

STUDY OF THE WEATHERING OF BASIC, INTERMEDIATE, AND
ACIDIC ROCKS UNDER TROPICAL HUMID CONDITIONS

by

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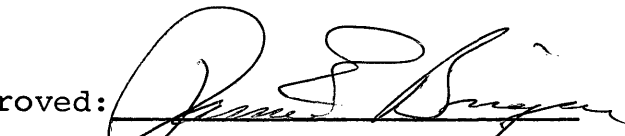
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ABSTRACT

Chemical and mineralogical changes that result during weathering of basic, acidic, and intermediate rocks in jungle and savanna environments have been studied.

The regional setting for this study was the Guayanan Shield, Venezuela. Six weathering profiles were studied:

- (1) El Callao metagabbro (Pit No. 1), jungle environment.
- (2) Las Patillas amphibolite (Pit No. 4), savanna environment.
- (3) Nuria diabase (Well Core No. 14), jungle environment.
- (4) El Carmen granodiorite (Pit No. 2), jungle environment.
- (5) Las Bombitas granodiorite (Pit No. 6), savanna environment.
- (6) La Paragua granite (Pit No. 7), savanna environment.

X-ray diffraction, x-ray spectrometry, and chemical techniques have been applied to the study of the weathering processes. Soils and rock samples have been analyzed for Si, Al, Ca, K, Fe, Ti, Mn, Ni, Cu, Zn, and organic carbon.

The relative mineral stabilities in the six weathering profiles under investigation generally follow the mineral-stability series proposed by Goldich (1938) from weathering studies of rock in a temperate environment.

The nature of the clays formed and their sequence in the soil profile depend principally on the rate of movement of water through the profile and its direction of flow. The secondary products identified by x-ray diffraction in the soil profiles were as follows (from the bottom to the surface):

- (1) Gibbsite, kaolinite, goethite - granite (Pit No. 7), savanna environment.
- (2) Kaolinite - granodiorite (Pit No. 6), savanna environment.
- (3) Kaolinite, goethite - granodiorite (Pit No. 2), jungle environment.
- (4) Kaolinite, gibbsite, goethite, hematite - diabase (Well Core No. 14), jungle environment.
- (5) Quartz, montmorillonite - metagabbro (Pit No. 1), jungle environment.
- (6) Montmorillonite, kaolinite, quartz - amphibolite (Pit No. 4), savanna environment.

The sequence of gibbsite and kaolinite is controlled by the direction of water flow. The presence of gibbsite underneath kaolinite (Pit No. 7) indicates an upward movement of leaching solutions in the savanna environment; the inverse sequence observed in the jungle (Well Core No. 14) indicates a downward flow of leaching solutions.

The order of loss of major elements generally follows the order of loss reported in the literature - Ca>K>Si>Al. This order is consistently observed regardless of rock types and distinctive biological environs (jungle and savanna).

Manganese, nickel, copper, and zinc are generally depleted during weathering of granite, granodiorite, and amphibolite in the savanna environment; whereas, the same heavy metals are generally enriched during weathering of diabase and metagabbro in jungle environments. On the basis of the present study it is believed that hydrous manganese oxide present in the soil profile is probably the principal control on the distribution of Ni, Cu, and Zn during weathering.

In the six soil profiles investigated, iron and titanium follow the same distribution pattern.

Combined field and laboratory evidence indicates that the transformation of goethite to hematite takes place in the tropical weathering environment. This transformation is the opposite of the phenomenon operating under temperate climates (Schwertmann, 1971).

Further work in the field and laboratory aspects of the study is suggested.

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INTRODUCTION

Weathering processes take place primarily as a response of materials which have been in equilibrium within the lithosphere, to conditions of disequilibrium in contact with the hydrosphere, atmosphere, and biosphere. The rate of decomposition of rock under these conditions is dependent upon numerous factors: size of the rock particles; permeability of the rock mass; position of the ground water table; relief of the land; composition of the rock; oxygen and other gases in the system; macro and micro flora and fauna; surface; time; and climate.

Three main types of weathering may be distinguished: physical, chemical, and biological. All these processes may take place in conjunction, though their relative importance varies according to the characteristics of the physiographic environment. In the arctic regions physical processes predominate, whereas in tropical regions chemical and biological weathering are the principal modes of rock decomposition.

An understanding of the factors controlling the chemical weathering under tropical conditions will provide insight applicable to two important areas:

(1) Fertility of soils - Bonazzi (1957 and 1969) reports the presence of ferruginous conglomerates covering extensive

regions in Venezuela, Colombia, Ecuador, Guyana, and parts of Brazil. This ferruginous matter makes the penetration of plant roots quite difficult preventing them from reaching nutrients and water.

(2) Geochemical prospecting; the role of hydrous oxides of manganese and iron in the distribution of heavy metals along the soil profile must be considered when geochemical prospecting methods are being used. These oxides commonly occur as a coating on clays concentrating trace elements.

Weathering does influence agriculture and the dispersion of heavy metals in the soil profile and therefore, a thorough study of weathering under tropical conditions will clarify some of the geochemical and biogeochemical problems inherent in these regions.

This investigation will be focused on three specific areas:

(1) To analyze the mineralogy and relative mobility of selected major and trace elements during weathering of basic, intermediate, and acidic rocks under conditions of both jungle and savanna environment. Almost all of the chemical and mineralogical data available to date are from humid temperate regions.

(2) To demonstrate that differences in the local physiographic environment produce distinctively different chemical changes even in similar rock under the same climatic conditions.

(3) To define and evaluate the factors controlling the distribution of Ni, Cu, and Zn during weathering.

The characteristic of the weathering processes and the parameters that may control their variations will be used as a basis to plan laboratory models, which will contribute to a better understanding of the weathering process in temperate and tropical conditions.

The relative mobility of an element during weathering is achieved as a ratio between the concentration of the element in the soil to the concentration of the same element of the parent rock. The values of relative mobility are reported as losses and gains of elements in the soil profile, relative to their concentration in the parent rock. For example, when the value of unity is assigned for each constituent of the parent rock, the constituents of any one sample, for which the ratios are less than one have been depleted. Those constituents whose ratios are greater than one have been concentrated.

The gains and losses will be used to correlate distribution of elements during weathering, and this distribution will be related to mineralogical changes which occur in the soil profile.

The relative enrichment of an element during weathering is accomplished either by the formation of stable secondary products or by the loss of other constituents; this loss results in an increase in the weight of the remaining element per unit volume of sample. An unchanged ratio of an element in an obviously weathered system arises only because of a fortuitous balance of gains and losses in it and other elements. Therefore, only the loss of an element in the weathering profile provides unequivocal indication of a chemical change. However, data of loss and gains are

valuable in order to interpret the processes affecting the distribution of elements and minerals.

The regional setting for this study is in the Guyanan Shield in the state of Bolivar, Venezuela (Plate 1, back pocket). Its areal extent is bounded approximately by latitudes $5^{\circ}52'$ to $7^{\circ}35'$ north and $63^{\circ}35'$ to $62^{\circ}41'$ west.

The region is approximately 250 meters above sea level. It has a humid tropical climate with an annual average temperature of 26°C , and an average rainfall of 1500 mm per annum (Figure 1).

The rainy season ranges from May to October and a relatively dry season from November through April.

Two types of biological environs are common, jungle and savanna. Although intermingled, they are very different in the characteristics that affect migrations of ions in soils.

In the savanna the soil is generally dry, hard, and exposed to temperatures up to 60°C . Rainfall on the savanna results in quick surface runoff to rivers, and there seems to be strong vertical migration of water to the surface as it is heated and evaporated by the sun during the day. This environment favors the concentration of ferruginous material and kaolinite close to the soil surface.

In the jungle the soil, generally moist, is covered by decomposing organic matter, and does not receive much direct sunlight. Rain water, slowly percolating into the soil with

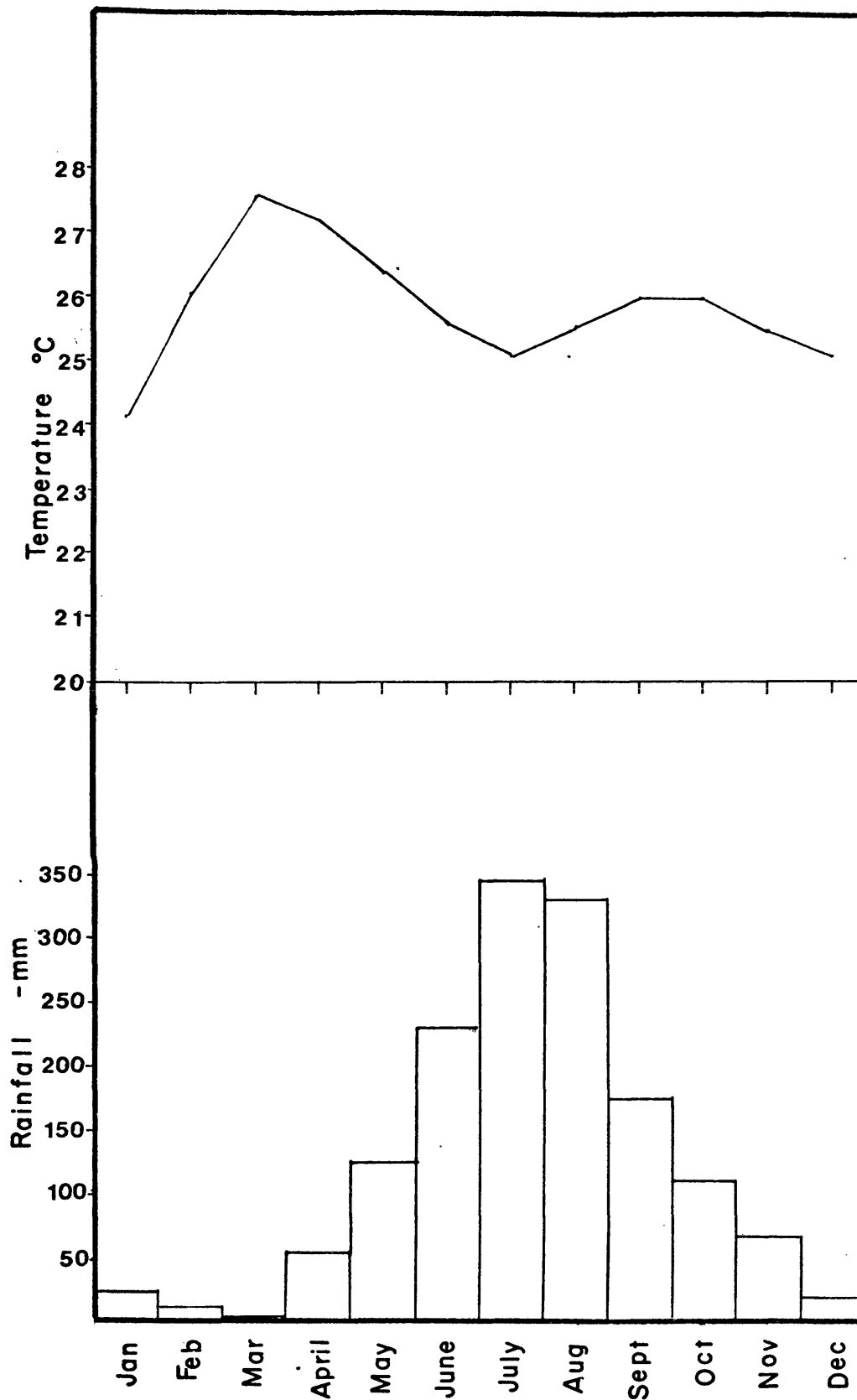


Figure 1. Temperature and rainfall distribution at Bolivar State, Venezuela.

a predominant downward flow of water from the surface, gives rise to extensive ion leaching.

The nutrient elements tend to be concentrated in the surface horizon as a result of extraction from the profile by plant roots and deposition on the surface by plant litter.

PREVIOUS WORK

The first detailed work dealing with the weathering of igneous rocks under tropical conditions was traced by Harrison (1933), from 1890 to 1919. Harrison analyzed the average quarry granite at Kalacoon British Guiana, and the sandy white (kaolinite) clay at the top of the quarry. He found in the alteration of granite to kaolinite the following order of relative proportions of elemental loss: $\text{Na}_2\text{O} > \text{CaO} > \text{K}_2\text{O} > \text{Fe}_2\text{O}_3 > \text{MgO}$; and Al_2O_3 is enriched at the top of the quarry in the kaolinite.

Subsequent workers who have published information regarding the chemistry of weathering processes include Goldich (1938), Brock (1943), Wahlstrom (1948), Reiche (1950), Butler (1953, 1954), Keller (1955, 1960, 1963a, 1963b), McLaughlin (1955), Anderson and Hawkes (1958), Miller (1961), Short (1961), Bolter (1961), Dennen and Anderson (1962), Correns (1963), Altschuler and others (1963), Davis (1964, 1966), Harris and Adams (1966), Lamar (1968), Marval (1968), Ong and Bisque (1968, 1970), Ruxton (1968), Pasquali and Lopez (1972).

The following generalizations appear valid on the basis of previous studies:

- (1) The distribution of major elements during weathering

under tropical conditions follow a complex and variable process which can be summarized by a few generalizations. Almost all the data available to date are from humid-temperate regions. It would appear from a few of the published studies - Harrison (1933), Brock (1943), Pasquali and Lopez (1972) - that the general tendency of distribution of major elements is as follows:

Enriched: Al_2O_3 , Fe_2O_3 , and TiO_2

Unchanged: SiO_2

Depleted: Na_2O , K_2O , CaO , and MgO

(2) The distribution of major elements during weathering under temperate conditions follows a pattern similar to that of elements under tropical conditions.

It is noted that temperate vs. tropical climate apparently has no direct influence upon the distribution of major elements during weathering, but they are probably effective in degree.

(3) Under humid weathering conditions mineral stability generally follows a sequence proposed by Goldich (1938). This sequence is the reverse of the normal sequence of crystallization of minerals from an igneous melt.

(4) The relative importance of factors such as parent-rock type, climate, topography, vegetation, and bacterial activity is highly variable and may be different for each case investigated. Reiche (1950, p. 70) supposed a general

agreement in the ways of formation of soils under temperate conditions, but indicates that under humid tropical conditions that agreement does not exist. He suggested that the lack of understanding among tropical-weathering workers is due to differences in microclimate, parent rocks, vegetation in their study areas, plus the fact that some researchers do not go to the field and try to explain the tropical weathering in terms of pedology in temperate regions.

(5) Mineralogy, although sometimes of primary importance, cannot be used to predict the course of chemical weathering. Loughnan and Bayless (1961) found that in an adequately "severe" environment, a parent material containing 90% silica and as little as 4% alumina may give rise to bauxites relatively deficient in silica.

(6) Researchers agree on the general influence of organic material in the mobilizations of ions during weathering: Wright and Schiutzen (1963, p. 340), Kauricher and Nozdrunova (1964), Schalscha and others (1967), Ong and Bisque (1967). The ability of soluble soil organic matter to form stable combinations with iron and other metals in aqueous solutions appears to be well established; although further research is needed to understand the oxidation of the metal-organic associations. There is some indication that hydrous oxide of iron catalyzes the oxidation of Fe^{++} to Fe^{+++} . Gasser and Bloomfield (1955, p. 219) found that

ferrous iron, chelated by natural organics, was readily oxidized at ferric oxide surfaces in the presence of oxygen and ferric hydrous oxide.

(7) Hydrous oxides of Mn and Fe found in soils, clays and sediments exert a chemical influence far greater than that of their concentrations. Jenne (1968) stated that these hydrous oxides furnish the principal control on the fixation of Co, Ni, Cu, and Zn in soil and fresh water sediments. The presence of only a fraction of a percent to a few weight percent of hydrous oxide of manganese and iron may be adequate to control the distribution of the heavy metals between earth materials and their associated aqueous phase.

FIELD AND LABORATORY METHODS

For the study of the variations of major and minor elements in the soil profiles, holes were dug until fresh or incipiently weathered rock was found.

The bedrock was reached from 2.50 to 14 m deep, depending on the relief and lithology.

The criteria used in selecting the areas for study were (1) regional geological data, (2) presence of outcrops, (3) favorable geomorphic setting, (4) presence of jungle and savanna environment, and (5) rock types.

The criteria of favorable geomorphic setting together with a saprolite texture similar to that of parent-rock indicate in place weathering. For example, if the most favorable geomorphic setting is a relatively flat topographically high area where the physical contamination and removal of material is minimized and the soil profile shows the presence of weathered rock with the same texture of the fresh rock, the soil profile indicates in place weathering.

These six soil profiles were sampled:

- (1) El Callao metagabbro (Pit No. 1), jungle environment.
- (2) Las Patillas amphibolite (Pit No. 4), savanna environment.
- (3) Nuria diabase (Well Core No. 14), jungle environment.

- (4) El Carmen granodiorite (Pit No. 2), jungle environment.
- (5) Las Bombitas granodiorite (Pit No. 6), savanna environment.
- (6) La Paragua granite (Pit No. 7), savanna environment.

Soil profile locations are given on the location map (Plate 1, back pocket).

Major and trace element analyses were performed by x-ray spectrometry methods. Organic carbon was determined by the method of Walkly-Black as described in Allison (1965, p. 1372-1375). This is a wet-combustion method commonly used to determine organic matter in soil and implies the oxidation of the organic matter by dichromate and backtitrating the excess of dichromate with ferrous iron.

Minerals present in soils and rocks were identified by standard x-ray diffraction techniques.

Details of sample preparation and analytical methods are given in Appendix I.

EXPLANATION OF DATA

The chemical data for concentration in relation to depth of the six profiles under investigation are given in Table 1 (Appendix II).

In figures 8, 9, 10, 11, 12, and 13, the chemical concentrations of Table 1 have been recalculated as concentration ratios; these ratios for each constituent have been plotted against depth from the surface: for example, the ratio of the content of an element at a specific level in the section to its content in the parent-rock.

The constituent of any sample which falls to the right of the point indicating unity (figures 8, 9, 10, 11, 12, and 13) has been gained. Those to the left have been lost.

The numerical values of concentration ratios are given in Table 2 (Appendix II).

The percentages of losses and gains (Tables 10, 11, 12, 13, 14, and 15) were calculated from the integration of the areas on the left and the right of the line indicating unity in figures 8, 9, 10, 11, 12, and 13.

Figures 2, 3, 4, 5, 6, and 7 present graphically the minerals in relation to depth. The minerals are plotted in order of approximate relative abundance as determined by relative integrated peak height on the x-ray diffraction

record. The x-ray diffraction values are given in Table 3 (Appendix III).

The nomenclature used in this study to describe the various horizons observed in the profiles under investigation is as follows:

A-horizon - the eluviated (leached) top layers.

B-horizon - the illuviated (enriched) intermediate layers.

C-horizon - highly weathered parent material.

D-horizon - moderately weathered rock (saprolite and/or unaltered parent material).

In a well-developed laterite profile the following nomenclature appears valid:

Concretionary zone (A-horizon) - pisolites and enriched iron oxides.

Pallid zone (B-horizon) - white clay and vertical accumulation of iron oxides.

Parent material (D-horizon) - moderately weathered rock (saprolite) and/or unaltered materials.

All these horizons do not necessarily occur in every soil profile.

Detailed description of the six soil profiles investigated are given in Appendix IV.

GENERAL GEOLOGICAL RELATIONS AND RESULTS

Basic Rocks

The mineralogical changes resulting from the weathering of the basic rocks are shown in figures 2 to 4. The residual soil profiles were formed by the weathering of (1) metagabbro (jungle), (2) amphibolite (savanna), and (3) diabase (jungle).

El Callao Metagabbro (Pit No. 1), Jungle Environment

General Statement. The El Callao metagabbro is located in the northern part of the El Callao district (Plate 1, back pocket). Metamorphosed gabbro rocks intrude concordantly into the formations of El Callao, Yuruary, and Caballape. These rocks (Ibm on Plate 2, back pocket) are predominantly exposed in synclinal structures on both sides of the Nacupai fault (Menendez, 1968).

The metagabbros of the area are generally coarse grained, and the essential minerals, identified by x-ray diffraction are labradorite-bytownite; augite; and the accessory minerals, hornblende and quartz. Chlorite and actinolite were also identified.

The chemical composition of the rock (Table 4) lies among the values quoted for the average gabbro (Nockold,

1954), although Al_2O_3 is definitely low in the El Callao metagabbro.

Table 4. Chemical Analyses of the El Callao Metagabbro

SiO_2 (percent)	49.01
Al_2O_3 (percent)	6.46
Fe_2O_3 (percent)	13.44
CaO (percent)	9.91
TiO_2 (percent)	0.46
Mn (ppm)	1868
Ni (ppm)	350
Cu (ppm)	151
Zn (ppm)	102

The metagabbro outcrops are found in a topographically high terrain, with gradient ranges from about 20 to 25%. The soil is well drained and the surface runoff is rapid. The vegetation is densely wooded, and trees protect the land against direct sunlight. Thus the evapotranspiration of the soil moisture is relatively low.

The weathering profile has not proceeded uniformly. The uppermost part of the soil profile represents the maximum pedochemical weathering (mature soil). Immediately below the mature soil is found the weathered rock with different degrees of alteration.

The complete weathering profile is described in Appendix IV.

Mineralogy in Relation to Depth. The mineralogy in relation to the degree of weathering developed on the El Callao metagabbro is shown in fig. 2. Chlorite is destroyed in an early stage of the weathering, and actinolite hornblende and plagioclases are progressively depleted toward the surface. Apparently resiliification occurs in the uppermost horizon yielding authigenic quartz and montmorillonite as secondary products in the late stage of the weathering.

The relative mineral stabilities in the El Callao metagabbro, from least to more stable, are:

chlorite < actinolite < labradorite-bytownite < hornblende

Las Patillas Amphibolite (Pit No. 4), Savanna Environment

General Statement. Las Patillas amphibolite is found 5 Km south of the Guri fault (Am on Plate 3, back pocket). These rocks are a part of the amphibolite of Panamo sequence described by Chase (1965). This sequence of mafic volcanic rocks contains mainly metavolcanic amphibolite and minor metachert layers.

The amphibolite outcrops are found in a topographically high terrain on the savanna; the gradient of these terrain ranges from 25% to 35% in steepness. The soil is well drained and surface runoff is rapid. The vegetation is mostly grass with far-spaced small trees. The fresh phase is a massive, well-foliated, fine-grained rock, composed

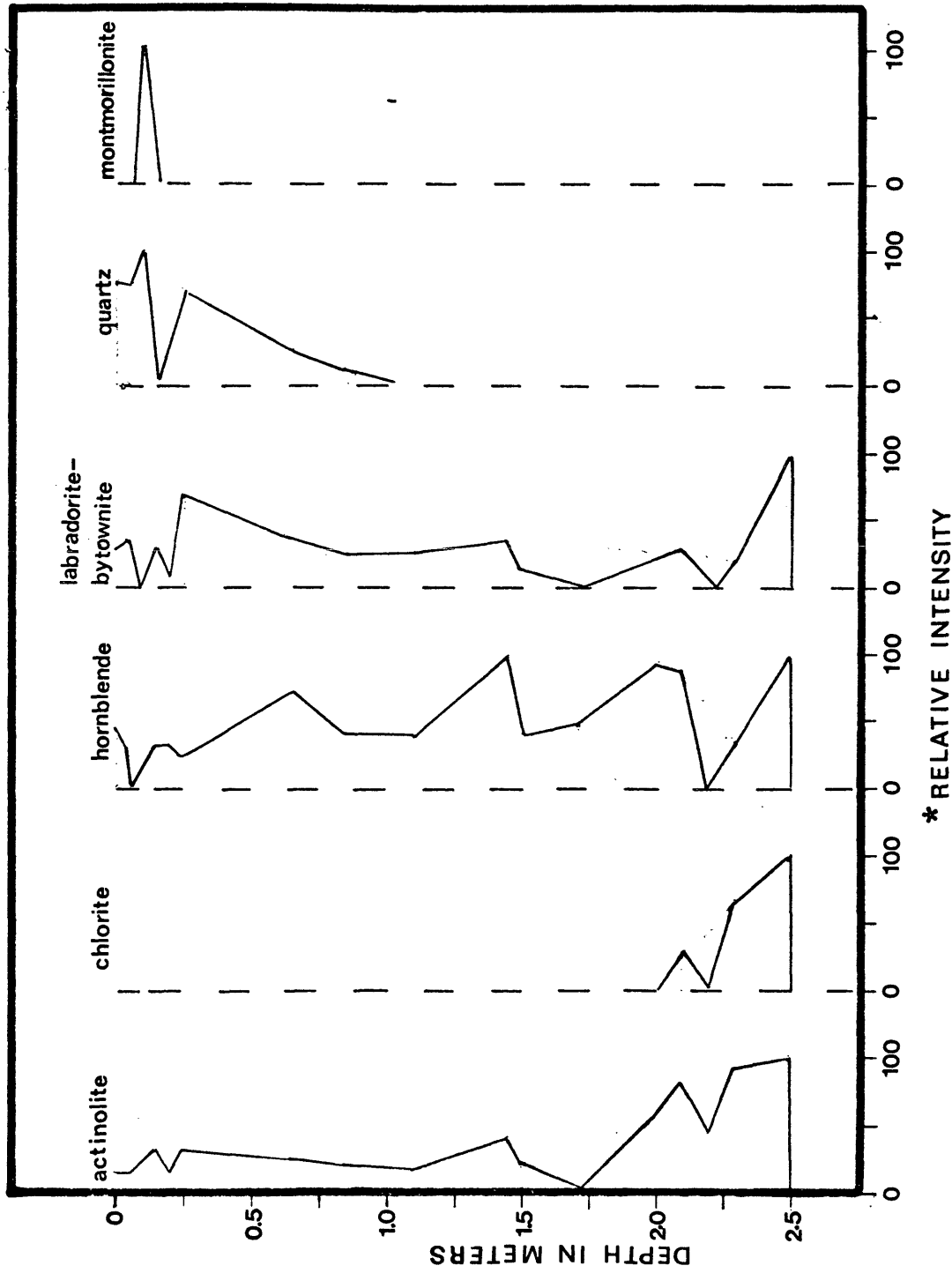


Figure 2. Mineralogy in relation to degree of weathering of the E1 Callao metagabbro (Pit No. 1), jungle environment.

* The minerals are plotted in order of approximate relative abundance as determined by relative (integrated) peak heights on x-ray diffraction record.

largely of dark-green hornblende. The essential minerals identified by x-ray diffraction are hornblende, albite-oligoclase, actinolite, and quartz.

The chemical analyses of the fresh rock are given in Table 5.

Table 5. Chemical Analyses of the Las Patillas Amphibolite

SiO ₂	(percent)	47.87
Al ₂ O ₃	(percent)	10.40
Fe ₂ O ₃	(percent)	16.98
CaO	(percent)	9.25
K ₂ O	(percent)	0.38
TiO ₂	(percent)	1.37
Mn	(ppm)	2128
Ni	(ppm)	68
Cu	(ppm)	93
Zn	(ppm)	143

Mineralogy in Relation to Depth. The mineralogical data for the alteration of amphibolite is given in fig. 3. A highly marked concentration of plagioclases (albite-oligoclase) appears in the D-horizon and decreases upward, reaching its lower intensity at the 1.10 m level from the surface. Actinolite and hornblende are completely depleted in the D-horizon. The presence of small amounts of actinolite and hornblende along the soil profile implies that the katamorphism of the rock does not occur with the same intensity in all the horizons.

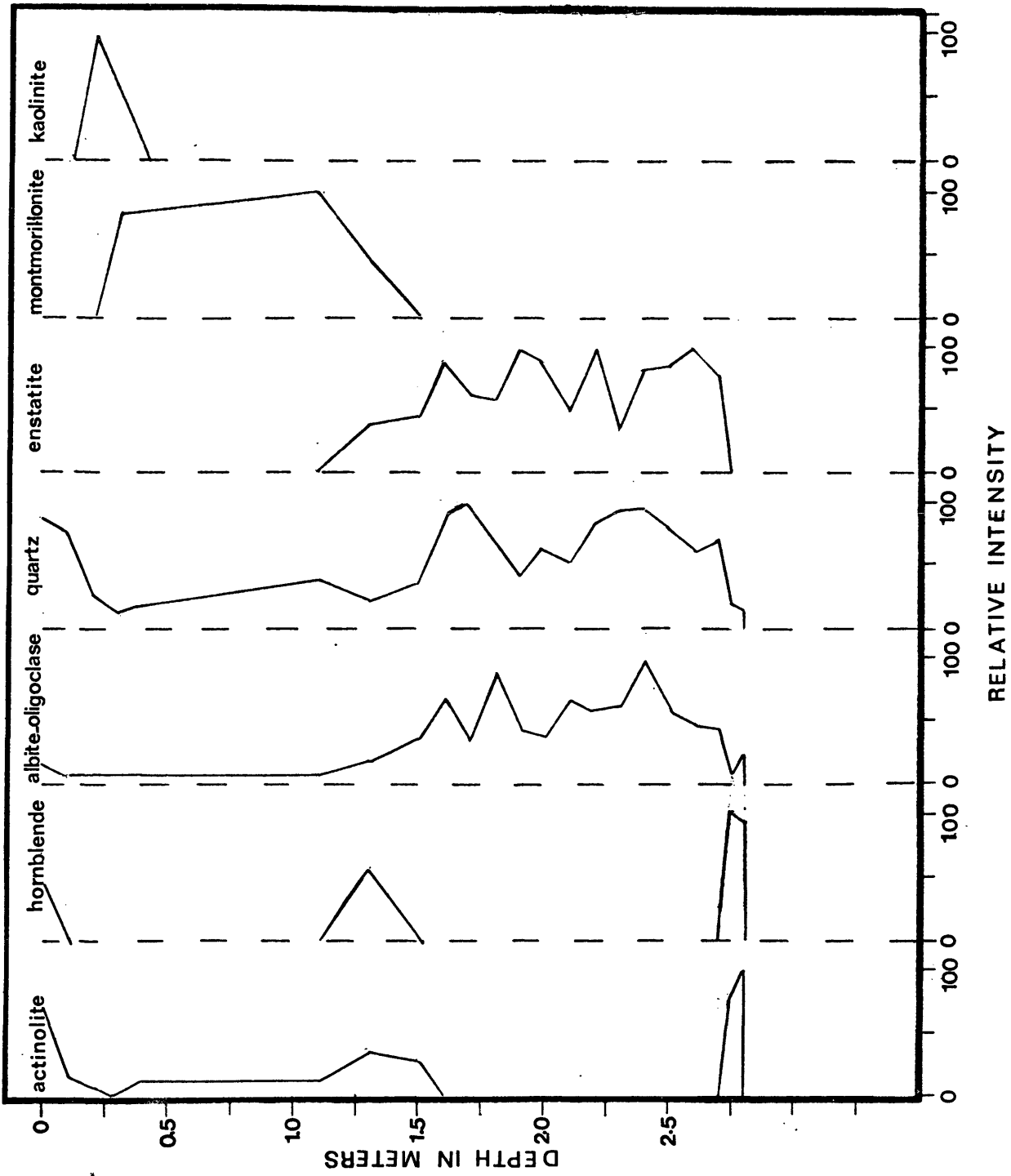


Figure 3. Mineralogy in relation to degree of weathering of the Las Patillas amphibolite (Pit No. 4), savanna environment.

Quartz is progressively dissolved upward in the soil profile, and apparently near the surface silicification takes place yielding authigenic quartz.

A transformation of montmorillonite into kaolinite is observed in the upper horizon of the same profile.

The change of montmorillonite to kaolinite in the tropical environment is particularly note-worthy; the change exemplifies the breakdown of complex sheet silicates to simpler 1:1 layer structure. The liberated SiO_2 accounts for the authigenic quartz formed in the uppermost horizon (Figure 3).

The relative mineral stabilities in the Las Patillas amphibolite, from least to more stable, are:

enstatite < hornblende < actinolite < albite-oligoclase << quartz

Nuria Diabase (Well Core No. 14), Jungle Environment

General Statement. The Nuria diabase is found at the north central part of the Guayanan Shield, Venezuela (Plate 1, back pocket). These rocks are made up of unmetamorphosed diabase in the form of a shallow plate-shaped intrusion in the mesa of Nuria (Ib on Plate 2, back pocket).

The shallow plate-shape of the mesa of Nuria and the diabase dikes (Laguna dike) are the youngest rocks in the region. The ages of these rocks have not been determined in this area, but similar rocks have been determined to the northeast to be 400 m.y. (Martin-Bellizzia, 1968).

The topography is high and varies from the smooth peneplain to steep mountain slopes. The terrain is drained, and the surface runoff is medium. The permeability is moderate. The vegetation is dense.

The minerals identified by x-ray diffraction in the fresh diabase are andesine-labradorite, augite, microcline, and quartz.

The chemical analyses of the fresh diabase are given in Table 6.

Table 6. Chemical Analyses of the Nuria Diabase

SiO ₂	(percent)	51.48
Al ₂ O ₃	(percent)	15.50
Fe ₂ O ₃	(percent)	10.44
CaO	(percent)	10.56
K ₂ O	(percent)	0.52
TiO ₂	(percent)	0.84
Mn	(ppm)	1171
Ni	(ppm)	81
Cu	(ppm)	176
Zn	(ppm)	106

The weathering profile developing on the Nuria diabase has proceeded more deeply than weathering on gabbro or amphibolite, and it has produced severe mineralogical changes. This profile (Appendix IV) corresponds to a typical laterite bauxite deposit developed on the diabase

in the mesa of Nuria. The local conditions, topography, internal drainage, dense tropical vegetation and time have promoted the leaching of silica in the early stage of weathering. These conditions later facilitate the breakdown of kaolinite with the subsequent accumulation and immobilization of bauxite in this area.

Mineralogy in Relation to Depth. The complete mineralogical sequence formed on the diabase is recorded in Figure 4. Four zones, each characterized by the mineralogy, are observed in the profile (Appendix IV):

(1) fresh diabase.

(2) kaolinite zone approximately 5.50 m thickness, kaolinite, quartz and goethite being the dominant constituents.

(3) gibbsite zone approximately 6 meters in thickness. In this zone gibbsite, hematite, and goethite predominate. The transformation of goethite to hematite observed in this zone is especially note-worthy -- it exemplifies the inverse of the process that is occurring in the temperate climate (Schwermann, 1971). This transformation is discussed in the interpretation of the geochemical processes followed in this study.

(4) concretionary zone approximately 2 meters thick. Goethite-rich pisolites roughly spherical shaped are predominant in this zone. The pisolites vary from 5 to 20 mm in diameter. Also gibbsite and traces of kaolinite are present in this horizon.

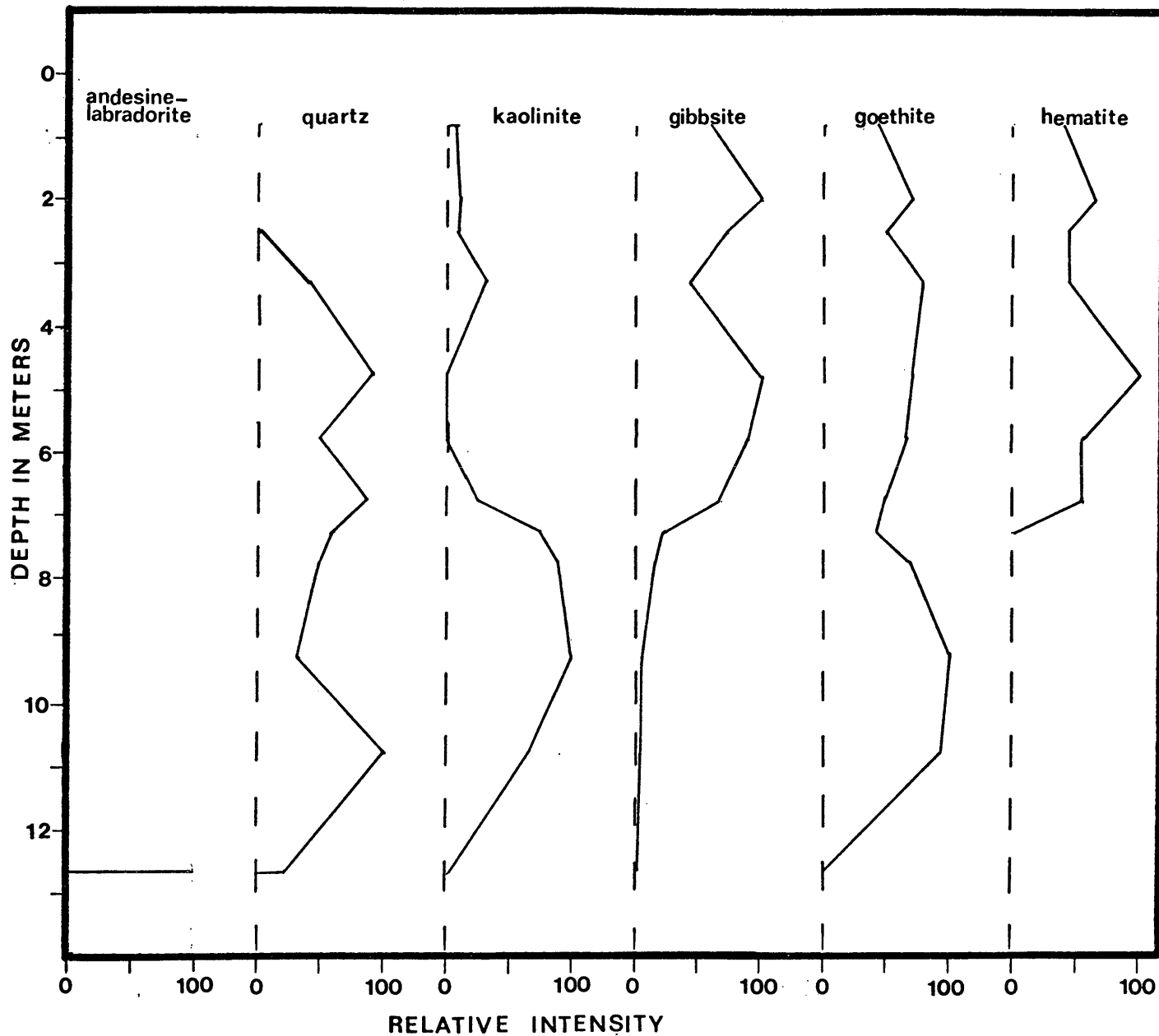


Figure 4. Mineralogy in relation to degree of weathering of the Nuria diabase (Well Core No. 14), jungle environment.

Intermediate Rocks

The mineralogical and chemical changes resulting from the weathering of granodiorite in both jungle and savanna environments are shown in figures 5 and 6.

El Carmen Granodiorite (Pit No. 2), Jungle Environment

General Statement. The El Carmen granodiorite is located in the northeast part of the Guayanan Shield, Venezuela (Plate 1, back pocket). These rocks are found in the Supamo Complex (Menendez, 1968), which includes a series of intrusives acid igneous rocks, migmatites and quartz-feldspar gneisses that have not been differentiated. The granodiorite outcrops are found in jungle surrounded by a rolling topography. The soil is moderately drained and surface runoff is slow to medium. The vegetation is typical of the jungle environment, densely wooded.

The fresh phase is a coarsely crystalline rock composed largely of labradorite, microcline, biotite, and quartz. The chemical analyses of the rock are shown in Table 7.

The weathering profile developed on granodiorite has proceeded very deeply. The fresh rock grades upward through a saprolite, passing into sand containing coarse material up to about 1 mm in diameter, then going on to pedologically well-developed soil. The description of the weathering profile is given in Appendix IV.

Table 7. Chemical Analyses of the El Carmen Granodiorite

SiO ₂	(percent)	60.45
Al ₂ O ₃	(percent)	11.28
Fe ₂ O ₃	(percent)	4.34
CaO	(percent)	3.22
K ₂ O	(percent)	2.66
TiO ₂	(percent)	0.64
Mn	(ppm)	530
Ni	(ppm)	52
Cu	(ppm)	74
Zn	(ppm)	75

Mineralogy in Relation to Depth. The complete mineralogical sequence developed on granodiorite is shown in Figure 5. A much marked concentration of plagioclases, microcline, biotite, and quartz appears in the D-horizon. Biotite and labradorite are completely exhausted in the D-horizon, whereas microcline still remains in the D- and C-horizons. Kaolinite appears in the C-horizon and its concentration increases toward the surface, reaching a maximum in the B-horizon; then it diminishes toward the surface. This maximum would mean that kaolinite undergoes two different effects in the profile:

(1) A strong leaching process in the uppermost horizon responsible for its degradation at the surface, evidently held by the downward movement of solutions very rich in organic matter. This observation supports very well the argument of downward flow of water and leaching solutions in jungle environment suggested by Pasquali and Lopez (1971).

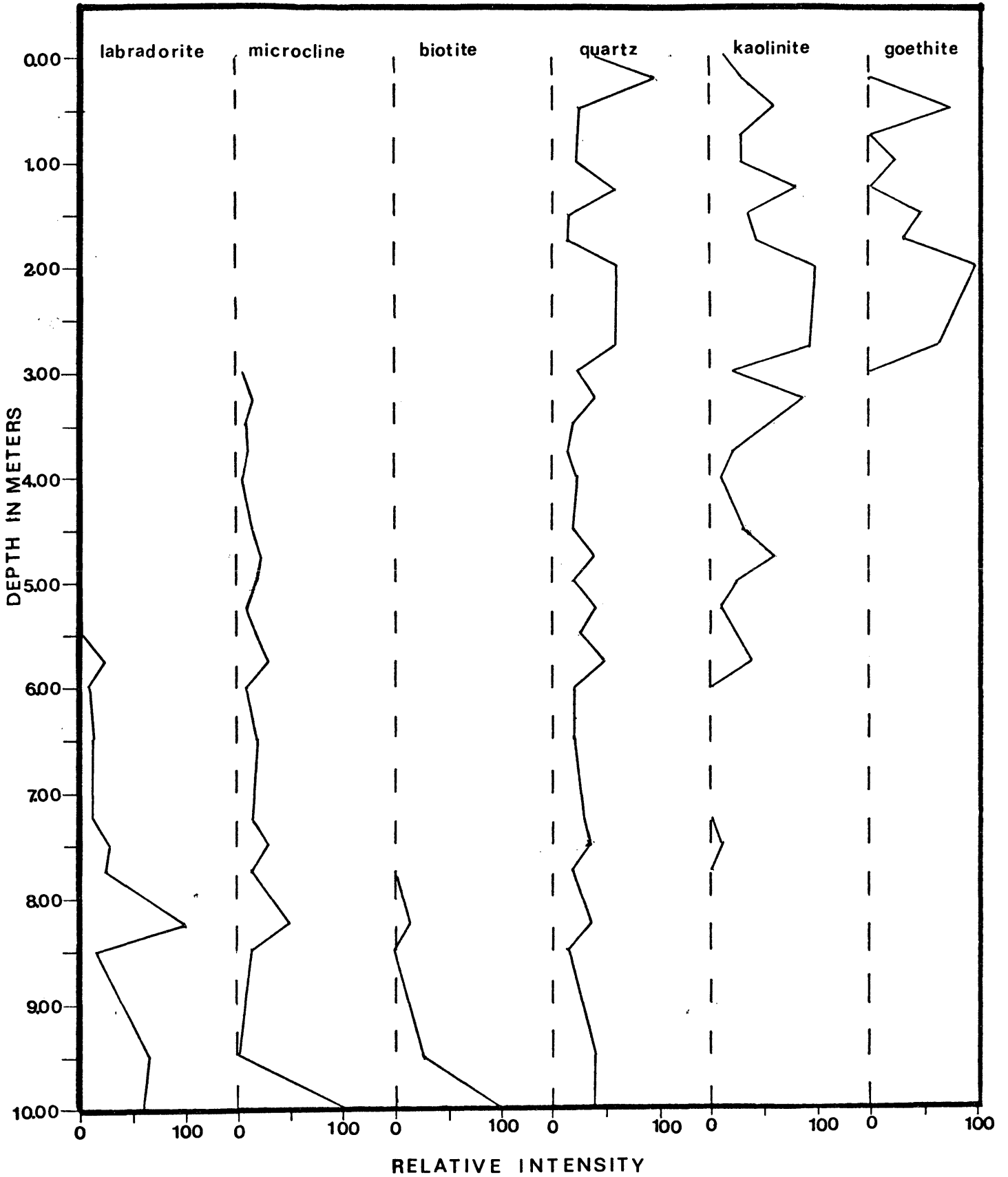


Figure 5. Mineralogy in relation to degree of weathering of the El Carmen granodiorite (Pit No. 2), jungle environment.

(2) A gradational formation of kaolinite from the parent materials.

Goethite appears in the B-horizon; its concentration decreases toward the surface. An inverse relationship in the formation of goethite relative to organic carbon is observed in the uppermost horizon of this soil profile.

The relative mineral stabilities in the El Carmen Granodiorite, from least to more stable, are:

biotite<labradorite<microcline<<quartz

Las Bombitas Granodiorite (Pit No. 6), Savanna Environment

General Statement. The Las Bombitas granodiorite is located at the southeast of the Guri fault in the Guayana Shield (Plates 1 and 3, back pocket). These rocks are found in the Supamo complex. It includes a series of intrusives acid igneous rocks (Espejo, 1972). The granodiorite outcrops are found in a topographically flat terrain on the savanna. The soil is excessively drained, and permeability is moderate.

The fresh phase is a coarsely crystalline rock composed of labradorite, microcline, biotite, and quartz.

The chemical analyses of the rock are given in Table 8.

Mineralogy in Relation to Depth. The residual soils on the Las Bombitas granodiorite are almost entirely composed of kaolinite, quartz, and iron oxides. Kaolinite appears in the C-horizon and its concentration increases

upward reaching a maximum at the 2.5 m level from the surface. Quartz is progressively dissolved reaching a minimum at the 2.5 m level from the surface, then it increases toward the upper part of the profile.

The distribution of kaolinite and quartz in relation to depth is given in Figure 6.

Table 8. Chemical Analyses of the Las Bombitas Granodiorite

SiO ₂	(percent)	66.51
Al ₂ O ₃	(percent)	12.24
Fe ₂ O ₃	(percent)	2.33
CaO	(percent)	3.11
K ₂ O	(percent)	0.85
TiO ₂	(percent)	0.28
Mn	(ppm)	291
Ni	(ppm)	153
Cu	(ppm)	313
Zn	(ppm)	222

Acidic Rocks

The mineralogical variations resulting from the weathering of the granite in the savanna environment are shown in Figure 7.

La Paragua Granite (Pit No. 7), Savanna Environment

General Statement. The La Paragua granite is located between the rivers Aro and La Paragua, and the latitude is

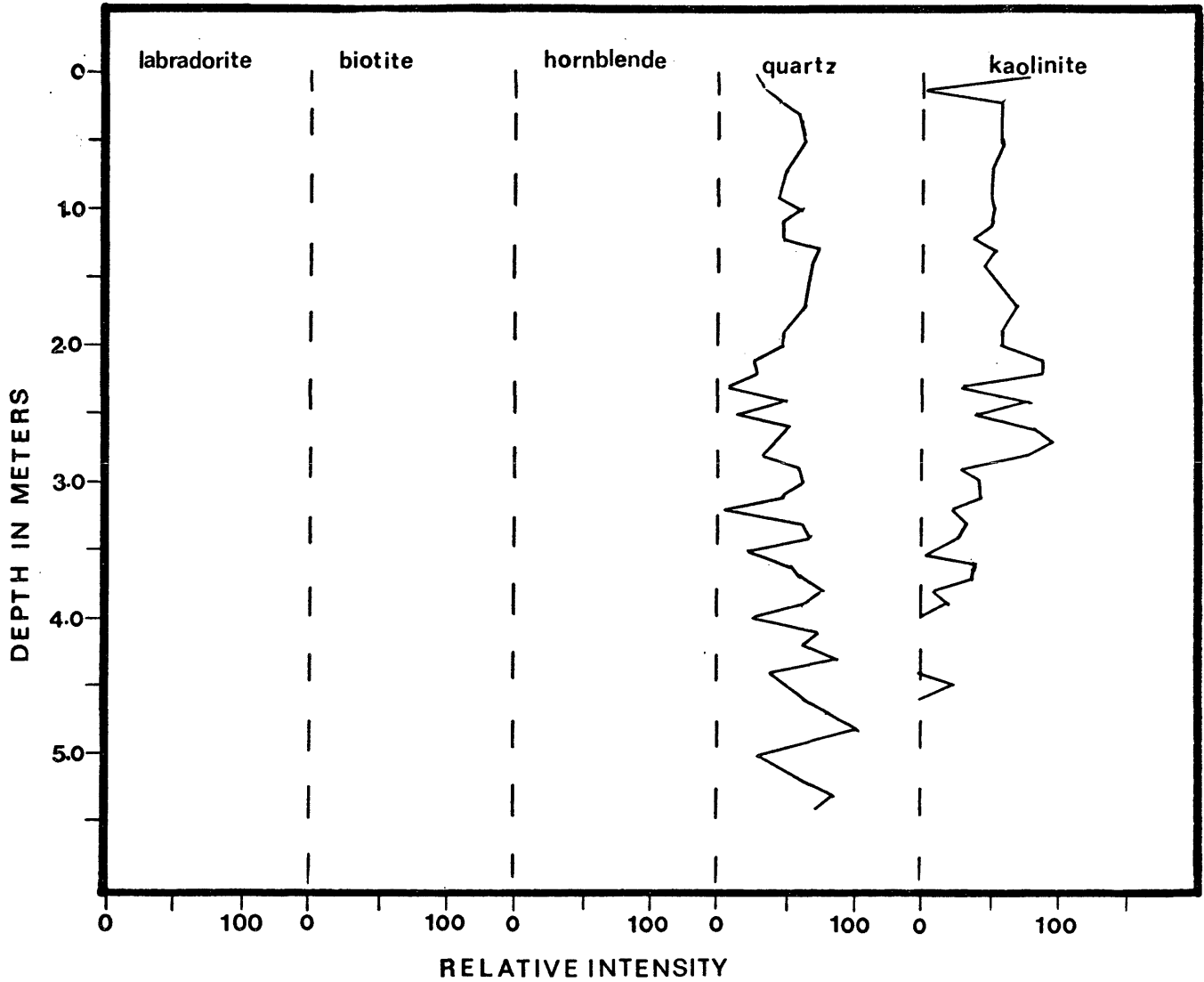


Figure 6. Mineralogy in relation to degree of weathering of the Las Bombitas granodiorite (Pit No. 6), savanna environment.

5°30' and 7° in the state of Bolivar (Plate 1, back pocket). The terrain lies at an elevation of about 250 meters.

Pit No. 7 is located in a topographically high terrain in the savanna environment. The surface runoff is rapid, and the soil is covered by a grassy vegetation.

The x-ray studies of the fresh rock show the presence of the following minerals: albite-oligoclase, microcline, biotite, and quartz. The chemical analyses of the fresh rock (Table 9) lie among the values quoted for the average granite (Nockolds, 1954).

Table 9. Chemical Analyses of the La Paragua Granite

SiO ₂	(percent)	69.67
Al ₂ O ₃	(percent)	11.78
Fe ₂ O ₃	(percent)	1.91
CaO	(percent)	0.99
K ₂ O	(percent)	4.83
TiO ₂	(percent)	0.30
Mn	(ppm)	375
Ni	(ppm)	21
Cu	(ppm)	47
Zn	(ppm)	74

The fresh rock weathers into a saprolite and then passes into sand containing material up to about 1 mm in diameter; finally it becomes a well-developed soil. Detailed description of this soil profile is given in Appendix IV.

Mineralogy in Relation to Depth. Albite-oligoclase, microcline, and biotite are depleted at the initial breakdown of the rock. The residual soil profile is a mixture of quartz, gibbsite, and kaolinite.

It appears from the x-ray diffraction pattern that the amount of gibbsite present relative to kaolinite decreases with increasing alteration.

The mineralogy in relation to degree of weathering is given in Figure 7.

Relative Mobility of the Selected Elements
During Weathering of Basic Intermediate
and Acidic Rocks

The variations in concentration ratios at various stages of profile development on acidic, intermediate, and basic rocks are presented graphically in figures 8 to 13. The values of elemental gains and losses during the transition from rock to soil are given in tables 10, 11, 12, 13, 14, and 15.

Silica

The distribution of silica was not uniform through each stage of the weathering in all the soil profiles investigated. However, the concentration ratios of silica tend to decrease with increasing weathering regardless of variations in the parent-rock mineralogy, environments, and local physiographic

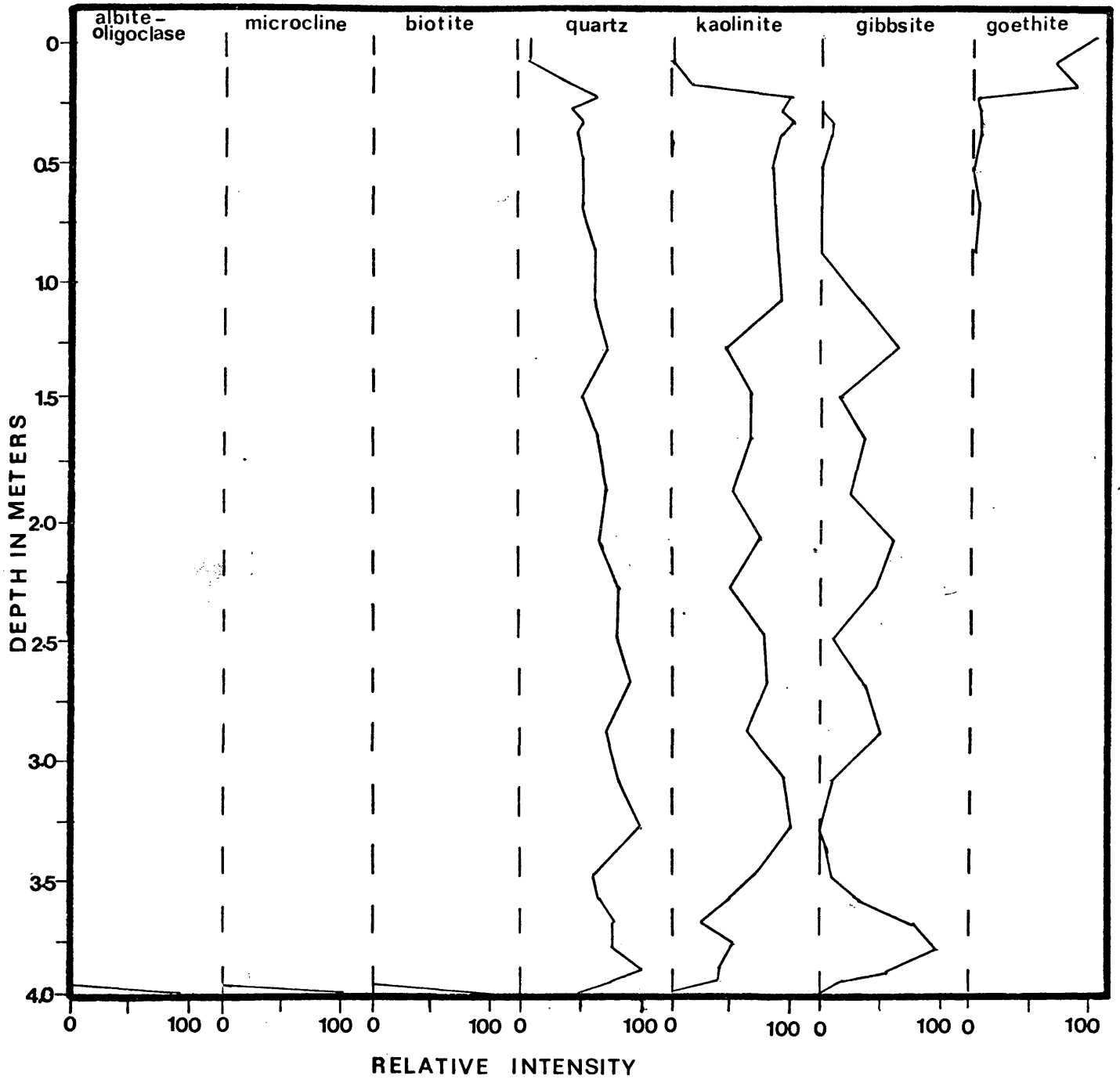


Figure 7. Mineralogy in relation to degree of weathering of the La Paragua granite (Pit No. 7), savanna environment.

conditions.

In the profiles from Well No. 14 on the Nuria diabase (jungle), Pit No. 2 on the El Carmen granodiorite (jungle), and the Pit No. 6 on the Las Bombitas granodiorite (savanna), kaolinite accounts for the silicon leached in the A-horizon. Whereas from the profiles - Pit No. 7 on the La Paragua granite (savanna), and Pit No. 4 on the Las Patillas amphibolite - quartz accounts for the solubilization of silica in the uppermost horizon.

An enrichment in silica was observed in the A-horizon of the profiles from Pit No. 2 and Pit No. 4. This increase in silica can be attributed to the formation of authigenic quartz, which results from the dissolution of kaolinite (Pit No. 2) or the transformation of montmorillonite into kaolinite (Pit No. 4).

The total amount of silica losses were in the range of 2 to 15%, with the exception of the strongly developed bauxite deposit on the Nuria diabase (Well No. 14). It undergoes 59% of silica loss.

Alumina

An inverse relationship in the geochemical distribution of alumina relative to the silicon was noted in each of the weathering profiles investigated. As with silica, the changes in alumina concentrations were not uniform through

each stage of the weathering. However, the concentration ratios of aluminum tend to increase with increasing rock alteration in all six profiles investigated. It should be noted that the apparent increase in alumina is not due to the addition of material, but rather is the result of the loss of other constituents yielding an increase in the weight percent of alumina per unit of volume of sample.

The pH in the weathering zone is especially significant for the transportation of alumina and its ultimate redeposition. Alumina is practically insoluble from pH 5 to 9, and in the first few centimeters of the A-horizon of the soil profiles investigated, alumina is depleted at pH 6 to 7. Thus, it infers that the accumulation of organic matter in these horizons is largely responsible for the leaching of alumina.

The total amount of alumina lost (0 to 3%) in the transition from rock to soil was similar in all the soil profiles investigated, with the exception of the profile Pit No. 6 on the Las Bombitas granite (savanna). This profile undergoes a 34% alumina loss. It is due to the very severe internal drainage in the lower horizons of this soil profile.

The total amount of alumina gain in all the soil profiles studied range from 1% to 71%. The largest percentage gain in alumina (71%) occurred in the profile on the Nuria diabase; and the lowest percentage (1%) occurred in the

profile from Pit No. 6 on the Las Bombitas granodiorite.

Calcium

A definite loss of calcium during weathering occurs in each of the profiles studied. The profiles (Pit No. 4, Pit No. 6, Pit No. 7, and Well 14) show the largest removal of calcium from the bulk rock.

In the profile from Pit No. 4, on the Las Patillas amphibolite, calcium content remains constant throughout the course of the weathering. The constancy in calcium along the soil profile can be attributed to the sorption of Ca^{2+} onto the montmorillonite in the upper horizon of the soil profile.

Pit No. 1 and Pit No. 2 show that the amount of calcium removed from the rock is proportional to the degree of alteration of the calcic plagioclases. Calcium generally exhibits much greater mobility during the early stages of weathering than any of the other elements investigated.

The calcium losses range from 35% to 100%, depending on the degree of maturity of the profile and the conditions of internal and external drainage of the terrain.

Potassium

In general the geochemical distribution of potassium is similar in each of the weathering profiles investigated. Potassium content in each case decreases during the trans-

formation of rock to soil with significant leaching in the early stage of the weathering.

The profile on the El Carmen granodiorite (Pit No. 2) shows an enrichment in potassium content in the lower horizons followed by a depletion in potassium with increased weathering. The small increase in potassium in the lower horizons can be attributed to the increase in the relative amount of potash-feldspar per unit of volume which results from the dissolution of plagioclases. Then during the later stage of weathering as the potash-feldspar begins to show significant alteration a decrease in the potassium content of the bulk sample is noted.

The total amount of potassium lost (80 to 99%) was very similar in all of the profiles investigated, with the exception of the immature profiles in Pit No. 2 on the El Carmen granodiorite (30%), and Pit No. 4 on the Las Patillas amphibolite (58%).

Iron

The distribution of iron during weathering is very irregular in the profiles investigated. In general, iron tends to be concentrated in the upper horizons. However, iron is depleted in the uppermost horizon in the jungle environment, with the exception of the well developed bauxite profile (Well Core No. 14) on the Nuria diabase.

In the profiles from Pit No. 1 and Pit No. 6 iron shows a tendency to be depleted in D- and C-horizons corresponding to the transition from weathered rock to a completely disaggregated and leached soil. Then it is enriched in the intermediate and late stage of the weathering.

In the profiles - Pit No. 7 on the La Paragua granite (savanna), Pit No. 2 on the El Carmen granodiorite (jungle), and Well Core No. 14 on the Nuria diabase (jungle) - iron content increases with increased weathering, whereas in the profile from Pit No. 4 on the Las Patillas amphibolite (savanna), iron is depleted throughout the course of the weathering.

The total amounts of iron lost (0 to 5%) in the transition from rock to soil were very similar in the profiles studied, with the exception of the highly drained profile in Pit No. 4, which has a loss of 49% and Pit No. 6 on the Las Bombitas granodiorite with 12% of iron lost.

Titanium

In general, the geochemical redistribution of titanium follows a pattern similar to that of iron in all six profiles.

In profiles from Pit No. 1, on the El Callao metagabbro (jungle), Pit No. 6, on the Las Bombitas granodiorite (savanna), and Pit No. 4 on the Las Patillas amphibolite

(savanna), titanium shows a tendency to be depleted in D-horizon and C-horizon and then enriched in the intermediate and late stages of weathering.

In profiles from Pit No. 2, on the El Carmen granodiorite (jungle), Pit No. 7, on the La Paragua granite (savanna), and Well Core No. 14, on the Nuria diabase (jungle), titanium increases with increased weathering alteration.

In the profile from Pit No. 7 on the La Paragua granite, titanium is depleted in the concretionary zone (uppermost horizon). This effect is due to the sorption of Ti^{4+} on the amorphous hydrous ferric oxide present in the soil profile. The Ti^{4+} is released when the crystalline goethite is formed in the concretionary zone. Apparently, the substitution of Ti^{4+} (0.60 Å) for Fe^{3+} (0.53 Å) does not take place in the goethite structure.

The total amount of titanium lost (0 to 3%) was very similar in the profiles studied, with the exception of the well drained profile in Pit No. 4 on the Las Patillas amphibolite (savanna), which lost 49% Ti and the profile in Pit No. 1 on the El Callao metagabbro with 8% of loss of titanium.

Manganese

The distribution of manganese within the soil profiles

is very irregular.

During weathering manganese is depleted in the D-horizon of the profiles in Pit No. 4 on the Las Patillas amphibolite (savanna), Pit No. 7 on the La Paragua granite (savanna), and Pit No. 6 on the Las Bombitas granodiorite (savanna), relative to the parent rock composition.

The depletion of manganese during the early stage of weathering in the savanna can be ascribed to the predominant upward flow of leaching solutions in this environment. Also, the anaerobic conditions and presumably low pH in the D-horizon favors the vertical migration of Mn^{2+} . Divalent manganese is readily oxidized to the quadrivalent state when the weathering solutions are brought into contact with atmospheric oxygen.

In profiles of Pit No. 2 on the El Carmen granodiorite (jungle), and Well Core No. 14 on the Nuria diabase (jungle), manganese shows a tendency to be enriched in the D-horizon and C-horizon and depleted in the intermediate and late stage of the weathering.

The enrichment of manganese in the D-horizon and C-horizon is due to the oxidant effect of dissolved oxygen in the downward leaching solutions characteristic of the jungle environment.

The profile from Pit No. 1 on the El Callao metagabbro (jungle) shows a slight decrease in manganese content during

the early stage of the weathering followed by increase in manganese with increased weathering. The manganese variations in this profile are more irregular and it is due to the very immature profile on the El Callao metagabbro.

The tendency for an enrichment of manganese in the uppermost horizons was noted in each of the profiles investigated.

The total amounts of manganese lost were very high in the profiles developed on savanna environment: 80%, 68%, and 63% for pits No. 7, 8, and 4, respectively. The percentages of losses for the profiles in the jungle were 2%, 18%, and 34% for pits No. 1, Well Core No. 14, and No. 2, respectively.

Nickel

The soil profiles generally showed a depletion in parts per million nickel with increasing alteration, whereas in Well Core No. 14 on the Nuria diabase, nickel increased during the intermediate stages of weathering and was depleted in the A-horizon and B-horizon. In general, the distribution of nickel follows a pattern similar to that of manganese in all the soil profiles investigated, with the exception of the immature profile in Pit No. 1 on the El Callao metagabbro (jungle).

The greater percentage of nickel increases occurred in

the profiles developed on basic rocks. These values are 43%, 26%, and 2% for Well Core No. 14 on the Nuria diabase (jungle), Pit No. 4 on the Las Patillas amphibolite, and Pit No. 1 on the El Callao metagabbro respectively. In contrast, the percentages of gains in nickel in the profiles on acidic and intermediate rocks range from 0 to 3%.

Copper

In profiles from Pit No. 4 on the Las Patillas amphibolite (savanna), Pit No. 2 on the El Carmen granodiorite (jungle), Pit No. 7 on the La Paragua granite (savanna), and Pit No. 6 on the Las Bombitas granodiorite (savanna), copper shows a tendency to be depleted in the D-horizon. In profile from Well Core No. 14 on the Nuria diabase (jungle) copper content increases in the lower horizons and then is depleted in the intermediate and late stages of weathering relative to the parent-rock composition.

Copper, similar to nickel, shows the same distribution pattern as manganese in all six profiles.

The percentages of copper gains are greater in the profiles from basic rocks 37%, 22%, and 16% for Pit No. 1 on the El Callao metagabbro (jungle), Pit No. 4 on the Las Patillas amphibolite, and Well Core No. 14 on the Nuria diabase (jungle), respectively. For the profiles from acidic rocks the gains values range from 0 to 1%.

Zinc

The soil profiles studied generally showed a depletion in parts per million zinc with increasing alteration. The redistribution of zinc, similar to nickel and copper, follow the same pattern as the distribution of manganese during weathering.

The total amounts of zinc gains in the transition from rock to soil were also larger in the profiles from basic rocks. These values are 12%, 4%, and 2% for Well Core No. 14 on the Nuria diabase, Pit No. 1 on the El Callao meta-gabbro, and Pit No. 4 on the Las Patillas amphibolite, respectively. In contrast, the profiles from acidic rocks do not undergo gains in zinc during weathering with the exception of the very immature D-horizon of the profile from Pit No. 2 on the El Carmen granodiorite (jungle), which has a 9% gain in zinc.

Table 10. Gains and losses of elements in the soil profile from Pit No. 1, El Callao metagabbro, jungle environment.

	LOSS		GAIN		NET LOSS	NET GAIN
	Area	Perc.	Area	Perc.	Perc.	Perc.
SiO ₂	42	2	5	0	2	-
Al ₂ O ₃	58	3	468	23	-	21
Fe ₂ O ₃	99	5	186	9	-	4
CaO	692	35	0	0	35	-
K ₂ O	-	-	-	-	-	-
TiO ₂	59	3	240	12	-	9
Mn	31	2	1163	58	-	57
Ni	53	3	44	2	0	-
Cu	12	1	730	37	-	36
Zn	132	7	73	4	-	3

Table 11. Gains and losses of elements in the soil profile for Pit No. 4, Las Patillas amphibolite, savanna environment.

	LOSS		GAIN		NET LOSS	NET GAIN
	Area	Perc.	Area	Perc.	Perc.	Perc.
SiO ₂	55	3	450	21	-	18
Al ₂ O ₃	9	0	485	22	-	22
Fe ₂ O ₃	1079	49	0	-	49	-
CaO	1516	69	0	-	69	-
K ₂ O	1271	58	0	-	58	-
TiO ₂	1035	47	14	1	46	-
Mn	1377	63	65	3	60	-
Ni	704	32	566	26	6	-
Cu	193	9	492	22	-	14
Zn	1111	51	2	0	50	-

Table 12. Gains and losses of elements in the soil profile from Well Core No. 14, Nuria diabase, jungle environment.

	LOSS		GAIN		NET LOSS	NET GAIN
	Area	Perc.	Area	Perc.	Perc.	Perc.
SiO ₂	1494	59	-	-	59	-
Al ₂ O ₃	-	-	1809	71	-	71
Fe ₂ O ₃	-	-	3076	121	-	121
CaO	2549	100	-	-	100	-
K ₂ O	2196	86	-	-	86	-
TiO ₂	-	-	3561	140	-	140
Mn	459	18	1640	65	-	46
Ni	708	28	1091	43	-	15
Cu	377	15	401	16	-	1
Zn	1017	40	294	12	28	-

Table 13. Gains and losses of elements in the soil profile for Pit No. 2, El Carmen granodiorite, jungle environment.

	LOSS		GAIN		NET LOSS	NET GAIN
	Area	Perc.	Area	Perc.	Perc.	Perc.
SiO ₂	147	4	68	2	2	-
Al ₂ O ₃	22	1	1854	46	-	46
Fe ₂ O ₃	10	0	1566	39	-	39
CaO	3089	77	-	-	77	-
K ₂ O	1207	30	245	6	24	-
TiO ₂	-	-	1560	39	-	39
Mn	1357	34	1100	28	6	-
Ni	771	19	17	0	19	-
Cu	837	21	-	-	21	-
Zn	813	20	364	9	11	-

Table 14. Gains and losses of elements in the soil profile for Pit No. 6, Las Bombitas granodiorite, savanna environment.

	LOSS		GAIN		NET LOSS	NET GAIN
	Area	Perc.	Area	Perc.	Perc.	Perc.
SiO ₂	42	1	663	15	-	14
Al ₂ O ₃	1483	34	60	1	32	-
Fe ₂ O ₃	472	11	1118	25	-	15
CaO	4111	93	-	-	93	-
K ₂ O	4361	99	-	-	99	-
TiO ₂	347	8	1128	26	-	18
Mn	2998	68	-	-	68	-
Ni	3565	81	-	-	81	-
Cu	3296	75	44	1	74	-
Zn	3922	89	-	-	89	-

Table 15. Gains and losses of elements in the soil profile for Pit No. 7, La Paragua granite, jungle environment.

	LOSS		GAIN		NET LOSS	NET GAIN
	Area	Perc.	Area	Perc.	Perc.	Perc.
SiO ₂	384	12	-	-	12	-
Al ₂ O ₃	28	1	1725	54	-	53
Fe ₂ O ₃	-	-	3431	107	-	107
CaO	3119	97	-	-	97	-
K ₂ O	2575	90	-	-	80	-
TiO ₂	59	2	2093	65	-	64
Mn	2570	80	-	-	80	-
Ni	1367	43	110	3	39	-
Cu	575	18	-	-	18	-
Zn	1632	51	-	-	51	-

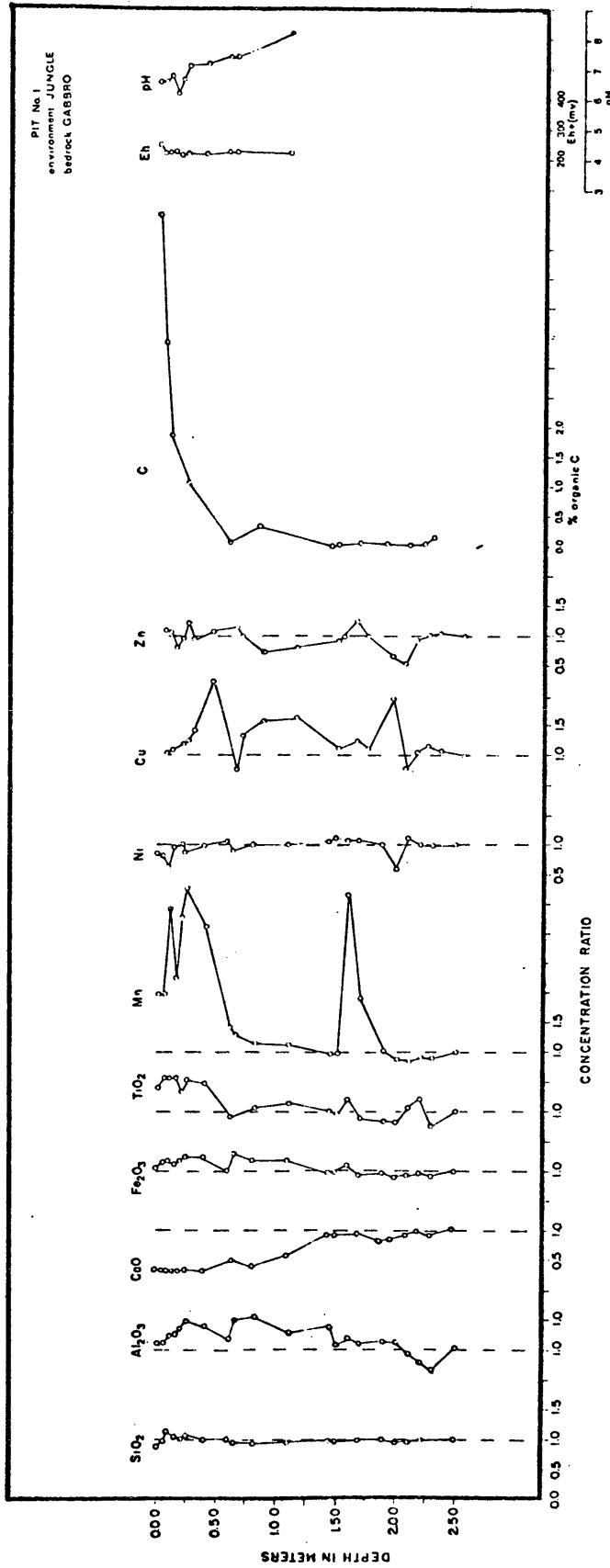


Figure 8. Concentration ratios versus depth for the weathered sequence developed on El Callao metagabbro (Pit No. 1), jungle environment.

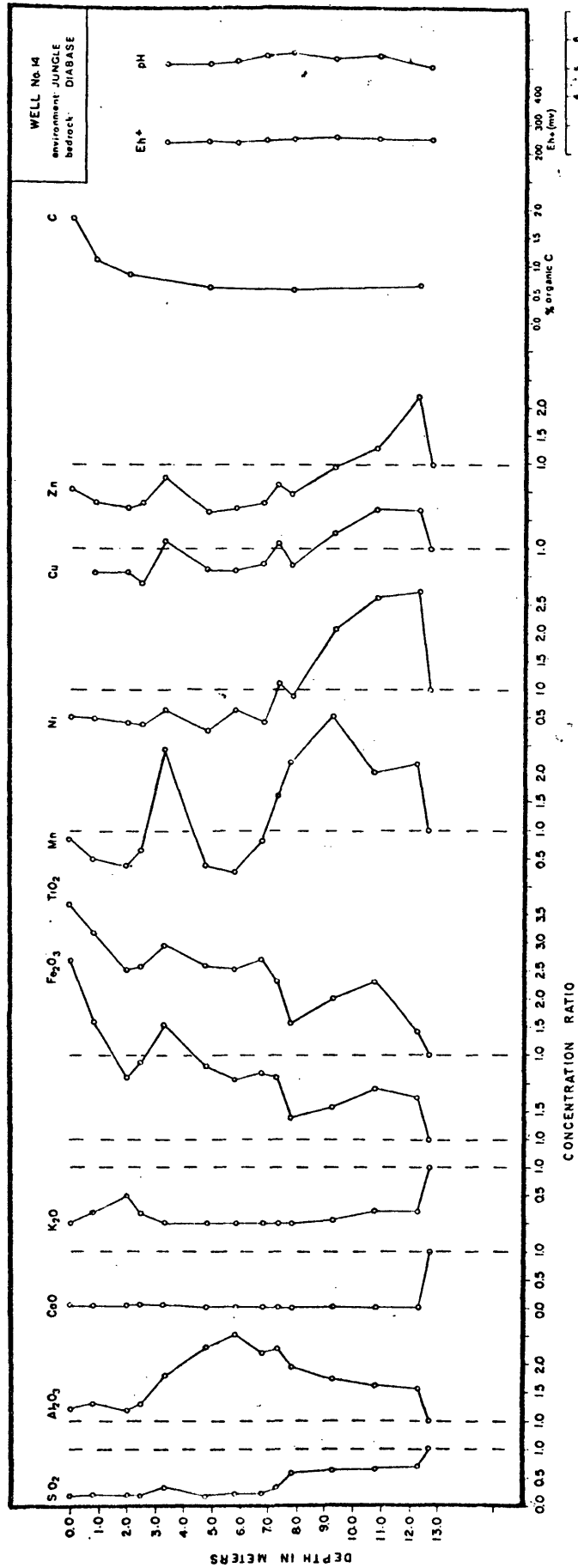


Figure 10. Concentration ratios versus depth for the weathered sequence developed on Nuria diabase (Well Core No. 14), jungle environment.

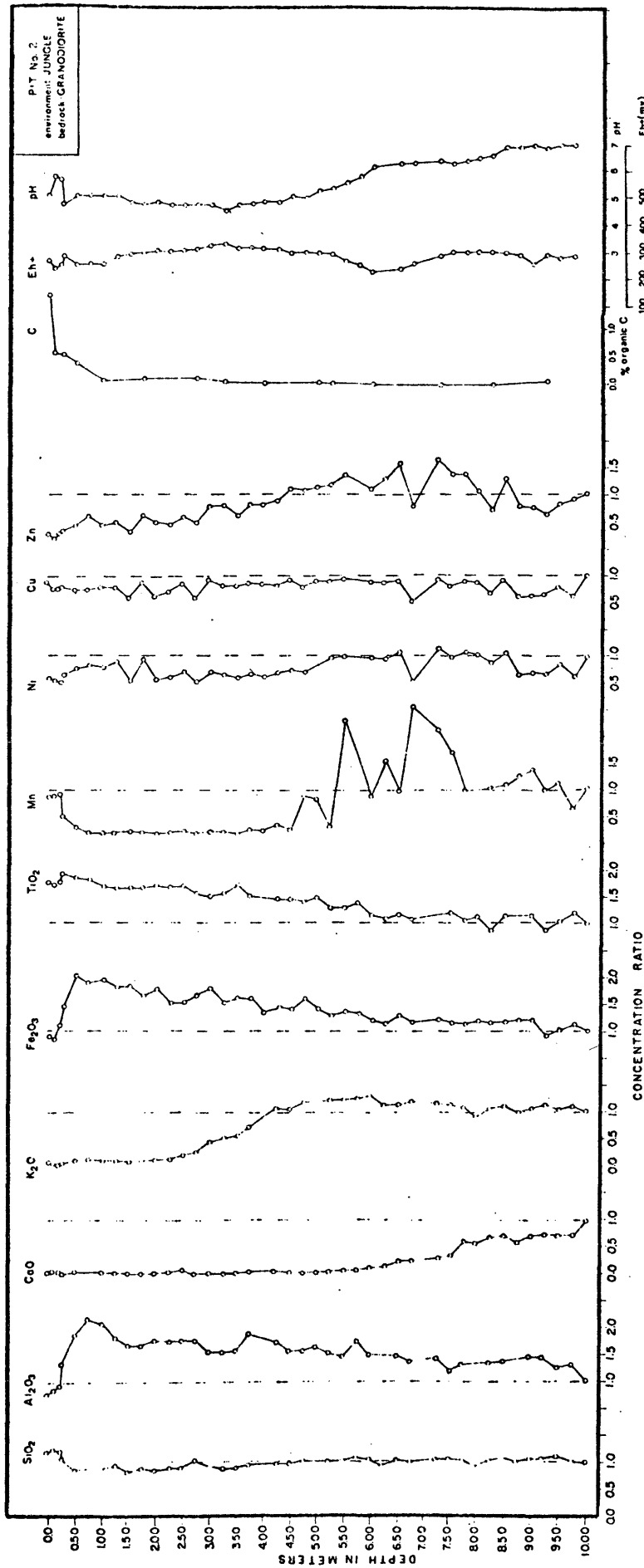


Figure 11. Concentration ratios versus depth for the weathered sequence developed on E1 Carmen granodiorite (Pit No. 2), jungle environment.

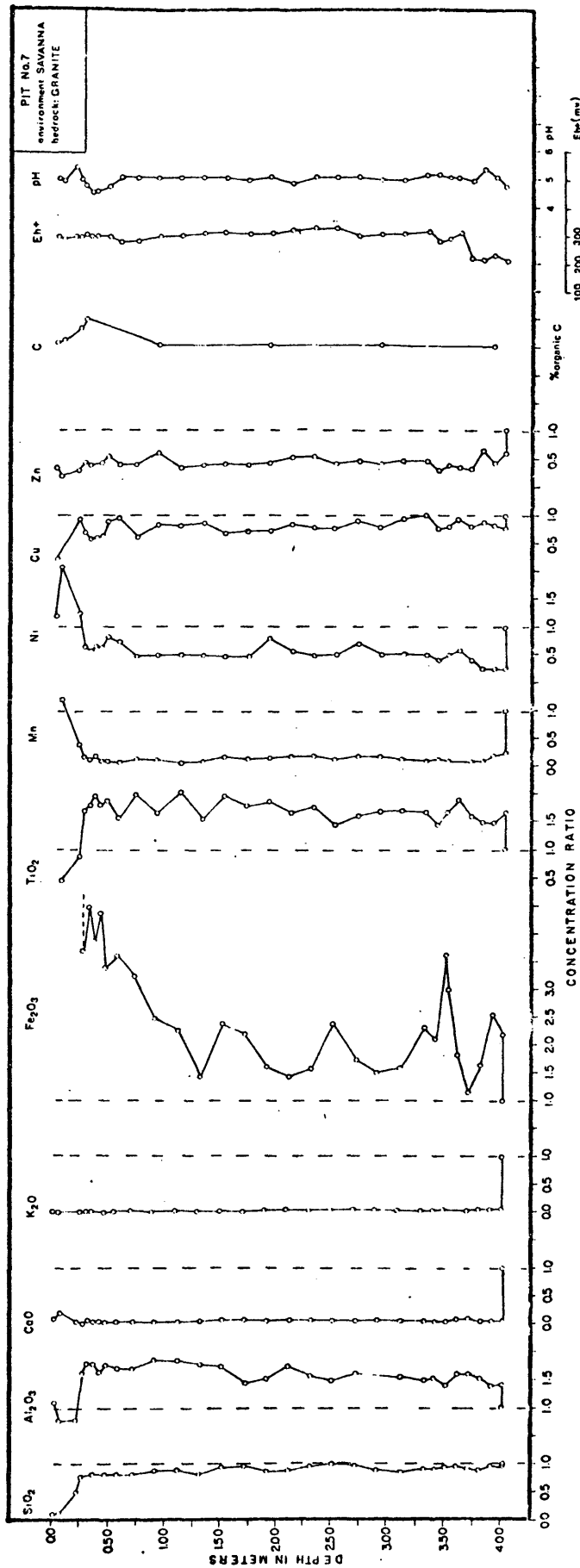


Figure 13. Concentration ratios versus depth for the weathered sequence developed on La Paragua granite (Pit No. 7), savanna environment.

INTERPRETATION OF GEOCHEMICAL PROCESSES

The relative enrichment of an element during the course of weathering is accomplished either by the formation of stable secondary products or by the loss of less stable elements. Therefore, only the depletion of an element in the weathering profile provides unequivocal indication of chemical change. However, data of losses and gains are valuable to understand the undergoing processes.

For comparative purposes losses and gains data from tables 10, 11, 12, 13, 14, and 15 have been summarized in table 16.

A detailed examination of the data presented in figures 8, 9, 10, 11, 12, and 13 and the summarized table 15 reveals certain characteristics in the geochemical distribution of both major and trace elements which recur in each of the soil profiles investigated.

Elemental Losses During Weathering and Relationship to Charge Densities

Both major and trace element losses show a strong inverse relationship with respect to their charge density during the weathering cycle. Figure 14 plots the loss percentage against the charge to radius ratio (charge density) for each of the elements investigated. The following

Table 16. Summary data of elemental gains and losses from tables 10, 11, 12, 13, 14, and 15.

		JUNGLE			SAVANNA		
Percentage		Metagabbro (Pit No. 1)	Diabase (Well No. 14)	Granodiorite (Pit No. 2)	Amphibolite (Pit No. 4)	Granodiorite (Pit No. 6)	Granite (Pit No. 7)
SiO ₂	Loss	2	59	4	3	1	12
	Gain	0	0	2	21	15	0
Al ₂ O ₃	Loss	3	0	1	0	34	1
	Gain	23	71	46	22	1	54
Fe ₂ O ₃	Loss	5	0	0	49	11	0
	Gain	9	121	39	0	25	107
CaO	Loss	35	100	77	69	93	97
	Gain	0	0	0	0	0	0
K ₂ O	Loss	-	86	30	58	99	90
	Gain	-	0	6	0	0	0
TiO ₂	Loss	3	0	0	47	8	2
	Gain	12	140	39	1	26	65
Mn	Loss	2	18	34	63	68	80
	Gain	58	65	28	3	0	0
Ni	Loss	3	28	19	32	81	43
	Gain	2	43	0	26	0	3
Cu	Loss	1	15	21	9	75	18
	Gain	37	16	0	22	1	0
Zn	Loss	7	40	20	51	89	51
	Gain	4	12	9	0	0	0

arguments may be drawn from those graphs. For all the profiles studied, the percentage of loss increases with decreasing charge density. However, this trend is not obeyed regularly due to the presence of physical and chemical factors that may affect the rate of mass loss during the weathering. Differences in topography, drainage, and permeability of soils appear to produce distinctive chemical changes even in similar rocks weathered under the same climate and environment (jungle or savanna) conditions.

Figure 7 shows that SiO_2 is depleted up to 60% from the parent rock (diabase) in the jungle environment. This value is anomalous with respect to the behavior of SiO_2 in either basic or acidic rock in both jungle and savanna. The soil profile developed on amphibolite in savanna environment undergoes the largest removal of Ti and Fe, in relation to rocks of similar mineralogy in the same environment. These observations indicate that mineralogy, although of primary importance cannot be used to predict the course of the chemical weathering.

Two general characteristics of element losses are noted in Figure 14:

(1) The tendency of major elements Si, Al, Ti, and Fe to undergo lower losses during weathering is explained simply by their solution from the parent mineral and almost immediate precipitation on clays and/or silt material. This is an effect achieved very easily by the high charge

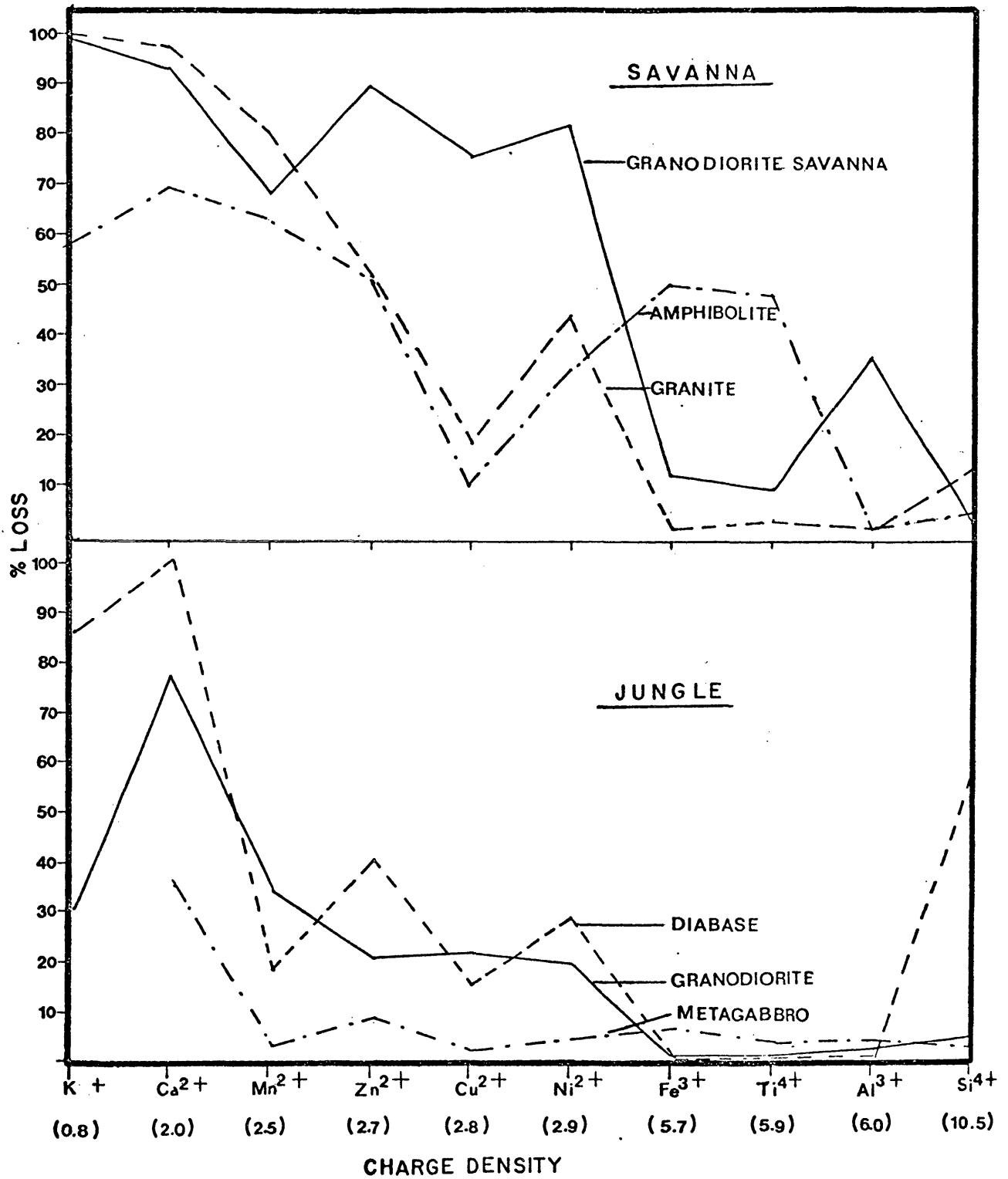


Figure 14. Elemental losses during weathering versus charge densities.

density of Si^{4+} , Al^{3+} , Ti^{4+} , and Fe^{3+} , and by their insolubility in the Eh-pH conditions of the weathering environment.

(2) Calcium and potassium show the largest losses due to their relative soluble oxides and hydroxides, although sometimes K^+ is concentrated by adsorption of the relatively large K^+ ion on the kaolinite structure (McLaughlin, 1955).

In general, the causes of elemental loss variations may be considered under the following subfactors:

(1) Capture of elements within the clay mineral structure.

(2) Sorption and desorption of ions on clays, silt, and amorphous oxides present in the soil profile.

(3) Nature of the adsorbent. It was noted in Pit No. 4 (Figure 9) that sorption of Ni, Cu, and Zn on silt occurs to a lesser degree than in the clay horizon.

(4) Chelating or complexing effect of organic matter. Organic matter is an effective agent in the transport of heavy metals during weathering, and its effect is more pronounced in the uppermost horizon of the soil profile.

(5) Local conditions such as permeability external and internal drainage of the soil profile, topographic expression and physiographic environment.

Influence of Mn on the Distribution of Ni, Cu, and Zn

During Weathering

Figures 9, 10, 11, 12, and 13 (Pits 2, 4, 6, 7, and

Well Core No. 14) show that the distribution of Ni, Zn, and Cu have a positive correlation relative to the concentration of Mn in the soil profiles. This observation is reconciled with the conclusion of Jenne (1967) that the principal control on the concentration of Ni, Cu, Zn, and Co in rock and fresh water are the hydrous oxides of manganese and iron.

The present study has found that generally Ni, Cu, and Zn do not correlate with iron distribution along the soil profile, although they follow a pattern similar to that of Mn in the same soils.

Manganese hydrous oxides are ubiquitous along the soil profile studied, and it may be ambiguous to consider either the manganese hydrous oxides or the clays responsible for the Ni, Cu, and Zn uptake during weathering. Bower and others (1940), Elgabaly (1950), Menzel (1950) have considered the possibility of either the sorption of complex ions on clay mineral surface or reaction of heavy metal cations with clay surface. Their results would indicate that the sorption on clays is not important in terms of concentration of heavy metals sorbed on clays.

The manganese hydrous oxide prepared in the laboratory are frequently amorphous or microcrystalline, with high surface area (Buser, 1955). Surface-area data are lacking for hydrous oxide coating on other minerals; and it can be expected that surface area is approximated to that of

laboratory preparations (Jenne, 1967).

The amorphous manganese hydrous oxide similar to that of iron hydrous oxide exerts a high sorption capacity. Morgan and Stumm (1964) reported sorption capacities of $\text{Fe}(\text{OH})_3$ and MnO_2 for manganous ion at pH 8.0 to be 0.3 and 1.0 mole/mole respectively. They state that the sorption capacities for Ni, Zn, and Co were only slightly less than for manganese. Also Burns and Fuerstenau (1966) determined the occluded heavy metal concentration in oceanic manganese nodules via electron probe. They found that Ni and copper occurred in the high Mn bands while cobalt occurred predominantly in the iron rich areas.

Combined field and laboratory evidence has led the author to consider three factors as responsible for manganese hydrous oxides controlling the distribution of Ni, Cu, and Zn in the soil profiles:

(1) High sorption capacity of manganese hydrous oxide relative to iron hydrous oxide. No data have been found which would clearly establish the sorption capacity of iron and manganese hydrous oxide although the experiments of Morgan and Stumm (1964) reported an adsorption capacity of MnO_2 three times greater than that of amorphous ferric hydroxide.

(2) Manganese hydrous oxide is more dispersed than iron hydrous oxide in the soil profile. Within the area of

interest in the stability diagrams (Eh-pH), ferric hydroxide precipitation is possible at lower oxidation potential than manganic manganese oxides at any given pH. Similarly at fixed Eh, ferric hydroxide precipitation is possible at lower pH than manganese oxides.

(3) Catalytic effect of manganic oxide. No data have been found which would clearly establish the ability of Mn^{4+} to catalyze the Fe^{2+} to Fe^{3+} oxidation, although it has been suggested that this situation occurs in the formation of oceanic manganese nodules (Jenne, 1967, p. 356). This effect suggests that when a part of Mn^{4+} is reduced to a lower oxidation state, a corresponding number of oxygen atoms are bonded to hydrogen forming hydroxyl groups yielding more amorphous manganese hydrous oxide in the profile.

Importance of Organic Matter on the Formation of Goethite and/or Amorphous Hydrous Ferric Oxide During Weathering

The soil profiles investigated show the formation of goethite in the presence of 0.10-0.90% organic carbon (Figure 15); whereas at other concentration ranges amorphous hydrous iron oxide is predominant.

The mechanisms of goethite and amorphous ferric oxide formation are closely related to the change in the organic matter regime in the soil, which in turn reflect the climatic conditions. For example, under tropical climate conditions the organic matter decomposes rapidly by comparison

with the high rate of iron released from the silicate during weathering. In a cooler climate the organic matter is more abundant, and the rate of iron release is less than in the tropics.

It is suggested that the effect of organic matter produces a reducing environment necessary to maintain the iron oxide in the amorphous conditions, whereas when a part of Fe^{+++} is reduced to Fe^{++} , a corresponding number of oxygen atoms are bonded to hydrogen forming hydroxyl groups. However, the role of organic matter on the formation of hydrous iron oxide and/or goethite is not well understood.

Transformation of Goethite to Hematite

The mineralogical transformation of hematite ($\alpha\text{Fe}_2\text{O}_3$) to goethite (αFeOOH) takes place in cool humid climates (Schwertmann, 1971). In this climate the soil bacterial activity is lower and it causes a slower decomposition rate of organic matter. Cool humid conditions favor the production of organic matter into the soil, and it dissolves the hematite by complexing the iron. When this iron is precipitated, the compound formed is goethite.

During laterization in Well Core No. 14 (Figure 6) the contrary process is observed, that is, the transformation of goethite to hematite.

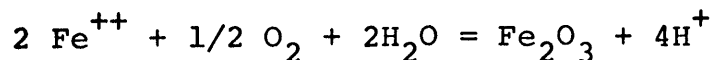
Both the reasons for the transformation of goethite to hematite and its mechanism are closely connected to the

low rate of organic matter surviving in the tropical climate. Under these conditions, the organic matter dissolves the goethite at a very low rate by reducing or complexing the iron. When iron is released into solution, it is readily oxidized and precipitated in the profile in the form of hematite. This effect is achieved very easily by the catalytic effect of ferric hydrous oxide and bacteria. Due to the low rate of organic-matter production, iron will remain as Fe_2O_3 in the profile.

The above observations are supported by the following field and laboratory evidences:

(1) There is some indication that hydrous iron oxide catalyzes the oxidation of Fe^{++} to Fe^{+++} . Gasser and Blomfield (1955) found that ferrous iron chelated by natural organics was readily oxidized at ferric oxide surface in the presence of oxygen. It is worthy to note that hematite formation takes place in the uppermost horizon of Well Core No. 14 (Fig. 6), where oxygen may be present.

(2) Some species of bacteria existing in soils have the ability to use the slow oxidation of iron compounds as an energy-producing reaction for their life processes. The bacterias serve as efficient catalysts in speeding up the oxidation of Fe^{++} (Razzel, 1962, and McDermid, 1965) in a process like:



yielding hematite as a final product.

Processes of Bauxitization During Weathering

The general pattern of bauxitization in the Guayana Shield involves chemical leaching and removal of bases and silica, addition of hydrogen retention of Al and Fe; and Ti, Ni, Ca, and Zn distribution, related to the distribution of manganese.

Formation of phyllosilicates is an important step in the production of bauxite, however, the presence and abundance of bauxite at any given locality depends upon climatic and other factors now or previously dominant there. In the soil profiles of Pit No. 7 and Well Core No. 14 the appearance of gibbsite as a secondary weathering product indicates that bauxitization is an active process in both profiles. Pit No. 7, located in savanna environment on granite rock, indicates alternating enrichment in kaolinite and gibbsite along the profile. Due to the upward water flow dominant in savanna environment, the formation of kaolinite and ferruginous concretions takes place in the uppermost horizons.

The particularly "optimum" local conditions necessary to convert diabase to deeply weathered bauxite profile were dominant in the soil profile of Well Core No. 14 in the jungle environment. The downward flow of leaching solutions gives rise to the formation of a thick bauxite horizon underlain by kaolinite. In accounting for this

particular deeply weathered bauxite profile, the role of no single factor can be isolated completely from that of others. However, the "weight" of some local variations such as topographic expression, internal drainage, and environment previously dominant there can be assessed reasonably well.

The abundance of ferruginous material and the overall iron concentration on the soil surface overlying the Nuria diabase (jungle) tends to increase toward the surface. This increase indicates that the savanna was the environment previously dominant there. Rapid surface runoff eroded part of the soil clay at the top, and left iron pisolites exposed on the surface in a way similar to what is happening today on the La Paragua granite (Pit No. 7).

Vegetation invaded the savanna and transformed it into a jungle, thus it allowed a minimum of erosion to occur in the peneplain area. Due to the presence of jungle environment, the profile undergoes downward flow of water and causes soil desilification. The presence of more abundant organic matter in this environment enhances the leaching effect during the downward flow of solutions.

It seems that under these conditions the soil has been subjected to the influence of weathering agents for a long enough time to form the bauxite deposit.

BIOGEOCHEMICAL IMPLICATIONS

Weathering processes control the release of metals into the soils and subsequently into the biosphere. This section shows what role weathering would have in the formation of nutritionally deficient soils from acidic, intermediate, and basic rocks.

The importance of the trace elements in biological and physiological processes has been well documented by Hutchinson (1943), Herriot (1953), and Warren (1962). Appropriate quantities of elements such as nickel, copper, zinc and manganese are now known to be vital to the health of some plants and animals. The concentration of any element needed for the fulfillment of these different needs varies considerably. However, a deficiency in these heavy metals may result in early recognizable pathologic and/or metabolic irregularities in the associated food chain. For example, zinc and cobalt deficiencies are a nutritional problem in animals grazed on plants grown in certain soil areas (Warren and Delavault, 1965).

A summary of data of elemental losses for manganese, nickel, copper, and zinc are given in Table 17. The data indicate that for soils developed on basic parent rock, these heavy metals are found in quantities equal to or greater than those found in their basic bedrock. For soils

Table 17. Summary of gains and losses of heavy metals during weathering of acidic, intermediate, and basic rocks.

	PERCENT GAIN				PERCENT LOSS			
	Mn	Ni	Cu	Zn	Mn	Ni	Cu	Zn
Bedrock								
Metagabbro (Jungle)	58	2	37	4	2	3	1	7
Diabase (Jungle)	65	43	16	12	18	28	19	40
Amphibolite (Savanna)	3	26	22	0	63	32	9	51
Granite (Savanna)	0	3	0	0	80	43	18	51
Granodiorite (Savanna)	28	0	0	9	34	19	21	20
Granodiorite (Jungle)	0	0	1	0	68	81	75	89

developed on acidic or intermediate parent rocks, these elements are found in quantities lower than those found in their bedrock.

The above considerations should be taken into account when the jungle is cleared of trees for agricultural or cattle-raising purposes.

The author has observed in certain regions of Venezuela that man-made savannas on acidic bedrock are no longer fertile after three to five years of animal grazing. Apparently two factors are responsible for this problem: (1) The humus matter is destroyed very rapidly in the savanna environment, and (2) soils developed on acidic bedrock are depleted of trace elements. Fertilizers may not solve the problem since the weathering process active in leaching the original trace elements may also be effective in mobilizing and removing any heavy metal additives.

On the other hand, high concentrations of trace elements may be toxic to plants and to a greater extent to animals.

It is considered that soils developed on acidic bedrock should be reserved for deep rooted plants, which can reach nutrients from the lower horizons of the soil profile.

The bedrock must be carefully considered in order to develop the land for agricultural and cattle-raising purposes since weathering processes are active in producing nutritional deficiencies in soils.

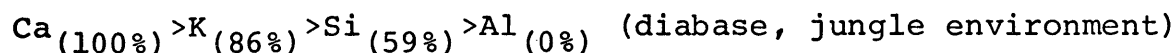
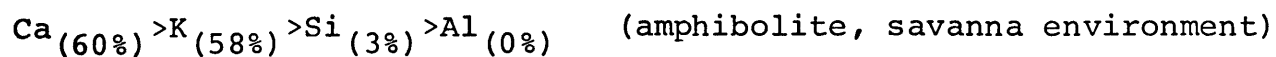
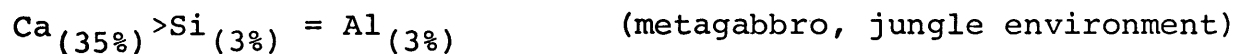
SUMMARY AND CONCLUSIONS

The Guayanan Shield provides an excellent setting in which to study the tropical weathering of basic, acidic, and intermediate igneous rocks. The presence of jungle and savanna on the same type of bedrock, short-range variation of rock composition, and distinctively local conditions make it possible to evaluate the relative importance of the variables involved in the present weathering process. The chemical and mineralogical distribution observed in the six profiles investigated led the author to draw the following conclusions:

(1) Computed from literature data, general estimates of the order of loss of major elements in the weathering cycle are as follows:



In the present study similar ratios were derived from analyses of soil profiles developed on amphibolite, diabase, metagabbro, granodiorite and granite, each having distinctive local conditions. The order of loss found was as follows:



Ca (77%) >K (30%) >Si (4%) >Al (1%) (granodiorite, jungle environment)

K (99%) >Ca (93%) >Al (34%) >Si (1%) (granodiorite, savanna environment)

Ca (97%) >K (9%) >Si (12%) >Al (1%) (granite, savanna environment)

The order of loss as shown by the two studies is the same with the exception of that of K and Al, which appear as more mobile elements in the granodiorite soil profile in savanna environment.

Mineralogy is the predominant factor controlling the order of loss of calcium and potassium. Calcium, found primarily in the plagioclases, is released during the early stage of the weathering. Potassium is found primarily in the relatively more stable microcline and is mobilized in a later stage of the weathering, where it is sorbed on the kaolinite during weathering.

(2) Manganese, nickel, copper, and zinc are definitely depleted during weathering of granite, granodiorite, and amphibolite. The order and degree of loss depends on distinctive local conditions in the weathering environment. In the savanna (granodiorite and amphibolite) with a most efficient internal drainage, the net loss is much greater than in jungle environment. The net loss order found was as follows:

Mn (80%) >Zn (51%) >Ni (39%) >Cu (18%) (granite, savanna environment)

Zn (89%) >Ni (81%) >Cu (74%) >Mn (68%) (granodiorite, savanna environment)

Cu (21%) > Ni (19%) > Zn (11%) > Mn (6%) (granodiorite, jungle environment)

Mn (60%) > Zn (50%) > Ni (6%) (amphibolite, savanna environment)

Copper is the exception in amphibolite. Copper appears to be a less mobile element due to its substituting for Ca^{2+} in plagioclases, in the amphibolite.

(3) Manganese, nickel, copper, and zinc are generally enriched during the weathering of diabase and metagabbro in jungle environment, with the exception of Zn which appears more mobile in the bauxite profile developed on diabase (Well Core No. 14). The net loss order found is as follows:

Mn (46%) > Ni (15%) > Cu (1%)

Mn (57%) > Cu (36%) > Zn (3%) > Ni (3%)

(4) From points 1, 2, and 3 presented above can be drawn the following suggestion.

Mineralogy and climate, although of primary importance, cannot be used to predict the course and intensity of weathering. Differences in the local weathering environment such as those of topography, permeability, internal drainage of the terrain, and vegetation are probably more effective on the degree of weathering.

(5) In the six soil profiles investigated, iron and titanium follow the same distribution pattern. This positive correlation is consistently observed regardless of environment and/or local weathering conditions. This

correlation is attributable to titanium dissolved from its parent mineral and almost immediately sorbed on iron hydrous oxides present in the soil profile - an effect rendered very easy by the high charge density on Ti^{4+} and its insolubility in the conditions of Eh-pH operating.

(6) Major and trace elements tend to increase their loss percentages when their charge to ionic radius ratio decreases. This trend is generally observed in all the soil profiles investigated regardless of physiochemical variations and different parent materials.

(7) Hydrous manganese oxides present in the soil profiles are probably the principal control on the distribution of nickel, copper, and zinc during the weathering process. Neither clays nor hydrous iron oxides exert greater control than manganese and hydrous oxide. This correlation was found in five out of six soil profiles investigated. The soil profile on metagabbro was the exception which shows a correlation only between manganese and copper; apparently this profile is not well developed. It shows differences in stages of soil development which may account for the differences observed.

(8) The formation of goethite in the soil profiles investigated is favored in a range of 0.10 to 0.50% of organic carbon, whereas greater organic matter concentration appears to favor the formation of hydrous iron oxides.

Apparently the role of organic matter is to produce a reducing environment necessary to maintain the iron oxide in the amorphous conditions. When part of Fe^{3+} is reduced to Fe^{2+} , a corresponding number of oxygen atoms are bonded to hydrogen forming hydroxyl groups yielding hydrous iron oxide and/or goethite, depending on iron to organic carbon ratios.

(9) Combined field and theoretical evidences indicate that transformation of goethite to hematite takes place in the bauxite profile (Well Core No. 14). This transformation is the opposite of the phenomenon operating under temperate climates (Schwertmann, 1971, p. 624-625).

(10) X-ray diffraction studies indicate that the relative mineral stability in some of the rock under investigation is as follows (from least to most stable):

albite-oligoclase<microcline<biotite<<quartz

(granite, savanna environment)

biotite<labradorite<microcline<<quartz

(granodiorite, jungle environment)

chlorite<actinolite<labradorite-bytownite<hornblende

(metagabbro, jungle environment)

enstatite<hornblende<actinolite<albite-oligoclase<<quartz

(amphibolite, savanna environment)

The relative stability sequence in general is consistently with the sequence proposed by Goldich (1938, pp. 17-58), on the basis of weathering study under temperate

conditions. Biotite is the exception in granodiorite (jungle environment) which appears more unstable than expected.

(11) The nature of the clays formed and their sequence in the soil profile depend principally on the rate of movement of water through the profile and its direction of flow. The secondary products identified by x-ray diffraction in the soil profiles investigated were as follows (from the bottom to the surface):

gibbsite, kaolinite, goethite - granite (Pit No. 7),
savanna environment

kaolinite - granodiorite (Pit No. 6), savanna environment

kaolinite, goethite - granodiorite (Pit No. 2), jungle
environment

kaolinite, gibbsite, goethite, hematite - diabase (Well Core
No. 14), jungle environment

quartz, montmorillonite - metagabbro (Pit No. 1), jungle
environment

montmorillonite, kaolinite, quartz - amphibolite (Pit No. 4),
savanna environment

As can be seen in figures 10 and 13 for Well Core No. 14 and Pit No. 7, direction-of-flow controls the sequence of gibbsite and kaolinite in the profile. The presence of gibbsite underneath kaolinite (Pit No. 7) indicates an upward movement of leaching solutions on savanna environments; the inverse sequence, observed in the jungle (Well Core No. 14), indicates downward flow of leaching solutions.

(13) The element losses in the uppermost horizon of the soil profiles generally is directly proportional to the amount of organic carbon in the same horizon. Both jungle and savanna show a complexing effect of organic matter on the solubilization of Al, Fe, Ti, Si, and Mn.

RECOMMENDATIONS

In the course of this investigation, it was observed that the following projects may be suggested for further research:

(1) Study of the extent to which concretionary iron and manganese oxides (pisolites) participate in the concentration of heavy metals. When Mn and Fe increases in the concretionary zone, Pit No. 7, Ti, Ni, Cu, and Zn are depleted relative to their concentrations in the soil horizon.

(2) Study of inter-element relationships in pisolites by electron probe x-ray microanalyzer.

(3) Study of the physical chemical factors affecting the rate of sorption and desorption of heavy metals by the hydrous oxides of manganese and iron. In the soil profiles investigated quite a good correlation was found among Ni, Cu, Zn, and Mn; however, in Pit No. 4 this correlation was also extended to Ti and Fe along the soil profile.

(4) Study of the sorption capacity of heavy metals by hydrous oxides of iron and manganese coating clay and silt materials.

(5) Study of the effect of organic matter on the formation of goethite and iron hydrous oxide. In this study it was noted that a content of organic carbon over 0.5% slowed down the formation of goethite in the soil profile.

(6) Study of the relative affinity of soil organic matter vs. iron and manganese oxides for the heavy metals. In some of the soil profiles investigated, the correlation among Ni, Cu, Zn, and Mn no longer exists in the uppermost horizon where organic matter is abundant.

(7) Study of the mechanism of oxidation of iron chelated by organic in the soil profile.

(8) Study of the mineralogy and chemical changes on the weathered crust of acidic, intermediate, basic, and ultrabasic rocks formed under different climatic conditions. It has been observed in this study that most of the mineralogical and chemical changes occur close to bedrock. Therefore, a careful study of the altered layer of rock exposed on the surface will contribute a deeper understanding of the weathering mechanisms. This will allow an evaluation of some isolated factors, such as mineralogy of the rock, and physical-chemical conditions at the soil-air interface.

(9) Study of the seasonal fluctuations of the water table and its relationship with the formation of gibbsite and/or kaolinite in the soil profile.

APPENDIX I
Sample Processing

The processing of the rock samples includes the following steps: (1) breaking pieces with a sledge, (2) passing through jaw crusher (steel), and (3) pulverizing in tungsten carbide grinder until at least 80% pass a -200 mesh screen.

The processing of the soil samples includes the following steps: (1) drying soils at 110°C for one hour, and (2) pulverizing in tungsten carbide grinder until at least 80% pass a -200 mesh screen. In both cases (rocks and soils) the bulk samples were used for analyses.

Analytical Methods

Major and trace element analyses were performed by x-ray spectrometry techniques. Three x-ray spectrometry methods were used: (1) Rose and others (1962) for Ca, K, Si, Al, and Fe; (2) Reynolds and others (1963) for Ni, Cu, and Zn; and (3) internal standard (Adler and Axelrod, 1955) for Mn. The method of Rose and others (1962) uses La_2O_3 as a heavy absorber in the x-ray fluorescence analysis of soils and silicate rocks. The addition of La_2O_3 causes some loss in intensity for the lighter elements, but minimizes differences due to absorption. Overall errors in major element analysis by this method amount to approximately 1 to 3%. The method

of Reynolds and others (1963) for trace element analysis is based on the estimation of the mass absorption coefficient by Compton scattering. Overall errors in trace element analysis by this method amount to approximately 3%. The method of the internal standard requires the selection of an element as an internal standard that will be absorbed in the same way as the element to be analyzed. In the present study iron was selected as internal standard to analyze manganese.

Minerals present in the samples were identified by standard x-ray diffraction techniques. A Philips x-ray diffractometer has been used under the following conditions:

Anode : Co
Filter: Fe
KV : 40
mA : 20

Analysis of the organic-carbon in the soil samples was made following the Walkley-Black method as described in Allison (1965, p. 1372-1374). This is a wet combustion method commonly used to determine organic matter in soils. The organic matter is oxidized by dichromate and back-titrated with the excess of dichromate with ferrous iron and O-phenanthroline as indicator.

Eh and pH determinations were made by adding 40 milliliter of distilled water to 20 g of fresh soil samples. The beakers were agitated for 20 minutes, then the pH's and Eh's of the soil-water systems were measured with a pH-Eh meter.

APPENDIX II

Table 1. Chemical Data for the Weathered Sequence

Table 2. Concentration Ratios

CHEMICAL DATA FOR THE WEATHERED SEQUENCE

EL CALLAO METAGABBRO (PIT NO.1), JUNGLE ENVIRONMENT

#	DEPTH METER	SI02 %	AL2O3 %	FE2O3 %	CAO %	K2O %	TIO2 %	MN PPM	NI PPM	CU PPM	ZN PPM	ORG-C %	PH	EH+ MV
001	00.00	43.15	7.17	14.31	3.18	0.00	0.65	3712	304	169	118	5.59	6.6	245
002	00.05	46.96	7.17	15.51	3.05	0.00	0.73	3737	298	175	112	3.47	6.6	220
003	00.10	54.21	7.93	15.78	3.04	0.00	0.72	6439	232	128	090	2.18	6.8	220
004	00.15	51.58	8.03	15.20	2.97	0.00	0.72	4247	341	190	103	-1	6.2	220
005	00.20	50.09	8.70	15.98	3.22	0.00	0.62	6109	364	199	131	-1	6.7	210
006	00.25	50.86	9.43	16.75	3.16	0.00	0.71	7024	323	222	101	1.13	7.1	215
007	00.40	48.16	8.99	16.54	3.49	0.00	0.68	5869	355	348	115	-1	7.2	215
008	00.60	48.42	7.54	13.69	-1	0.00	0.43	2714	377	125	120	0.10	7.4	220
009	00.65	46.77	9.55	17.58	4.62	0.00	0.47	2461	336	207	105	-1	7.4	220
010	00.85	45.95	9.93	15.81	3.78	0.00	0.49	2173	360	244	82	0.34	-1	-1
011	01.10	46.56	8.55	15.85	5.55	0.00	0.53	2147	360	252	88	-1	8.2	215
012	01.45	47.31	8.99	13.11	8.97	0.00	0.47	1839	374	177	98	0.03	-1	-1
013	01.50	47.53	6.94	13.32	9.08	0.00	0.44	1848	397	178	103	0.05	-1	-1
014	01.60	-1	7.59	14.75	-1	0.00	0.67	6862	388	192	132	1.96	-1	-1
015	01.70	47.40	7.16	12.78	9.29	0.00	0.41	1717	380	172	105	0.10	-1	-1
016	01.90	48.57	7.21	13.02	7.93	0.00	0.39	1904	356	150	73	0.08	-1	-1
017	02.00	46.86	7.15	12.20	8.58	0.00	0.38	1664	219	122	60	0.02	-1	-1
018	02.10	47.01	6.10	12.23	9.13	0.00	0.49	1601	395	162	98	0.05	-1	-1
019	02.20	48.35	4.95	13.10	9.52	0.00	0.56	1735	357	176	106	0.07	-1	-1
020	02.30	-1	4.27	12.46	8.73	0.00	0.35	1711	350	165	107	0.15	-1	-1
021	02.50	49.01	6.46	13.44	9.91	0.00	0.46	1868	350	151	102	-1	-1	-1

* -1= NOT LOOKED FOR

TABLE 1 CONTINUED

EL CARMEN GRANODIORITE (PIT NO. 2), JUNGLE ENVIRONMENT

#	DEPTH METER	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ %	CaO %	K ₂ O %	TiO ₂ %	Mn PPM	Ni PPM	Cu PPM	Zn PPM	ORG-C %	PH	EM+ MV
053	00.00	72.15	8.18	3.86	0.13	0.11	1.15	452	31	66	19	1.69	5.0	260
054	00.10	74.91	9.07	3.74	0.16	0.06	1.12	325	29	56	14	0.87	5.7	235
055	00.20	72.85	9.70	4.88	0.16	0.06	1.18	338	27	56	22	.1	5.6	250
056	00.25	63.60	14.36	6.34	0.09	0.13	1.25	262	35	57	23	0.58	4.7	280
057	00.50	51.98	20.43	8.80	0.13	0.22	1.21	150	41	55	32	0.44	5.0	250
058	00.75	-1.	23.69	8.14	-1.	0.33	1.17	102	44	55	44	.1	5.0	250
059	01.00	53.25	22.68	8.43	0.12	0.25	1.10	98	41	57	32	0.12	5.0	250
060	01.25	57.03	19.83	7.86	0.08	0.23	1.08	86	48	57	35	.1	5.0	280
061	01.50	48.74	18.19	7.85	0.09	0.18	1.07	104	29	42	28	.1	4.8	290
062	01.75	53.63	18.44	7.14	0.05	0.22	1.07	93	45	63	46	0.16	4.7	295
063	02.00	50.60	19.07	7.64	0.04	0.24	1.10	92	31	46	35	.1	4.8	300
064	02.25	55.43	19.35	6.59	0.11	0.32	1.08	128	32	52	33	.1	4.7	300
065	02.50	54.64	19.15	6.63	0.29	0.46	1.09	105	37	63	42	.1	4.7	300
066	02.75	61.00	19.39	7.02	0.04	0.66	1.00	92	28	44	37	0.16	4.7	310
067	03.00	55.01	16.79	7.68	0.03	1.20	0.98	103	37	68	58	.1	4.7	320
068	03.25	53.42	16.96	6.54	0.06	1.34	1.00	97	33	61	59	0.10	4.5	325
069	03.50	53.27	17.26	7.00	0.05	1.44	1.11	84	31	59	46	.1	4.7	310
070	03.75	57.62	20.65	6.96	0.12	2.52	0.98	122	35	63	61	.1	4.7	310
071	04.00	-1.	-1.	5.83	-1.	.1	.1	117	33	62	59	0.05	4.8	310
072	04.25	57.82	19.11	6.15	0.07	2.83	0.93	165	37	61	65	.1	4.8	305
073	04.50	57.33	17.14	6.08	0.09	2.80	0.93	129	39	67	84	.1	5.0	290
074	04.75	60.15	17.03	6.95	0.07	3.07	0.91	457	38	58	81	.1	4.9	290
075	05.00	-1.	17.80	6.11	0.06	.1	0.94	423	-1	66	85	0.06	5.2	290
077	05.50	57.27	16.12	5.83	0.16	3.21	0.82	1115	52	69	102	.1	5.5	260
076	05.25	60.75	16.85	5.49	0.13	3.19	0.83	154	50	66	88	0.05	5.3	285
078	05.75	64.00	19.18	5.67	0.23	3.29	0.88	-1	-1	-1	-1	.1	5.7	250
079	06.00	62.93	16.34	5.13	0.41	3.37	0.74	429	50	66	83	0.05	6.1	220
080	06.25	56.54	11.01	4.98	0.43	2.95	0.70	813	50	64	95	.1	.1	-1
081	06.50	61.95	16.03	5.53	0.78	2.97	0.75	508	56	66	119	.1	6.2	232
082	06.75	60.39	14.98	5.01	0.76	3.15	0.69	1343	28	38	57	.1	6.2	250
083	07.25	62.33	15.56	5.22	0.89	3.05	.1	1113	59	68	127	0.03	6.3	280
084	07.50	62.30	13.12	5.01	1.04	2.99	0.78	884	50	59	104	.1	6.2	295
085	07.75	61.72	14.27	4.92	1.80	2.83	0.68	515	56	66	103	.1	6.3	295
086	08.00	54.95	-1.	5.02	1.78	2.36	0.71	550	53	64	79	.1	6.4	295
087	08.25	61.50	14.61	4.95	2.15	2.77	0.54	530	33	45	53	0.03	6.5	298
088	08.50	64.04	15.00	4.94	2.19	2.89	0.74	562	55	68	97	.1	6.8	290
089	08.75	60.15	10.07	4.96	1.81	2.63	0.71	643	33	42	58	.1	6.8	281
090	09.00	62.65	15.80	5.12	2.21	2.80	0.75	720	35	45	57	.1	6.9	252
091	09.25	63.69	15.84	3.50	2.36	2.98	0.56	509	34	48	48	0.10	6.8	271
092	09.50	65.44	13.91	4.33	2.26	2.75	0.67	573	43	56	61	.1	6.9	260
093	09.75	62.34	14.20	4.85	2.24	2.85	0.77	619	32	43	68	.1	6.9	260
094	10.00	60.45	11.28	4.34	3.22	2.66	0.64	530	52	74	75	.1	.1	-1

* -1= NOT LOOKED FOR

TABLE 1 CONTINUED

LAS PATILLAS AMPHIBOLITE (PIT NO.4), SAVANNA ENVIRONMENT

#	DEPTH METER	SiO2 %	Al2O3 %	Fe2O3 %	CaO %	K2O %	TiO2 %	Mn PPM	Ni PPM	Cu PPM	Zn PPM	ORG-C %	PH	EH+ MV
139	00.00	58.54	8.85	11.81	3.01	0.00	1.51	2347	63	69	83	1.60	6.7	310
140	00.10	52.55	11.86	17.34	2.31	0.00	1.60	3710	106	82	82	1.15	7.0	295
141	00.20	44.73	11.69	15.63	1.99	0.00	1.31	1624	130	146	121	-.1	7.0	315
142	00.30	43.33	14.46	16.49	2.14	0.00	1.18	1607	160	148	108	0.72	7.1	280
143	00.40	45.92	15.57	17.26	2.47	0.00	1.21	1551	122	144	97	0.62	6.8	262
144	00.50	43.79	14.99	15.96	2.38	0.00	1.12	1152	141	142	98	-.1	7.7	215
145	00.60	41.81	15.43	14.77	2.31	0.00	0.81	1401	145	131	99	-.1	7.5	215
146	00.70	34.05	8.19	14.01	2.37	0.00	0.94	1331	118	112	91	0.24	8.3	175
147	00.80	54.60	13.81	9.36	2.30	0.00	0.80	396	39	63	-1	0.20	8.1	182
148	00.90	53.26	12.15	10.75	2.80	0.00	0.92	649	41	100	56	-.1	8.2	200
149	01.00	46.85	11.14	13.94	4.38	0.16	1.20	846	74	128	109	-.1	8.2	221
150	01.10	44.42	11.27	15.31	3.15	0.09	1.35	724	96	191	147	-.1	7.7	210
151	01.20	46.94	10.61	13.53	3.62	0.06	1.30	796	95	216	150	-.1	8.2	220
152	01.30	51.10	11.03	12.46	4.78	0.08	1.07	782	71	148	114	-.1	8.1	220
153	01.40	56.92	11.93	9.37	4.06	0.04	0.74	503	56	139	92	0.16	8.1	220
154	01.50	61.71	13.27	6.14	4.09	0.19	0.58	487	26	66	51	-.1	-.1	-1
155	01.60	67.71	13.93	2.95	2.77	0.21	0.33	99	27	89	39	-.1	8.5	230
156	01.70	68.81	13.85	2.58	2.67	0.20	0.28	129	28	100	33	-.1	8.3	232
157	01.80	67.38	14.16	2.42	2.83	0.16	0.27	121	26	80	34	-.1	8.1	230
158	01.90	62.07	9.65	2.50	2.77	0.31	0.32	123	28	91	39	-.1	7.9	230
159	02.00	67.82	13.65	2.24	2.94	0.26	0.29	119	27	79	40	-.1	7.8	300
160	02.10	67.49	11.15	2.42	2.64	0.24	0.29	150	25	74	38	-.1	7.9	300
161	02.20	70.07	13.32	2.01	2.87	0.31	0.27	180	22	71	62	-.1	7.3	300
162	02.30	66.50	13.17	2.13	2.75	0.25	0.27	162	28	87	39	-.1	7.7	290
163	02.40	69.23	12.33	2.12	2.81	-.1	0.27	186	18	69	50	0.05	7.6	280
164	02.50	68.82	10.40	2.20	2.73	0.30	0.26	182	24	76	-1	-.1	7.7	275
165	02.60	67.78	13.60	2.32	2.81	0.38	0.26	143	17	54	32	-.1	7.7	270
166	02.70	68.68	13.55	2.26	2.80	0.33	0.28	141	23	68	43	-.1	7.9	262
167	02.75	47.06	10.36	15.21	6.37	1.01	1.33	2058	87	92	141	-.1	7.7	270
168	02.80	47.87	10.40	16.98	9.25	0.38	1.37	2128	68	93	146	0.40	-.1	-1

* -1= NOT LOOKED FOR

TABLE 1 CONTINUED

NURIA DIABASE (WELL CORE NO.14), JUNGLE ENVIRONMENT

#	DEPTH METER	SI02 %	AL2O3 %	FE2O3 %	CAO %	K2O %	TIO2 %	MN PPM	NI PPM	CU PPM	ZN PPM	ORG-C %	PH	EH+ MV
195	00.00	11.46	19.43	43.52	0.10	0.00	3.09	994	42	-1	59	1.28	-0.1	-1
196	00.80	12.07	20.50	32.17	0.05	0.09	2.66	574	39	102	35	0.62	-0.1	-1
197	02.00	11.03	18.46	21.82	0.04	0.25	2.11	437	33	103	25	0.34	-0.1	-1
198	02.50	10.40	20.40	24.59	0.07	0.09	2.17	769	30	66	34	-0.1	-0.1	-1
199	03.30	13.56	28.14	31.76	0.13	0.00	2.49	2862	52	203	79	-0.1	5.1	-1
200	04.80	10.42	36.76	23.83	0.06	0.00	2.18	440	22	114	18	0.11	5.1	-1
201	05.80	12.19	38.97	21.49	0.06	0.00	2.12	307	51	108	25	-0.1	-0.1	-1
202	06.80	12.51	34.57	22.84	0.07	0.00	2.28	947	36	131	32	-0.1	5.4	-1
203	07.30	17.52	35.58	22.18	0.08	0.00	1.95	1889	90	194	66	-0.1	-0.1	-1
204	07.80	31.72	30.36	14.44	0.05	0.00	1.33	2608	73	126	48	0.07	-0.1	-1
205	09.30	33.85	27.12	17.30	0.07	0.03	1.70	3545	168	224	100	-0.1	4.7	245
206	10.80	33.90	25.44	19.81	0.08	0.12	1.94	2376	213	298	133	-0.1	4.5	255
207	12.30	36.41	24.57	18.37	0.15	0.12	1.24	2568	201	294	227	0.17	-0.1	-1
208	12.70	51.48	15.50	10.44	10.56	0.52	0.84	1171	81	176	103	-0.1	-0.1	-1

* -1= NOT LOOKED FOR

TABLE 1 CONTINUED

LAS BOMBITAS GRANODIORITE (PIT NO.6), SAVANNA ENVIRONMENT

#	DEPTH METER	SI02 %	AL203 %	FE203 %	CAO %	K2O %	TIO2 %	MN PPM	NI PPM	CU PPM	ZN PPM	ORG-C %	PH	EH+ MV
209	00.00	65.75	16.52	3.86	0.27	0.03	0.49	72	29	46	37	0.55	5.7	280
210	00.10	66.01	15.55	4.12	0.36	0.02	0.47	68	36	74	42	0.43	5.7	272
211	00.20	63.24	15.30	3.91	0.38	0.00	0.45	61	35	70	40	.1	5.7	269
212	00.30	71.45	12.93	3.51	0.30	0.00	0.43	125	23	51	28	.1	5.9	250
213	00.50	71.28	11.24	2.92	0.22	0.00	0.40	76	24	52	24	.1	6.1	252
214	00.70	55.89	11.63	3.39	0.18	0.00	0.41	69	21	52	34	.1	6.2	240
215	00.90	58.83	-1.	3.28	0.16	0.00	0.40	61	17	46	24	.1	6.2	250
216	01.00	59.99	-1.	3.23	0.18	0.00	0.37	58	20	50	23	0.11	6.3	253
217	01.10	78.19	12.63	3.11	0.18	0.00	0.41	76	20	53	28	.1	6.3	251
218	01.20	75.58	11.08	3.12	0.17	0.00	0.40	141	18	50	23	.1	6.4	250
219	01.30	75.59	9.85	2.69	0.17	0.00	0.36	64	21	51	22	.1	6.4	250
220	01.40	79.10	10.71	2.71	0.19	0.00	0.36	74	16	44	18	.1	6.5	245
221	01.50	71.61	11.85	2.98	0.25	0.00	0.40	49	26	65	31	.1	6.6	245
222	01.70	76.99	11.18	2.64	0.20	0.00	0.37	78	20	46	15	.1	6.3	250
223	01.90	72.91	11.26	3.04	0.28	0.00	0.39	105	20	49	26	.1	6.5	250
224	02.00	69.36	12.57	3.35	0.21	0.00	0.41	71	18	47	26	.1	6.3	240
225	02.10	70.53	8.29	3.71	0.19	0.00	0.45	54	25	56	37	.1	6.3	250
226	02.20	67.53	8.82	3.66	0.17	0.00	0.47	61	22	71	31	0.09	6.3	250
227	02.30	62.64	12.59	3.62	0.18	0.00	0.45	48	30	67	39	.1	6.4	230
228	02.40	63.74	6.42	3.20	0.16	0.00	0.43	50	23	52	33	.1	6.6	236
229	02.50	70.80	7.93	3.13	0.18	0.00	0.40	57	28	68	38	.1	6.3	250
230	02.60	79.21	-1.	3.11	-1.	.1	.1	-1	25	-1	29	.1	6.6	231
231	02.70	78.96	8.99	2.51	0.18	0.00	0.37	69	24	53	28	.1	6.7	231
232	02.80	76.91	10.59	2.52	0.17	0.00	0.38	101	17	49	25	.1	6.5	231
233	02.90	81.01	9.44	2.24	0.17	0.00	0.35	54	20	53	26	.1	6.6	240
234	03.00	73.64	9.48	-1.	0.17	0.00	0.36	-1	22	61	28	0.05	6.8	240
235	03.10	79.75	8.73	3.69	0.13	0.00	0.37	226	19	48	23	.1	6.8	240
236	03.20	68.59	14.01	4.37	0.17	0.00	0.47	68	20	44	28	.1	6.5	240
237	03.30	78.90	8.36	3.67	0.17	0.00	0.38	240	20	50	22	.1	6.8	230
238	03.40	79.67	9.06	3.80	0.18	0.00	0.37	211	21	51	17	.1	6.4	222
239	03.50	79.06	6.62	3.44	0.20	0.00	0.35	58	30	68	17	.1	6.8	228
240	03.60	77.36	9.34	3.52	0.20	0.00	0.41	23	20	46	19	.1	7.1	227
241	03.70	80.11	4.08	2.44	0.15	0.00	0.32	99	18	50	12	.1	7.0	221
242	03.80	90.32	4.26	1.84	0.10	0.00	0.29	37	17	49	5	.1	7.0	221
243	03.90	80.38	-1.	2.05	0.11	0.00	0.32	31	18	50	7	.1	7.0	221
244	04.00	91.09	3.54	2.80	0.10	0.00	0.26	-1	17	49	8	0.07	6.9	245
245	04.10	89.05	1.76	1.04	0.08	0.00	0.18	20	18	54	1	.1	7.1	242
246	04.20	96.23	0.78	1.19	0.08	0.00	0.17	29	17	53	1	.1	7.1	250
247	04.30	88.33	0.62	1.67	0.09	0.00	0.14	26	19	53	1	.1	7.1	250
248	04.40	92.88	1.87	0.83	0.09	0.00	0.17	24	13	45	7	.1	7.1	200
249	04.50	92.16	2.77	1.17	0.09	0.00	0.24	35	17	48	7	.1	7.0	220
250	04.60	92.55	3.90	1.04	0.10	0.00	0.18	18	21	60	6	.1	7.0	240
251	04.70	88.21	3.99	1.30	0.09	0.00	0.23	22	22	60	8	.1	7.0	250
252	04.80	87.26	2.67	1.05	0.12	0.00	0.20	11	21	53	4	0.03	7.1	250
253	04.90	88.62	2.63	1.10	0.11	0.00	0.18	12	24	68	7	.1	7.0	258
254	05.00	88.29	3.38	1.46	0.11	0.00	0.18	17	25	64	7	.1	7.0	246
255	05.10	90.97	3.11	1.04	0.11	0.00	0.16	15	18	51	13	.1	6.9	262
256	05.20	90.50	2.44	2.25	0.08	0.00	0.16	11	17	52	5	.1	7.0	264
257	05.30	87.83	2.31	1.35	0.10	0.00	0.16	11	18	53	3	.1	6.9	266
258	05.40	85.97	2.59	1.53	0.13	0.00	0.14	14	11	37	0	0.04	7.0	248
259	05.50	66.51	12.24	2.33	3.11	0.85	0.28	291	153	313	222	.1	.1	-1

* -1 = NOT LOOKED FOR

TABLE 1 CONTINUED

LA PARAGUA GRANITE (PIT NO 7), SAVANNA ENVIRONMENT

#	DEPTH METER	SI02 %	AL2O3 %	FE2O3 %	CAO %	K2O %	TIO2 %	MN PPM	NI PPM	CU PPM	ZN PPM	ORG-C %	PH	EH+ MV
279	00.00	8.58	12.67	69.04	0.11	0.00	-1	-1	26	12	25	0.14	5.0	320
280	00.05	9.26	9.09	63.63	0.22	0.00	0.14	460	44	-1	15	0.19	5.0	292
282	00.15	-1.	-1.	-1.	-1.	-1.	-1.	-1	-1	-1	-1	-1	5.5	320
283	00.20	33.94	9.25	43.56	0.05	0.00	0.27	159	27	45	21	0.41	5.0	322
284	00.25	53.23	19.05	7.08	0.03	0.02	0.52	70	14	35	32	0.56	4.8	316
285	00.30	56.69	20.88	8.62	0.07	0.00	0.54	57	13	28	28	-1	4.6	314
286	00.35	55.86	20.82	7.43	0.04	0.00	0.59	82	14	30	32	-1	4.7	322
287	00.40	53.96	19.45	8.39	0.04	0.00	0.55	54	14	31	32	-1	-1	-1
288	00.45	56.11	20.74	6.53	0.05	0.00	0.57	48	18	43	41	-1	4.8	322
289	00.55	57.04	20.13	6.95	0.04	0.02	0.55	42	11	45	30	-1	5.1	280
290	00.70	56.22	19.74	6.23	0.05	0.03	0.60	57	10	31	28	-1	5.1	282
291	00.90	61.33	21.75	4.78	0.04	0.03	0.50	51	11	40	46	0.08	5.1	320
292	01.10	61.12	21.72	4.33	0.04	0.06	0.61	44	11	40	25	-1	5.1	320
293	01.30	57.30	20.85	2.78	0.06	0.05	0.47	40	11	42	29	-1	5.1	310
294	01.50	61.94	20.52	4.59	0.07	0.06	0.59	72	10	34	30	-1	5.1	320
295	01.70	64.43	16.93	4.23	0.07	0.07	0.55	54	10	35	29	-1	5.0	310
296	01.90	60.88	17.80	3.10	0.06	0.12	0.56	63	17	35	30	0.08	5.1	310
297	02.10	60.88	20.53	2.76	0.06	0.11	0.50	70	12	40	39	-1	4.9	320
298	02.30	66.91	18.38	2.99	0.06	0.11	0.53	75	10	37	38	-1	5.1	330
299	02.50	68.14	17.29	4.54	0.06	0.07	0.44	55	11	37	31	-1	5.1	330
300	02.70	64.91	18.80	3.37	0.06	0.09	0.49	74	15	43	34	-1	5.1	320
301	02.90	58.34	-1.	2.87	0.06	0.09	0.51	71	11	37	30	0.08	5.0	325
302	03.10	59.06	18.16	3.09	0.05	0.12	0.52	55	11	45	34	-1	5.0	310
303	03.30	63.95	17.45	4.36	0.04	0.12	0.51	44	10	48	34	-1	5.2	315
304	03.40	64.31	17.95	4.09	0.04	0.03	0.44	48	9	36	21	-1	5.2	280
305	03.50	65.44	16.76	6.94	0.05	0.08	0.51	45	11	38	27	-1	5.1	290
306	03.60	67.23	18.60	3.52	0.07	-1	0.57	-1	12	45	25	-1	5.1	310
307	03.70	63.16	19.09	2.21	0.08	0.07	0.48	44	9	38	24	-1	5.0	220
308	03.80	61.25	17.93	3.16	0.05	0.09	0.45	43	11	42	48	-1	5.4	215
309	03.90	66.21	16.37	4.85	0.05	0.10	0.45	71	11	39	31	0.05	5.1	231
310	04.00	67.92	16.50	4.16	0.05	0.24	0.50	97	11	36	43	-1	4.8	210
311	24.00	69.67	11.78	1.91	0.99	4.83	0.30	375	21	47	74	-1	-1	-1

* -1= NOT LOOKED FOR

TABLE 2
CONCENTRATION RATIOS

EL CALLAO METAGABBRO (PIT NO.1), JUNGLE ENVIRONMENT

#	DEPTH	SI	AL	FE	CA	K	TI	MN	NI	CU	ZN
1	0.00	0.88	1.11	1.06	0.32	0.00	1.41	1.99	0.87	1.12	1.16
2	0.05	0.96	1.11	1.15	0.31	0.00	1.59	2.00	0.85	1.16	1.10
3	0.10	1.11	1.23	1.17	0.31	0.00	1.57	3.45	0.66	0.85	0.88
4	0.15	1.05	1.24	1.13	0.30	0.00	1.57	2.27	0.97	1.26	1.01
5	0.20	1.02	1.35	1.19	0.32	0.00	1.35	3.27	1.04	1.32	1.28
6	0.25	1.04	1.46	1.25	0.32	0.00	1.54	3.76	0.92	1.47	0.99
7	0.40	0.98	1.39	1.23	0.35	0.00	1.48	3.14	1.01	2.30	1.13
8	0.60	0.99	1.17	1.02	-1.00	0.00	0.93	1.45	1.08	0.83	1.18
9	0.65	0.95	1.48	1.31	0.47	0.00	1.02	1.32	0.96	1.37	1.03
10	0.85	0.94	1.54	1.18	0.38	0.00	1.07	1.16	1.03	1.62	0.80
11	1.10	0.95	1.32	1.18	0.56	0.00	1.15	1.15	1.03	1.67	0.86
12	1.45	0.97	1.39	0.98	0.91	0.00	1.02	0.98	1.07	1.17	0.96
13	1.50	0.97	1.07	0.99	0.92	0.00	0.96	0.99	1.13	1.18	1.01
14	1.60	-1.00	1.17	1.10	-1.00	0.00	1.46	3.67	1.11	1.27	1.29
15	1.70	0.97	1.11	0.95	0.94	0.00	0.89	0.92	1.09	1.14	1.03
16	1.90	0.99	1.12	0.97	0.80	0.00	0.85	1.02	1.02	0.99	0.72
17	2.00	0.96	1.11	0.91	0.87	0.00	0.83	0.89	0.63	0.81	0.59
18	2.10	0.96	0.94	0.91	0.92	0.00	1.07	0.86	1.13	1.07	0.96
19	2.20	0.99	0.77	0.97	0.96	0.00	1.22	0.93	1.02	1.17	1.04
20	2.30	-1.00	0.66	0.93	0.88	0.00	0.76	0.92	1.00	1.09	1.05
21	2.50	1.00	1.00	1.00	1.00	0.00	1.00	1.00	1.00	1.00	1.00

* -1.00 = NOT LOOKED FOR

TABLE 2 CONTINUED

EL CARMEN GRANODIORITE (PIT NO. 2), JUNGLE ENVIRONMENT

#	DEPTH	SI	AL	FE	CA	K	TI	MN	NI	CU	ZN
53	0.00	1.19	0.73	0.89	0.04	0.04	1.80	0.85	0.60	0.89	0.25
54	0.10	1.24	0.80	0.86	0.05	0.02	1.75	0.61	0.56	0.76	0.19
55	0.20	1.21	0.86	1.12	0.05	0.02	1.84	0.64	0.52	0.76	0.29
56	0.25	1.05	1.27	1.46	0.03	0.05	1.95	0.49	0.67	0.77	0.31
57	0.50	0.86	1.81	2.03	0.04	0.08	1.89	0.28	0.79	0.74	0.43
58	0.75	-1.00	2.10	1.88	-1.00	0.12	1.83	0.19	0.85	0.74	0.59
59	1.00	0.88	2.01	1.94	0.04	0.09	1.72	0.18	0.79	0.77	0.43
60	1.25	0.94	1.76	1.81	0.02	0.09	1.69	0.16	0.92	0.77	0.47
61	1.50	0.81	1.61	1.81	0.03	0.07	1.67	0.20	0.56	0.57	0.37
62	1.75	0.89	1.63	1.65	0.02	0.08	1.67	0.18	0.87	0.85	0.61
63	2.00	0.84	1.69	1.76	0.01	0.09	1.72	0.17	0.60	0.62	0.47
64	2.25	0.92	1.72	1.52	0.03	0.12	1.69	0.24	0.62	0.70	0.44
65	2.50	0.90	1.70	1.53	0.09	0.17	1.70	0.20	0.71	0.85	0.56
66	2.75	1.01	1.72	1.62	0.01	0.25	1.56	0.17	0.54	0.59	0.49
67	3.00	0.91	1.49	1.77	0.01	0.45	1.53	0.19	0.71	0.92	0.77
68	3.25	0.88	1.50	1.51	0.02	0.50	1.56	0.18	0.63	0.82	0.79
69	3.50	0.88	1.53	1.61	0.02	0.54	1.73	0.16	0.60	0.80	0.61
70	3.75	0.95	1.83	1.60	0.04	0.95	1.53	0.23	0.67	0.85	0.81
71	4.00	-1.00	-1.00	1.34	-1.00	-1.00	-1.00	0.22	0.63	0.84	0.79
72	4.25	0.96	1.69	1.42	0.02	1.06	1.45	0.31	0.71	0.82	0.87
73	4.50	0.95	1.52	1.40	0.03	1.05	1.45	0.24	0.75	0.91	1.12
74	4.75	1.00	1.51	1.60	0.02	1.15	1.42	0.86	0.73	0.78	1.08
75	5.00	-1.00	1.58	1.41	0.02	-1.00	1.47	0.80	-1.00	0.89	1.13
77	5.50	0.95	1.43	1.34	0.05	1.21	1.28	2.10	1.00	0.93	1.36
76	5.25	1.00	1.49	1.26	0.04	1.20	1.30	0.29	0.96	0.89	1.17
78	5.75	1.06	1.70	1.31	0.07	1.24	1.38	-1.00	-1.00	-1.00	-1.00
79	6.00	1.04	1.45	1.18	0.13	1.27	1.16	0.81	0.96	0.89	1.11
80	6.25	0.94	0.98	1.15	0.13	1.11	1.09	1.53	0.96	0.86	1.27
81	6.50	1.02	1.42	1.27	0.24	1.12	1.17	0.96	1.08	0.89	1.59
82	6.75	1.00	1.33	1.15	0.24	1.18	1.08	2.53	0.54	0.51	0.76
83	7.25	1.03	1.38	1.20	0.28	1.15	-1.00	2.10	1.13	0.92	1.69
84	7.50	1.03	1.16	1.15	0.32	1.12	1.22	1.67	0.96	0.80	1.39
85	7.75	1.02	1.27	1.13	0.56	1.06	1.06	0.97	1.08	0.89	1.37
86	8.00	0.91	-1.00	1.16	0.55	0.89	1.11	1.04	1.02	0.86	1.05
87	8.25	1.02	1.30	1.14	0.67	1.04	0.84	1.00	0.63	0.61	0.71
88	8.50	1.06	1.33	1.14	0.68	1.09	1.16	1.06	1.06	0.92	1.29
89	8.75	1.00	0.89	1.14	0.56	0.99	1.11	1.21	0.63	0.57	0.77
90	9.00	1.04	1.40	1.18	0.69	1.05	1.17	1.36	0.67	0.61	0.76
91	9.25	1.05	1.40	0.81	0.73	1.12	0.88	0.96	0.65	0.65	0.64
92	9.50	1.08	1.23	1.00	0.70	1.03	1.05	1.08	0.83	0.76	0.81
93	9.75	1.03	1.26	1.12	0.70	1.07	1.20	1.17	0.62	0.58	0.91
94	10.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* -1.00 = NOT LOOKED FOR

TABLE 2 CONTINUED

LAS PATILLAS AMPHIBOLITE (PIT NO. 4), SAVANNA ENVIRONMENT

#	DEPTH	SI	AL	FE	CA	K	TI	MN	NI	CU	ZN
139	0.00	1.22	0.85	0.70	0.33	0.00	1.10	1.10	0.93	0.74	0.57
140	0.10	1.10	1.14	1.02	0.25	0.00	1.17	1.74	1.56	0.88	0.56
141	0.20	0.93	1.12	0.92	0.22	0.00	0.96	0.76	1.91	1.57	0.83
142	0.30	0.91	1.39	0.97	0.23	0.00	0.86	0.76	2.35	1.59	0.74
143	0.40	0.96	1.50	1.02	0.27	0.00	0.88	0.73	1.79	1.55	0.66
144	0.50	0.91	1.44	0.94	0.26	0.00	0.82	0.54	2.07	1.53	0.67
145	0.60	0.87	1.48	0.87	0.25	0.00	0.59	0.70	2.13	1.41	0.68
146	0.70	0.71	0.79	0.83	0.26	0.00	0.69	0.63	1.74	1.20	0.62
147	0.80	1.14	1.33	0.55	0.25	0.00	0.58	0.19	0.57	0.68	-1.00
148	0.90	1.11	1.17	0.63	0.30	0.00	0.67	0.30	0.60	1.08	0.38
149	1.00	0.98	1.07	0.82	0.47	0.42	0.88	0.40	1.09	1.38	0.75
150	1.10	0.93	1.08	0.90	0.34	0.24	0.99	0.34	1.41	2.05	1.01
151	1.20	0.98	1.02	0.80	0.39	0.16	0.95	0.37	1.40	2.32	1.03
152	1.30	1.07	1.06	0.73	0.52	0.21	0.78	0.37	1.04	1.59	0.78
153	1.40	1.19	1.15	0.55	0.44	0.11	0.54	0.24	0.82	1.49	0.63
154	1.50	1.29	1.28	0.36	0.44	0.50	0.42	0.23	0.38	0.71	0.35
155	1.60	1.41	1.34	0.17	0.30	0.55	0.24	0.05	0.40	0.96	0.27
156	1.70	1.44	1.33	0.15	0.29	0.53	0.20	0.06	0.41	1.08	0.23
157	1.80	1.41	1.36	0.14	0.31	0.42	0.20	0.06	0.38	0.86	0.23
158	1.90	1.30	0.93	0.15	0.30	0.82	0.23	0.06	0.41	0.98	0.27
159	2.00	1.42	1.31	0.13	0.32	0.68	0.21	0.06	0.40	0.85	0.27
160	2.10	1.41	1.07	0.14	0.29	0.63	0.21	0.70	0.37	0.80	0.26
161	2.20	1.46	1.28	0.12	0.31	0.82	0.20	0.08	0.32	0.76	0.42
162	2.30	1.39	1.27	0.13	0.30	0.66	0.20	0.08	0.41	0.94	0.27
163	2.40	1.45	1.19	0.12	0.30	-1.00	0.20	0.09	0.26	0.74	0.34
164	2.50	1.44	1.00	0.13	0.30	0.79	0.19	0.09	0.35	0.82	-1.00
165	2.60	1.42	1.31	0.14	0.30	1.00	0.19	0.07	0.25	0.58	0.22
166	2.70	1.43	1.30	0.13	0.30	0.87	0.20	0.07	0.34	0.73	0.29
167	2.75	0.98	1.00	0.90	0.69	2.66	0.97	0.97	1.28	0.99	0.97
168	2.80	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* -1.00 = NOT LOOKED FOR

TABLE 2 CONTINUED

NURIA DIABASE (WELL CORE NO.14), JUNGLE ENVIRONMENT

#	DEPTH	SI	AL	FE	CA	K	TI	MN	NI	CU	ZN
195	0.00	0.22	1.25	4.17	0.01	0.00	3.68	0.85	0.52	-1.00	0.57
196	0.80	0.23	1.32	3.08	0.00	0.17	3.17	0.49	0.48	0.58	0.34
197	2.00	0.21	1.19	2.09	0.00	0.48	2.51	0.37	0.41	0.59	0.24
198	2.50	0.20	1.32	2.36	0.01	0.17	2.58	0.66	0.37	0.38	0.33
199	3.30	0.36	1.82	3.04	0.01	0.00	2.96	2.44	0.64	1.15	0.77
200	4.80	0.20	2.37	2.28	0.01	0.00	2.60	0.38	0.27	0.65	0.17
201	5.80	0.24	2.51	2.06	0.01	0.00	2.52	0.26	0.63	0.61	0.24
202	6.80	0.24	2.23	2.19	0.01	0.00	2.71	0.81	0.44	0.74	0.31
203	7.30	0.34	2.30	2.12	0.01	0.00	2.32	1.61	1.11	1.10	0.64
204	7.80	0.62	1.96	1.38	0.00	0.00	1.58	2.23	0.90	0.72	0.47
205	9.30	0.66	1.75	1.66	0.01	0.06	2.02	3.03	2.07	1.27	0.97
206	10.80	0.66	1.64	1.90	0.01	0.23	2.31	2.03	2.63	1.69	1.29
207	12.30	0.71	1.59	1.76	0.01	0.23	1.48	2.19	2.48	1.67	2.20
208	12.70	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* -1.00 = NOT LOOKED FOR

TABLE 2 CONTINUED

LA PARAGUA GRANITE (PIT NO 7), SAVANNA ENVIRONMENT

#	DEPTH	SI	AL	FE	CA	K	TI	MN	NI	CU	ZN
279	0.00	0.12	1.06	36.15	0.11	0.00	-1.00	-1.00	1.24	0.26	0.34
280	0.05	0.13	0.77	33.31	0.22	0.00	0.47	1.23	2.10	-1.00	0.20
282	0.15	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00	-1.00
283	0.20	0.49	0.79	22.81	0.05	0.00	0.90	0.42	1.29	0.96	0.28
284	0.25	0.76	1.62	3.71	0.03	0.00	1.73	0.19	0.67	0.74	0.43
285	0.30	0.81	1.77	4.51	0.07	0.00	1.80	0.15	0.62	0.60	0.38
286	0.35	0.80	1.77	3.89	0.04	0.00	1.97	0.22	0.67	0.64	0.43
287	0.40	0.77	1.65	4.39	0.04	0.00	1.83	0.14	0.67	0.66	0.43
288	0.45	0.81	1.76	3.42	0.05	0.00	1.90	0.13	0.86	0.91	0.55
289	0.55	0.82	1.71	3.64	0.04	0.00	1.83	0.11	0.52	0.96	0.41
290	0.70	0.81	1.68	3.26	0.05	0.01	2.00	0.15	0.48	0.66	0.38
291	0.90	0.88	1.85	2.50	0.04	0.01	1.67	0.14	0.52	0.85	0.62
292	1.10	0.88	1.84	2.27	0.04	0.01	2.03	0.12	0.52	0.85	0.34
293	1.30	0.82	1.77	1.46	0.06	0.01	1.57	0.11	0.52	0.89	0.39
294	1.50	0.89	1.74	2.40	0.07	0.01	1.97	0.19	0.48	0.72	0.41
295	1.70	0.92	1.44	2.21	0.07	0.01	1.83	0.14	0.48	0.74	0.39
296	1.90	0.87	1.51	1.62	0.06	0.02	1.87	0.17	0.81	0.74	0.41
297	2.10	0.87	1.74	1.45	0.06	0.02	1.67	0.19	0.57	0.85	0.53
298	2.30	0.96	1.56	1.57	0.06	0.02	1.77	0.20	0.48	0.79	0.51
299	2.50	0.98	1.47	2.38	0.06	0.01	1.47	0.15	0.52	0.79	0.42
300	2.70	0.93	1.60	1.76	0.06	0.02	1.63	0.20	0.71	0.91	0.46
301	2.90	0.84	-1.00	1.50	0.06	0.02	1.70	0.19	0.52	0.79	0.41
302	3.10	0.85	1.54	1.62	0.05	0.02	1.73	0.15	0.52	0.96	0.46
303	3.30	0.92	1.48	2.28	0.04	0.02	1.70	0.12	0.48	1.02	0.46
304	3.40	0.92	1.52	2.14	0.04	0.01	1.47	0.13	0.43	0.77	0.28
305	3.50	0.94	1.42	3.63	0.05	0.02	1.70	0.12	0.52	0.81	0.36
306	3.60	0.96	1.58	1.84	0.07	-1.00	1.90	-1.00	0.57	0.96	0.34
307	3.70	0.91	1.62	1.16	0.08	0.01	1.60	0.12	0.43	0.81	0.32
308	3.80	0.88	1.52	1.65	0.05	0.02	1.50	0.11	0.52	0.89	0.65
309	3.90	0.95	1.39	2.54	0.05	0.02	1.50	0.19	0.52	0.83	0.42
310	4.00	0.97	1.40	2.18	0.05	0.05	1.67	0.26	0.52	0.77	0.58
311	4.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

* -1.00 = NOT LOOKED FOR

APPENDIX IIITable 3. X-Ray Diffraction Data

El Callas Metagabbro (Pit No. 1), Jungle Environment

Sample No.	Quartz 2θ=30.8	Actinolite 2θ=12.05	Chlorite 2θ=14.4	Hornblende 2θ=30.6	Labradorite- Bytownite 2θ=32.5	Montmorillonite 2θ=6.6
001	108	14	0	8	9	0
002	105	14	0	4	10	0
003	140	19	0	0	0	0
004	6	29	0	6	9	0
005	46	9	0	6	3	0
006	98	28	3	4	20	0
009	34	23	0	14	10	0
010	12	16	0	8	8	0
011	0	15	0	8	8	0
012	0	36	0	21	10	0
013	0	20	0	8	3	0
015	0	0	0	10	0	0
017	0	48	0	18	6	0
018	0	71	12	17	8	0
019	0	36	0	6	0	0
020	0	83	31	12	6	0
021	0	86	44	21	29	0

Las Patillas Amphibolite (Pit No. 4), Savanna Environment

Sample No.	Quartz 2θ=30.9	Kaolinite 2θ=14.2	Actinolite 2θ=12.1	Hornblende 2θ=30.5	Albite-Oligoclase 2θ=32.5	Montmorillonite 2θ=6.6	Enstatite 2θ=32.8
139	.141	0	40	4	23	0	4
140	122	0	11	0	9	0	0
141	46	14	5	0	11	0	0
142	21	7	0	0	0	81	0
143	30	0	9	0	11	90	0
150	64	0	8	0	10	99	0
152	38	0	21	5	24	44	8
154	60	0	16	0	50	0	9
155	152	0	0	0	93	0	18
156	158	0	0	0	49	0	12
157	116	0	0	0	116	0	12
158	65	0	0	0	69	0	20
159	102	0	0	0	46	0	18
160	86	0	0	0	90	0	10
161	132	0	0	0	80	0	21
162	151	0	0	0	84	0	7
163	152	0	0	0	132	0	17
164	130	0	0	0	75	0	18
165	102	0	0	0	63	0	20
166	114	0	0	0	61	0	16
167	34	0	38	9	12	0	0
168	25	0	57	8	33	0	0

Nuria Diabase (Well Core No. 14), Jungle Environment

Sample No.	Quartz 2 θ =30.9	Kaolinite 2 θ =14.2	Andesine- Labradorite 2 θ =32.5	Gibbsite 2 θ =21.2	Goethite 2 θ =24.8	Hematite 2 θ =43.9
196	0	7	0	122	39	20
197	0	10	0	203	63	33
198	0	8	0	146	46	22
199	30	32	0	90	70	23
200	65	0	0	203	64	49
201	36	0	0	183	60	28
202	63	25	0	135	44	28
203	43	76	0	45	39	0
204	36	90	0	33	63	0
205	24	99	0	10	91	0
206	72	65	0	10	84	0
207	16	0	70	0	0	0

El Carmen Granodiorite (Pit No. 2), Jungle Environment

Sample No.	Quartz 2 θ =30.9	Kaolinite 2 θ =14.2	Biotite 2 θ =10.0	Microcline 2 θ =31.9	Labradorite 2 θ =32.5	Goethite 2 θ =24.8
53	118	13	0	0	0	0
55	290	30	0	0	0	0
57	75	56	0	0	0	35
58	65	28	0	0	0	0
59	65	30	0	0	0	9
60	178	75	0	0	0	0
61	46	35	0	0	0	18
62	48	41	0	0	0	12
63	170	96	0	0	0	36
66	166	90	0	0	0	23
67	64	19	0	5	0	0
68	119	85	0	11	0	0
69	55	58	0	6	0	0
70	41	18	0	6	0	0
71	67	10	0	5	0	0
73	56	27	0	11	0	0
74	120	59	0	18	0	0
75	61	25	0	16	0	0
76	113	8	0	9	4	0
77	76	0	0	14	5	0
78	138	40	0	24	33	0
79	62	0	0	9	12	0
81	52	0	0	15	18	0
83	80	0	0	12	16	0
84	99	11	0	22	38	0
85	48	0	0	11	36	0
87	103	0	5	38	138	0
88	43	0	0	10	24	0
92	108	0	11	0	88	0
94	107	0	42	80	80	0

Las Bombitas Granodiorite (Pit No. 6), Savanna Environment.

Sample No.	Quartz 2 θ =30.9	Kaolinite 2 θ =14.2	Biotite 2 θ =10.0	Hornblende 2 θ =35.3	Labradorite 2 θ =32.5
209	162	55	0	0	0
210	216	0	0	0	0
211	285	40	0	0	0
212	362	41	0	0	0
213	400	39	0	0	0
214	286	35	0	0	0
215	278	35	0	0	0
216	378	36	0	0	0
217	306	35	0	0	0
218	310	26	0	0	0
219	468	36	0	0	0
220	430	32	0	0	0
222	390	48	0	0	0
223	305	40	0	0	0
224	288	40	0	0	0
225	168	61	0	0	0
226	177	61	0	0	0
227	53	21	0	0	0
228	315	53	0	0	0
229	92	26	0	0	0
230	313	54	0	0	0
231	261	66	0	0	0
232	200	52	0	0	0
233	360	18	0	0	0
234	373	28	0	0	0
235	293	30	0	0	0
236	282	16	0	0	0

Las Bombitas Granodiorite (Continued)

Sample NO.	Quartz 2 θ =30.9	Kaolinite 2 θ =14.2	Biotite 2 θ =10.0	Hornblende 2 θ =35.3	Labradorite 2 θ =32.5
237	378	23	0	0	0
238	423	18	0	0	0
239	118	0	0	0	0
240	333	28	0	0	0
241	384	25	0	0	0
242	475	5	0	0	0
243	404	14	0	0	0
244	161	0	0	0	0
245	450	0	0	0	0
246	380	0	0	0	0
247	535	0	0	0	0
248	227	0	0	0	0
249	308	18	0	0	0
250	398	0	0	0	0
251	493	0	0	0	0
252	605	0	0	0	0
255	177	0	0	0	0
256	395	0	0	0	0
257	523	0	0	0	0
258	440	0	0	0	0
259	350	0	45	9	125

La Paragua Granite (Pit No. 7), Savanna Environment

Sample No.	Quartz 2θ=30.9	Kaolinite 2θ=14.2	Gibbsite 2θ=21.2	Goethite 2θ=38.8	Albite- Oligoclase 2θ=32.4	Microcline 2θ=31.9	Biotite 2θ=10.2
279	20	0	0	60	0	0	0
280	15	0	0	39	0	0	0
283	158	13	0	49	0	0	0
284	235	75	0	0	0	0	0
285	158	68	0	2	0	0	0
286	190	77	5	2	0	0	0
287	180	68	5	2	0	0	0
289	195	63	0	0	0	0	0
290	196	64	0	2	0	0	0
291	236	67	0	0	0	0	0
292	226	68	20	0	0	0	0
293	271	33	38	0	0	0	0
294	202	49	10	0	0	0	0
295	246	49	23	0	0	0	0
296	280	39	15	0	0	0	0
297	255	56	38	0	0	0	0
298	313	38	28	0	0	0	0
299	315	58	6	0	0	0	0
300	344	60	23	0	0	0	0
301	278	48	32	0	0	0	0
302	311	72	6	0	0	0	0
303	400	76	0	0	0	0	0
305	227	52	6	0	0	0	0
306	261	36	20	0	0	0	0
307	300	20	50	0	0	0	0
308	290	40	63	0	0	0	0
309	393	30	35	0	0	0	0
310	288	34	12	0	0	0	0
311	178	0	0	0	57	45	12

APPENDIX IV

Description of the Weathering Profiles

Description of the Weathering Profile (Pit No. 1) on the
El Callao Metagabbro.

Sample	Depth (meters)	Weathering Horizon	Description
1	0.00	A	Dark-brown horizon, highly weathered soil, with great content of organic matter; contains actinolite, hornblende, calcic-plagioclase, authigenic quartz, and montmorillonite.
2	0.05		
3	0.10		
4	0.15		
5	0.20		
6	0.25	B	Light brown horizon, highly weathered soil, slightly greater amounts of calcic-plagioclases. Textural resemblance to parent rocks begins to disappear; some ferruginous fragments are found in this horizon, also contains actinolite, hornblende, and residual quartz.
7	0.40		
8	0.60		
9	0.65		
10	1.10		
11	1.35		
12	1.45	C	Partially weathered rock to more advanced alteration stage. The rock appears rotten, though the texture and structure are similar to those of fresh rock.
13	1.50		
14	1.60		
15	1.70		
16	1.90		
17	2.00		
18	2.10		
19	2.20		
20	2.30		
21	2.50	D	Fresh rock underneath the soil.

Description of the Weathering Profile (Pit No. 4) on the Las Patillas Amphibolite.

Sample	Depth (meters)	Weathering Horizon	Description
139	0.00	A	Highly weathered, black soil; slight amount organic matter and some plant roots; contains kaolinite, quartz, actinolite, hornblende, and slight amount of albite-oligoclase.
140	0.10		
141	0.20	B	Highly weathered, yellowish soil; maximum accumulation of silicate clays; contains kaolinite, montmorillonite, actinolite quartz, and feldspars. Organic matter is very scarce and diminishes with depth.
142	0.30		
143	0.40		
144	0.50		
145	0.60		
146	0.70		
147	0.80	C	Partially weathered rock easily desegregated. The rock appears rotten; the texture and structure are similar to that of the fresh rock; the weathered parent material occasionally is present; contains montmorillonite, quartz, actinolite, and small amount of plagioclases.
148	0.90		
149	1.00		
150	1.10		
151	1.20		
152	1.30		
153	1.40		
154	1.50	D	Moderately weathered rock, very friable, light-grayish sand. Sand and weathered rock are intermingled; contains plagioclases and quartz.
155	1.60		
156	1.70		
157	1.80		
.	.		
.	.		
.	.		
.	.		
.	.		
.	.		
168	2.90		Fresh rock.

Description of the Weathering Profile (Well Core No. 14)
on the Nuria Diabase.

Sample	Depth (meters)	Weathering Horizon	Description
195	0.00	Concretion- ary Zone	Dark-reddish soil; contains pisolites made up of goethite and lesser amounts of hema- tite.
196	0.80		
197	2.00	Gibbsite Zone	Brown-yellowish soil (ferru- ginous laterite); contains gibbsite, goethite, hematite quartz, and traces of kaolin- ite.
198	2.50		
199	3.30		
200	4.80		
201	5.80		
202	6.80		
203	7.30	Kaolinite Zone	Yellowish soil, high clay concentration; contains kaolinite, goethite, and quartz.
204	7.80		
205	9.30		
206	10.80		
207	12.30		
208	12.70	Parent Rock	Fresh diabase.

Description of the Weathering Profile (Pit No. 2) on the El Carmen Granodiorite.

Sample	Depth (meters)	Weathering Horizon	Description
53	0.00	A ₁ (Dark Zone)	Dark-black soil, high content of organics intermingled with mineral; contains kaolinite and quartz.
54	0.10		
55	0.20	A ₂ (Dark Reddish Zone)	Dark reddish soil, abundant plant roots; contains kaolinite, quartz and goethite.
56	0.25		
57	0.50		
58	0.75		
59	1.00	B (Mottled Zone)	Yellowish soil with dark reddish mottles or vertical accumulation of iron oxides; contains kaolinite, quartz, and goethite.
60	1.25		
.	.		
.	.		
68	3.25		
69	3.50	C (Palled Zone)	Highly leached yellowish soil, maximum accumulation of clays; contains kaolinite, quartz, and slight amount of K-feldspar. Organic matter is very scarce and it is depleted with depth
70	3.75		
71	4.00		
.	.		
.	.		
79	6.00		
80	6.25	D (Saprolite)	Moderately weathered rock, very friable, and light grayish sand intermingled with fragments of altered rock; it contains plagioclase, K-feldspar, biotite, and quartz.
81	6.50		
.	.		
.	.		
.	.		
94	10.00		

Description of the Weathering Profile (Pit No. 6) on Las Bombitas Granodiorite.

Sample	Depth (meters)	Weathering Horizon	Description
209	0.00	A (Dark Reddish Zone)	Dark reddish soil, abundant plant roots; contains kaolinite, quartz, and organic matter.
210	0.10		
211	0.20		
212	0.30		
213	0.50		
214	0.70	B (Light-Reddish Zone)	Light reddish soil; lesser plant roots; contains kaolinite and quartz.
215	0.90		
.	.		
.	.		
223	1.90		
224	2.00	C (Pallid Zone)	Highly weathered yellowish soil, maximum accumulation of clays; and organic matter is very scarce; contains kaolinite and quartz.
225	2.10		
226	2.20		
.	.		
229	2.50		
230	2.60	D	Moderately weathered rocks very friable, light-grayish sand material; contains kaolinite and quartz.
.	.		
.	.		
.	.		
258	5.40		

Description of the weathering profile (Pit No. 7) on the La Paragua Granite.

Sample	Depth (meters)	Weathering Horizon	Description
279	0.00	A	Pisolites are found loosening on the surface, and deeper in this horizon they are intermingled with a reddish soil. The pisolites are made up mainly by goethite and amorphous iron and manganese hydrous oxides.
280	0.05	(Concretionary	
281	0.10	Zone)	
282	0.15		
283	0.20		
284	0.25	B (Mottled Zone)	Yellowish soil with red mottles or vertical accumulation of iron hydrous oxide; contains quartz kaolinite and amorphous oxides.
.	.		
.	.		
.	.		
291	0.90		
292	1.10	B ₂ (Mottled Zone)	Sandy clay with red mottles of iron hydrous oxide, contains quartz, kaolinite, and gibbsite.
.	.		
.	.		
.	.		
303	3.30		
304	3.40	C	Bleached soil between the mottled zone and the saprolite beneath, contains quartz, gibbsite, and lesser amounts of kaolinite.
.	.		
.	.		
.	.		
308	3.80		
309	3.90	D (Saprolite and Parent Rock)	Highly weathered rock, very friable; contains albite-oligoclase, K-feldspar, and quartz.
310	4.00		
311	4.00		

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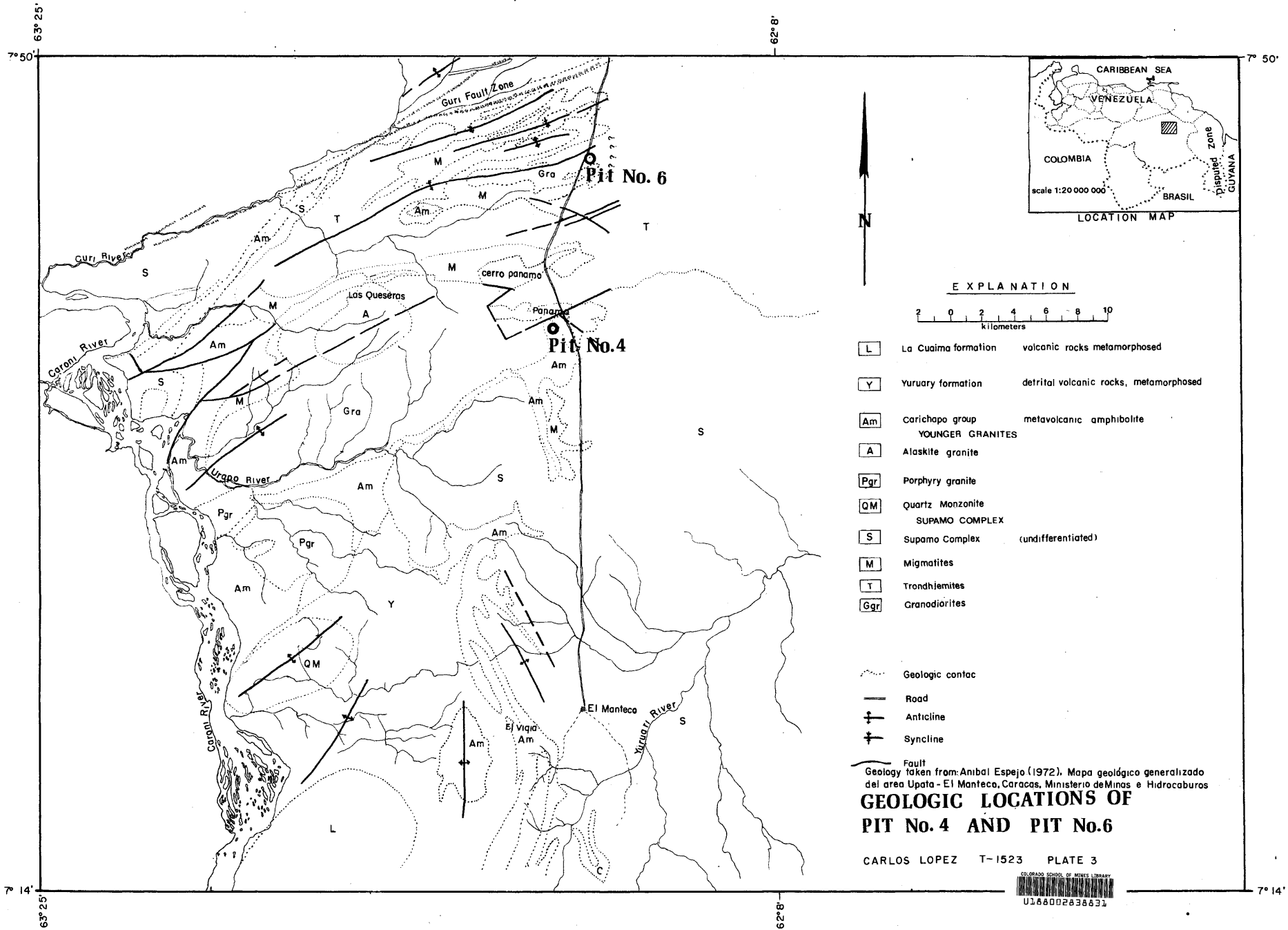
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