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GEOCHEMICAL CHARACTERISTICS OF SOME SRI LANKAN SOILS

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ABSTRACT

A preliminary geochemical characterization of Sri Lankan soils is established using total soil analyses for major oxides. The differences between the soil samples from the wet and the dry zones show that the climatic contrast has resulted in a clear geochemical signature in the soils. The geochemical analyses indicate extensive removal of major and secondary inorganic nutrient elements from wet zone soils and suggest the need for total replenishment of nutrients instead of nutrient addition in parts as embodied in the NPK fertilizer concept, to restore and maintain a nutritatively balanced environment such as is found in naturally fertile soils.

KEY WORDS: Geochemical, Rock Powder Fertilizer, Soils

INTRODUCTION

A comprehensive geochemical characterization of

Sri Lanka's soils is not available, and this omission should be rectified in view of the need to formulate a new fertilizer strategy, because of soaring fertilizer prices and recent knowledge emerging from research into tropical soils. As pointed out by Leonardos et al., (1986) conventional NPK soluble fertilizer (as employed in Sri Lanka) was originally formulated for the fertile soils of the temperate regions characterized by lower rainfall. In these regions generally of young post glacial soils, soil fertility is ensured by low leaching rates which are responsible for the formation and preservation of soil minerals such as smectite and illite that have as a result of their structures, high retention powers of bio-essential elements. In contrast, the only minerals that can form and survive the intense leaching environment in the tropics are the kaolin group of minerals and oxides and oxyhydroxides of elements such as Al and Fe. However these minerals, because of their structures, have very low retention capabilities of bio-essential elements. Thus these soils are incapable of buffering the array of plant elements required to maintain soil fertility.

A concept that is rapidly gaining acceptance resulting from the work done on Brazilian soils is that in the tropics where leaching rates are high and soil retention powers low, continued addition of conventional highly soluble NPK fertilizer constitutes a rather ineffectual and uneconomic means of maintaining soil fertility. In Sri Lanka this is bourn out by the increasing spread of Mg deficiency in wet zone soils. Mg deficiency was first identified in the 1950's in the South and Southwestern parts and has extended to other regions as well (Jeganathan and Dias, 1986). Secondly the list of trace elements considered essential by plant scientists, keeps growing. Currently the list includes Fe, Mn, Cu, Zn, B, Mo, Cl, and Cu. This is highly significant to Sri Lanka, when viewed from the perspective of the alarming number of trace element deficiencies that are being identified not surprisingly in the country's intensely cultivated wet zone climatic region where leaching rates are high. A review paper (Pavanasasivam and Kalpage, 1973), lists the occurrence of manganese deficiency in some tea and rubber growing soils, iron and molybdenum deficiency mostly in tea growing soils, boron deficiency in tea growing especially in soils derived from quartzitic rocks and increasingly common zinc deficiencies in tea, coffee and cocoa growing soils.

The need has arisen to look at soils in these regions as geochemical entities with secondary and trace element contents that need total replenishment, instead of addition in parts (Kronberg et al., 1985). This is embodied in the concept of rock powder fertilizer currently being developed in Brazil (Fyfe et al., 1983) for wet zone type soils. It originates with the idea that rocks which contain an array of elements unmatched by any fertilizer commercially available today is in addition Nature's own choice of a nutrient source.

In Sri Lanka, the wet zone, comprising Red Yellow Podzolic soils is under stress to support the country's agricultural economy. In order to make a comparative study for Sri Lanka it was necessary to obtain data on the major oxide and trace element composition of soils and common rock types found in Sri Lanka. Major oxide suite determinations exist only for limited batches of soil (Panabokke, 1959). Only Al_2O_3 and SiO_2 analyses are given for a large number of profiles in the Handbook of the Soils of Sri Lanka (De Alwis and Panabokke, 1973). Trace element data is presented by Pavanasasivam and Kalpage, (1973), and Sanmugadas (1973). An extensive collection of literature deals with 'fertility characteristics' of soils designated as 'rice growing soils' (Nagarajah et al., 1979; Thenabadu, 1977; Panabokke and Nagarajah, 1964), and 'coconut lands' (Nethsinghe, 1963), named after the 4 major crops grown in Sri Lanka, tea, rubber, coconut and rice. In keeping with the traditional concept of soil fertility, much of this literature deals with the availability of the major plant nutrients, Nitrogen (N), Phosphorus (P), and Potassium (K) and recommendations for required input mainly of these elements together with Mg in the case of coconut and Zn and B in the case of tea (Handbook of Fertilizer Recommendations, Somapala 1986). The status of the remaining elements required by plants, both secondary and trace is largely not considered. A preliminary sampling was conducted to study the geochemical characteristics of Sri Lankan soils and their parent rock types with special reference to the major oxides including K_2O, Na_2O, MgO and CaO - the macro and secondary plant nutrients - in order to obtain a basis for overall comparison of their nutrient status with reference to the earth's crust and some important rock types and minerals (primary as well as secondary). Part of this study was also aimed at obtaining comparative major and trace element data for the soils of the main climatic zones, the wet zone and the dry zone regions of Sri Lanka. This in turn, it was hoped, would provide information regarding the feasibility of adding/not adding rock powder fertilizer as a cheap method of providing an array of plant nutrients.

The climate of Sri Lanka can be described as tropical humid to sub-humid. The wet zone (Fig. 1) receives over 2500 mm rainfall reaching a maximum of 5000 mm, distributed evenly throughout the year. The dry zone is characterized by a prominent dry season lasting at least 4 to 5 months of the year, and an annual rainfall of 1875 -1250 mm.

MATERIALS AND METHODS

For comparative purposes samples from wet, dry and intermediate zones were taken at depths of 10cm, 30cm and 100cm within the root zone, using a hand

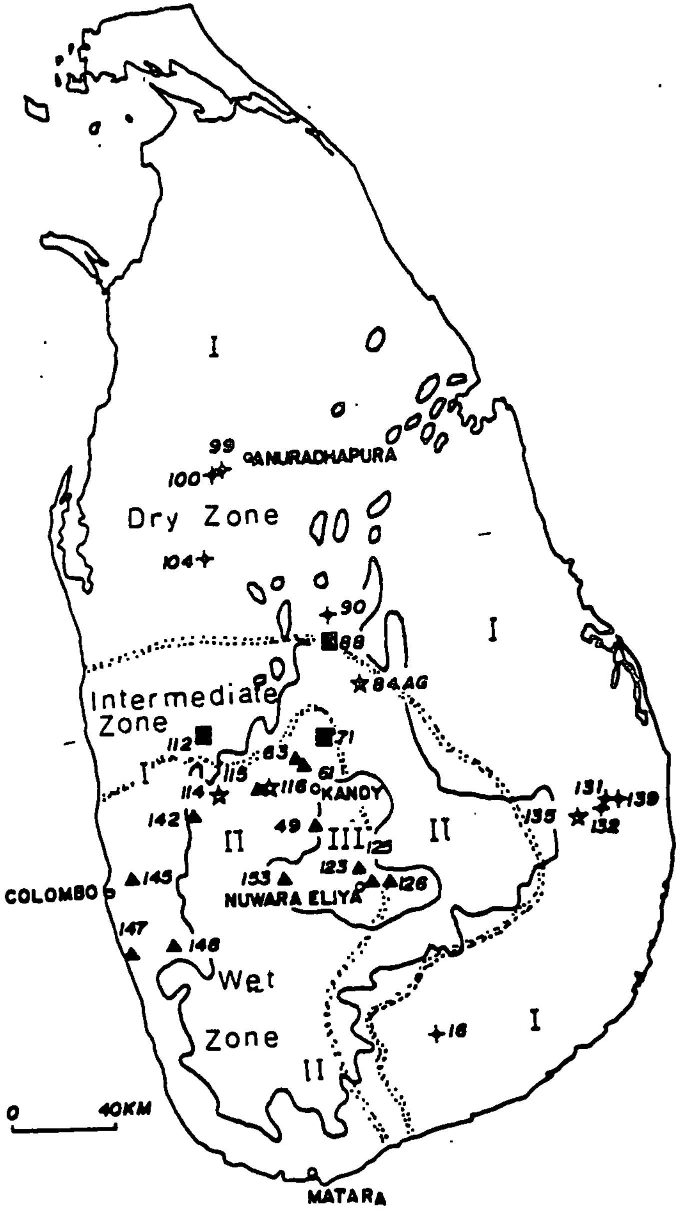

Fig. 1 Map showing sequence locations of present study, the three main morphological regions and the climatic zones of Sri Lanka. I - Lowlands; II - Uplands; III - Highlands. (✦) Dry zone sequences; (■)intermediate zone sequences; (▲) wet zone sequences; (★) river sediment.

auger. The sampling sites (Fig. 1) were located near fresh rock outcrop. 140 samples were analyzed for Si, Al, Fe, Mg, Ca, K, Na, Mn, P and trace elements using X-ray fluorescence at X-ray Assay Laboratories Ltd., Canada and at The University of Western Ontario.

To compare and assess the nutritive status of the soils between the two climatic regions, analyses were normalized against crustal abundances (Fairbridge, 1972) as shown in Fig. 2 and oxide ratios calculated and plotted according to the Kronberg and Nesbitt (1981) weathering diagram (Fig. 3-4). The latter type diagram is useful because it not only allows comparison but gives an indication of weathering processes the sequences are undergoing.

RESULTS AND DISCUSSION

Geochemical Differentiation of Sequences:

Few of the soil elements analyzed are heavily enriched compared to the Earth's crust (Fig. 2). Of interest is the difference in type of element showing this minor enrichment. Zr, Ti, Sr and P are enriched in the dry zone compared to Al, Fe, Ga, Zr and Ti in the wet zone. The latter suite belongs to typical residual chemical enrichment (Goldich, 1938). The majority of samples analyzed compare in range of elemental composition to the Earth's crust excepting the alkaline and alkaline earth elements, both major and trace. Not surprisingly, depletion is extensive especially in the wet zone compared to the dry zone. Of these, Na and Ca depletion is especially heavy. K

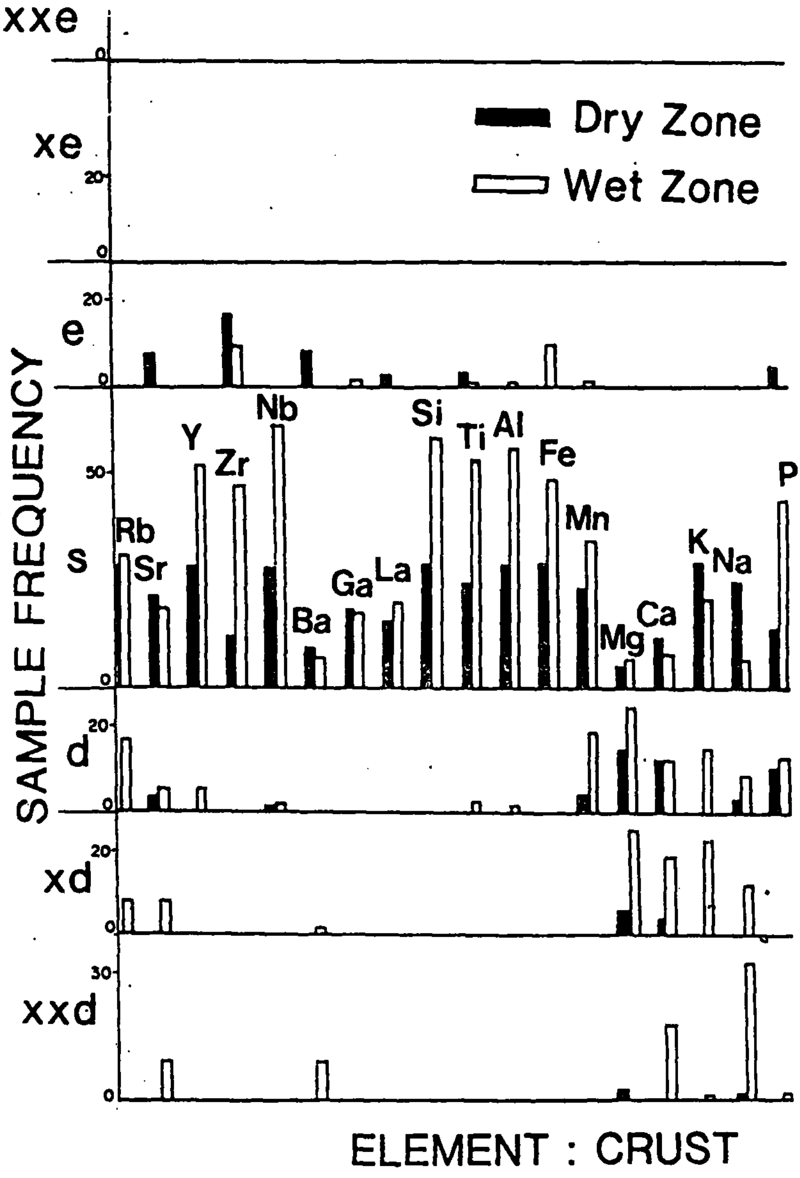

Figure 2. Distribution of elements in Sri Lankan soils relative to crustal abundance (CA). xxd (0.001X-0.01X CA); xd (0.01-0.1XCA); d(0.1-0.3XCA); s(0.3-3.0XCA); e(3-10XCA), xe(10-100XCA); xxe (>100XCA).

is not as heavily depleted and is in accordance with global observations. The strong polarity of the enrichment - depletion pattern of the wet zone samples ie. enrichment of resistate elements and depletion of mobile base cations compared to dry zone samples, indicates the higher degree of weathering in the wet zone Joachim, 1955).

In the weathering diagram (Fig.3), primary minerals plot high along the Y-axis due to their relatively high content of nutrient elements Ca, K, Mg and Na, according to Kronberg and Nesbitt (1981), Removal of these elements during weathering by ground water results in partitioning of primary mineral elements between residual soil minerals and river water. This results from the dissolution of mobile elements in primary minerals by ground waters which then seep and flow into river water. This in turn drives the residual soil composition directly away from that of river water. This is expressed in the diagram by opposing evolutionary trends of (a) river water and (b) residual soil minerals (Fig. 3). They branch out on either side of the plots of primary minerals. The residual soil weathering trend from unweathered rock to highly weathered residues such as gibbsite and kaolin evolves 'down' the diagram while the river solution evolves 'up' the diagram as it continually extracts Ca, K, Mg and Na from the soils. In contrast to primary rock forming minerals, soil minerals plot lower along the Y-axis due to depletion of base cations and corollary enrichment of Al and Si

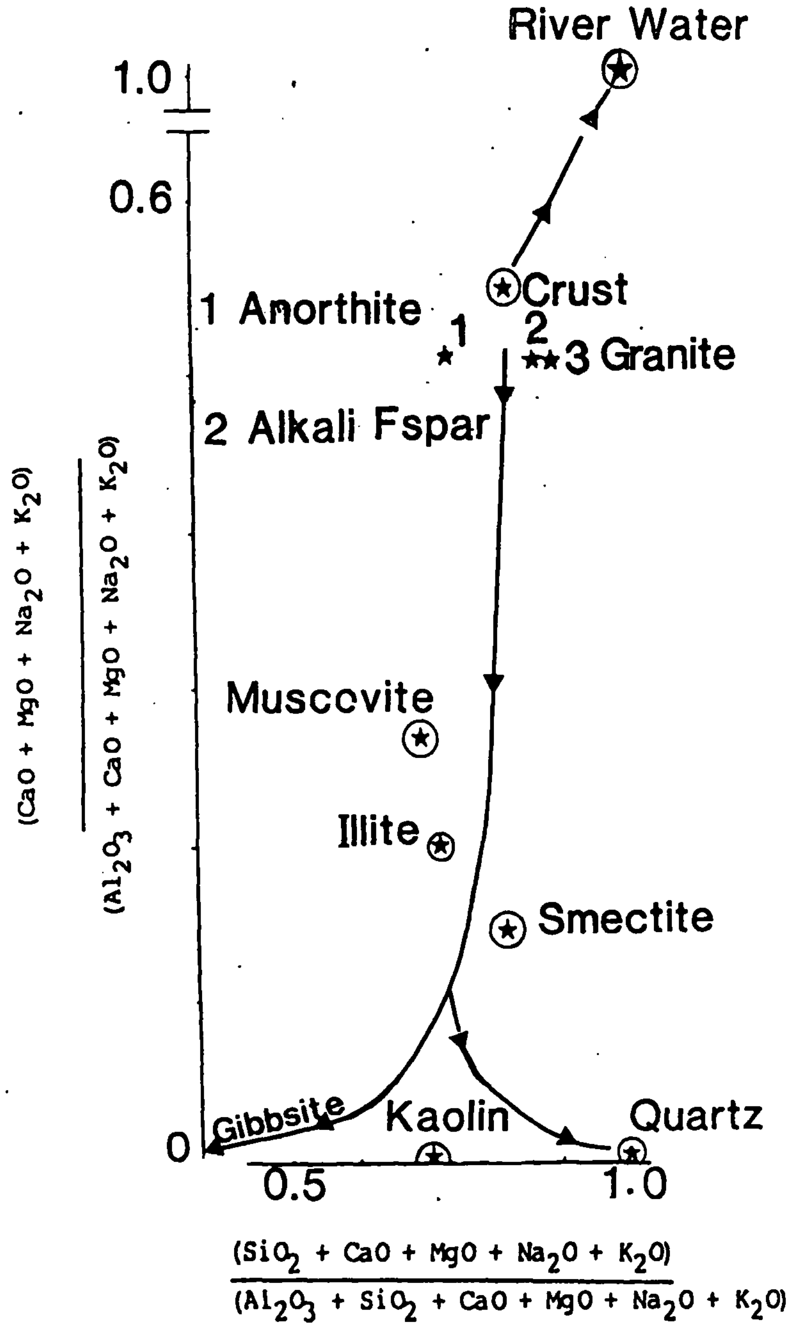

Figure 3. Weathering digram after Kronberg and Nesbitt (1981).

(Fig. 3).

Chemical weathering of the parent rock yields a convex downward trend directed to the left joining primary rock forming minerals to gibbsite. Conversely, physical processes of winnowing and sorting where clay minerals are either blown off or washed out leading to accumulation of sand and silt sized chemically inert quartz are indicated by trends joining primary minerals to quartz. Other heavy minerals rich in Fe, Ti and Mn which are relatively resistant to chemical weathering cannot be represented within the framework of this diagram..

Fresh rock (FR) samples plot in a relatively tight cluster (Fig. 4) regardless of the climatic conditions of their sampling sites. They cluster close to feldspar along the mixing curve between primary feldspars and quartz with the exception of the quartzite sample, FR49.

Derivative soil samples on the other hand clearly fall into 3 distinct fields, fields designated 1, 2 and 3 in Fig. 4. The direction of decreasing depth in soil sequences are indicated by arrows. Inspection of Fig. 4 shows that the direction of decreasing depth points both up and down. In sequence 104 (Fig. 4) the downward directed arrows in the direction of decreasing depth indicate that the subsurface layer that plots close to fresh rock has a higher nutrient content and is less weathered than the surface layer. Hence downward directed arrows indicate the presence of a high nutrient content at depth, signifying possibly the proximity to relatively fresh material. Therefore in an evolutionary sense the trend is 'downward', i.e. the most weathered soil layers are at the top of the sequence characteristic of a chemical weathering system. The reverse (upward facing arrows in the direction of decreasing depth) which is the dominant trend, implies extensive accumulation of aluminum at depth and is seen in the most highly weathered lateritic sequence, 145, and even more strikingly by sequence 49 developed on a quartzite precursor (FR49), exceptionally low in nutrient elements and aluminum, (Fig. 4). Formation of a coupled upper Fe_2O_3 rich zone and a lower Al_2O_3 rich zone is a commonly observed phenomenon in laterite profiles (Dahanayake, 1982; Ambrosi and Nahon, 1986; Tampoe, 1989). Muller and Bocquire (1986) observed replacement of kaolin by hematite in the red mottles within the deeper soft laterite in SEM studies and computed the amount of Al_2O_3 that would be displaced as a result. Part of this reprecipitates as less crystalline kaolinite while part of it forms gibbsite. Another portion remains unaccounted for. In this transformation silica is released. Tardy (1971) showed that even Al is soluble in heavily undersaturated hence chemically aggressive soil solutions in the upper layers of these sequences that represent the most advanced stages of weathering. It appears that in laterite systems classical concepts of absolute chemical inertness no longer remain valid. The time factor involved in laterite formation should also be taken into account. Continued replacement of the yellow kaolin matrix at the base of the upper iron rich crust generates the iron crust itself leading to Fe_2O_3 enrichment in the upper zone relative to Al_2O_3 . The iron crust itself breaks up at the surface according to Ambrosi and Nahon (1986), into nodular iron (gravel) and quartz. Fe_2O_3 is not represented in Figs. 3 and 4. Hence only the enrichment of silica in the surface levels and Al_2O_3 in the lower levels is highlighted. Tampoe (1989) has calculated the extent of Al_2O_3 (which is chemically inert in most weathering systems) lost relative to parent rock through mass balance calculations using zircon and titanium as inert chemical indexes.

Superimposition of the interpretation of the up and down facing trends onto the original significance of the left and right facing trends of Kronberg and Nesbitt, (1981), gives four alternative routes of weathering. In the dominant upward left facing trends (Fig. 4 - eg. sequence 145), the surface samples are farthest along both Y and X axes, implying that they have greater nutrient and silica contents than the subsurface samples which plot closer to gibbsite. Relative increase in base content could be due to vegetative recycling. Accumulation of silica at the surface has been explained above. Hence it appears inconsistent with the expected aluminum enrichment in the surface layers which would be found in an idealized *chemical only* weathering system, as in sequence 104, Fig. 4, where the weathering front moves downward enriching the surface material with more and more aluminum as it proceeds compared to the subsurface material. As noted previously in an idealized *chemical only* weathering system where the weathering front moves downward, downward facing arrows in the direction of the surface would result indicating proximity to fresh material with greater depth. In laterite profiles 100 cm represents mainly the upper iron rich crust. The weathering front itself lies in the soft kaolin and gibbsite dominated layer below which coincides with the Al_2O_3 rich zone.

Since samples collected from the wet zone plot in field 1, the field of kaolinite and gibbsite, it indicates their probable mineralogy and the fact that they have lost most essential elements, Na, K, Ca and Mg during the process of weathering regardless of their parent rock type, rendering them to be indistinguishable from each other. The exception is sequence 115, which has developed on a calc-silicate gneiss. The intensity of leaching that proceeds in the wet zone can be gauged by the plot of weathered rock samples (WR), that are still structurally coherent but are far removed from the fresh rock plots, eg. 142WR, 123bWR, (Fig. 4). Wet and intermediate zone river sediment samples that are seen to carry visible primary minerals plot high along the Y-axis outside field 1, testifying to the intensity of erosion. Beach sand samples containing Ca bearing shells plot above field 1.

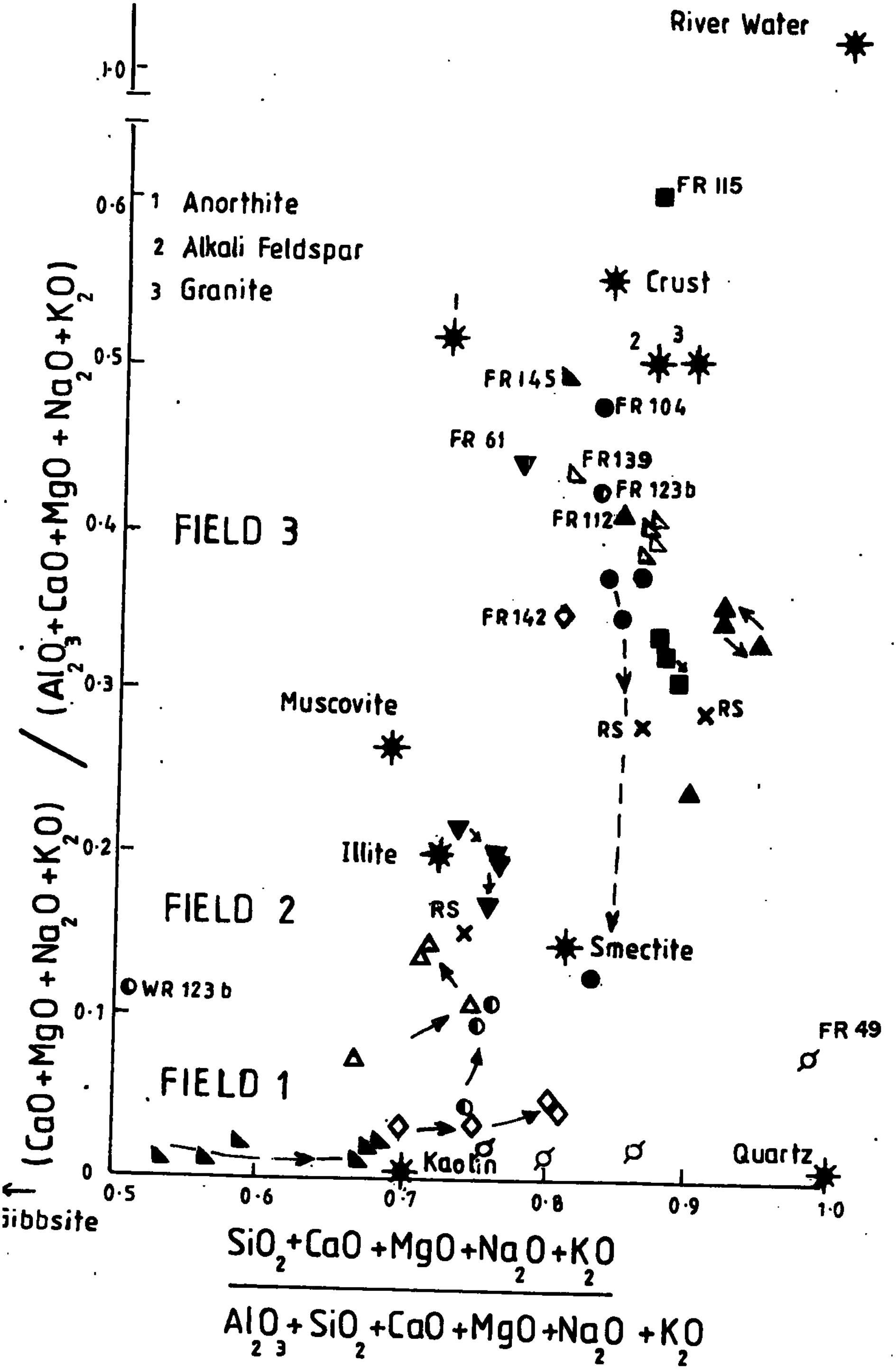
River Water
1·0
1 Anorthite
2 Alkali Feldspar
3 Granite
0·6
0·5
0·4
0·3
0·2
0·1
0
FR 115
Crust
1
2
3
FR145
FR 104
FR 61
FR139
FR 123b
FR 112
FIELD 3
FR 142
Muscovite
RS
RS
Illite
FIELD 2
RS
Smectite
WR 123 b
FIELD 1
FR 49
Kaolin
Quartz
← Gibbsite
0·5
0·6
0·7
0·8
0·9
1·0
(Al2O3+CaO+MgO+Na2O+K2O) / (CaO+MgO+Na2O+K2O)
SiO2+CaO+MgO+Na2O+K2O / Al2O3+SiO2+CaO+MgO+Na2O+K2O

Figure 4. (Opposite page) Sample distribution plot on weathering diagram modified after Kronberg and Nesbitt (1981). Sequences are represented by symbols designated at the fresh rock (FR) plot, and below. Arrows indicate directions of decreasing depth.

RS = River sediments; WR = Weathered Rock.
▲ = sequence 112: Int. Zone - Granite Gneiss
◺ = sequence 129: Dry Zone - Granite Gneiss
● = sequence 104: Dry Zone - Augen Gneiss
▼ = sequence 61 : Wet Zone - Hornblend biotite migmatite
△ = sequence 63 : Wet Zone - Charnokite
◣ = sequence 145 : Wet Zone - Charnokite
◐ = sequence 123b : Wet Zone - Charnokite
Ø = sequence 49 : Wet Zone - Quartzite
■ = sequence 115 : Wet Zone - Calc Gneiss
◇ = sequence 142 : Wet Zone - Hornblend biotote Gneiss

Sequences sampled from the wet zone close to the wet/intermediate boundary (field 2), plot in the smectite-illite zone giving a possible indication of their mineralogy.

Samples from the dry zone, field 3, plot just below the fresh rock samples, indicating either the presence of abundant unweathered primary minerals and/or the presence of clays with very high exchange capacities. A convex downward curvature directed to the right towards greater abundance of silica, is noted in some of the sequences of the dry and intermediate zone (sequence 115, and 139, Fresh Rock to soil trend, Fig. 4). This implies the dominance of physical weathering over chemical weathering (Kronberg and Nesbitt, 1981). A vertical differentiation between levels and fresh rock is more often observed in the dry zone sequences (eg. sequence 104, Fig. 4).

The overall dominance of climate in determining soil characteristics in Sri Lanka irrespective of parent rock type, pointed out before by Joachim (1955) is reconfirmed in this diagram.

CONCLUSIONS

The Kronberg and Nesbitt weathering diagram is useful in screening soils to determine their nature of weathering. The differences between the soil samples from the wet and the dry zones show that the climatic contrast has resulted in a clear geochemical signature in the soils.

(a). Wet zone samples are the most weathered in that they have lost most major and secondary nutrient elements compared to their parent rock type. Their geochemistry indicates that these soils would most probably be characterized by the presence of kaolin and free oxides. This prediction correlates well with well established mineralogical observations of earlier workers (Herath and Grimshaw, 1971). These samples provide a dramatic illustration of the stripping power of humid tropical weathering, which shows that weathering appears to be almost completed while the rock itself is still structurally coherent. This last observation has not been noted previously in the case of Sri Lankan soils. Weathering in the wet zone is dominated by chemical processes. However in the surface layers physical processes such as rainwash of clay material is likely to be active leading to enrichment of silica. Also in the advanced stages of weathering as exemplified by laterites and latosols, the classical concept of chemical immobility in elements such as Al may not remain valid.

(b). Dry zone samples are the least weathered and predictions based on geochemistry indicate that in addition to silica these soils must also contain either residual primary minerals that contain nutrient elements and/or clay minerals with greater cation exchange capacity than kaolin, such as smectite or vermiculite. Again these predictions are justified by mineralogical observations of earlier workers. Hence these soils constitute fertile agricultural soils. In addition;

(c). Fresh rocks plot in a relatively tight cluster along the mixing line between quartz and other primary minerals. The overall dominance of climate in determining soil characteristics in tropical regions irrespective of parent rock type, is clearly brought out in these diagrams.

The intensely cultivated wet zone soils have been subject to severe weathering, and, as a result, have very low nutrient reserves compared to parent rock and dry zone soils. The degree of depletion of bases is indicated in both figs. 2 and 4. A clear case is made for the need to restore and maintain a nutritively balanced environment in the wet zone soils such as is found in naturally fertile soils. This is embodied in the concept of powder rock fertilizer currently being developed in Brazil (Fyfe et al., 1983) for wet zone type soils. Considering the increasing trend for secondary and trace nutrient deficiencies, this should clearly be a remedial objective of agricultural policy in Sri Lanka before the situation worsens and calls for costly imported amendments.

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