, 1992). Some other plants tend to avert high absorption since they have a physiological system to abate toxic elements *i.e.* absorb up to a ceiling concentration.

Groundwater and surface water draining the serpentinite area may also be charged with toxic elements. However the concentration may be very low due to the presence of soil organic matter, oxide and hydroxide content in this soil. Musta (1995) showed that the pH of 12 water samples draining through subsoil of serpentinite soil in Telupid, Sabah is between 7 to 7.5. This is very important because the solubility of Cr and Ni are pH dependent. The solubility of Cr is low at pH 4 and complete precipitation occurs at pH above 5.5. High solubility of Ni

occur only when the pH is lower than pH 6 together with low CEC (McGrath, 1995). The presence of soil organic matter, oxide and hydroxide in serpentinite soil in Sabah (Fox and Tan, 1971; Musta, 1995) ensure that Cr and Ni cation are held strongly to soil particulates.

High mobility and solubility of toxic elements in ground/surface water occur only at the right pH condition. At pH value of less than pH 6 and less than pH 4 for Ni and Cr respectively, they are in their soluble form, thus easily mobilised by ground or surface water. The pH value of ultrabasic soil from Ranau is between pH 5.2 to pH 6.4 (Rahim, 1995). At this value the solubility of Ni should be higher compared to Cr. Moderate to high CEC values (17-44 meq%) in soil developed from serpentinite (Acres, *et al.*, 1975) ensure that these cations are held on the surface of soil particles, thus making them available for plant absorption. Thus, building up to a toxic concentration in plants.

Agricultural area developed on other types of parent material situated adjacent to serpentinite soil or at a place lower than it might also be influenced with high Ni and Cr contents (Rahim, 1995). This could be attributed to sedimentation of eroded topsoil by surface flow or by movement of dissolved cation through surface flow or/and percolating water. Though basalt soils contain some heavy metals (e.g. Cr and Pb) the presence of which at threshold values may suggest some potential heavy metals toxicity.

## CONCLUSION

From the above discussion, serpentinite soils which occur rather widely in Sabah are generally not suitable for agricultural purposes due to their high content of toxic heavy metal composition. Alternative use of the land apart from agriculture should be found *viz.* either forestry or recreation is strongly advised for areas covered with serpentinite soils. Toxic heavy metals content of basalt soils is generally less than the threshold heavy metal value indicating that it is suitability for agriculture. However, types of agriculture should be identified *i.e.* crop plantations, cash crops or grazing reserves. This is because if it is present in even minute concentrations, these heavy metals tend to accumulate in biological systems. In passing through the food chain associated with plant and animal life, their concentration may eventually increase to harmful levels in the top members of the food chain, e.g., fish, eagles and humans (Tan, 1994).

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