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# A QUANTITATIVE GEOCHEMICAL, MINERALOGICAL AND PHYSICAL STUDY OF SOME SELECTED ROCK WEATHERING PROFILES FROM BRAZIL

FINAL REPORT

CHARLES V. CLEMENCY

PRINCIPAL INVESTIGATOR

17 AUGUST 1977

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Three hundred and forty-three samples, representing weathering profiles or sequences of some twenty-three different rock types collected in the field in Brazil, have been analyzed by wet-chemical, physical and x-ray diffraction methods for the purpose of understanding the processes involved in the decomposition of rocks by weathering and in the formation of clay minerals. Evi-

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dence indicates that there is a strong relationship between a) the presence or absence of quartz in the parent rock and the type of decomposition product formed, and b), the width of the "transition zone" between fresh rock and completely weathered saprolite. Quartz-rich rock types exhibit wide, gradational weathered zones and usually form kaolinite or halloysite in well-drained , or perhaps smectite in poorly-drained, environments. Quartz-free rocks exhibit extremely narrow, sharply-defined weathered zones, and weather to gibbsite (plus or minus iron oxides) in well-drained, and smectite in poorly-drained, environments. Kaolinite found in the vicinity of quartz-free rocks is either formed by re-silication of gibbsite, or is of secondary origin (transported). Texture of the rock (aphanitic vs. phaneric) has little or no effect on weathering product formed, each producing identical materials. Rate of flux of water through the environment, which is one of the factors controlling the concentration of dissolved species, is believed to be an important control on the nature of the weathering product formed. Rate of flux may be affected by many factors, such as, total rainfall, seasonal periods of wetting and drying, topography, permeability, position of water table, etc.

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## LIST OF PARTICIPATING PERSONNEL AND DEGREES RECEIVED

1. The following students participated in some phase of this research:

| Name | Function | Degree |
|---|---|---|
| Richard M. Pollastro | Summer assistant | M.A. |
| Eugene Palmer | " " | M.A. |
| Eurybiades Busenberg | Research associate | PhD |
| Timothy M. Welch | " " | M.A. (expected 1/78) |

2. The chemical and physical measurements were made by:

Charles V. Clemency-Principal Investigator

Carol C. Clemency- Chemical technician

David L. Borden- Chemical analyst, Department of Geological Sciences

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## ABSTRACT

Over five hundred samples representing weathering profiles or sequences of some twenty-three different rock types were collected in the field in Brazil. Of these, three hundred and forty-three of the more promising samples have been studied by x-ray diffraction, chemical and physical methods for the purpose of trying to gain insight into the processes involved in the decomposition of rocks by weathering, and into the mechanism of formation of clay minerals. The data indicate that there is a strong relationship between the presence or absence of quartz in a rock and, a) the type of decomposition product formed, and b), the nature of the "transition zone" between fresh rock and completely weathered saprolite. Quartz-rich rocks exhibit wide transition zones with blurred and indistinct interfaces between the fresh, unaltered rock and the weathered material. In addition, quartz-rich rocks usually form kaolinite or halloysite, especially in well-drained environments, while smectites may form in poorly-drained environments. In contrast, quartz-free rocks exhibit very narrow, sharply defined transition zones, and weather to gibbsite (plus or minus iron oxides) in well-drained, and smectites in poorly-drained, environments. Kaolinite found in the vicinity of quartz-free rocks may originate by resilication of gibbsite, or in some cases may be of secondary (transported) origin, rather than from direct alteration from primary minerals. Rock texture has little or no influence on the weathering product formed, since aphanitic and phaneric equivalents of the same composition were found to weather to the same products. Rate of flux of water through the environment is believed to be an important control on the nature of the weathering product formed, through its influence on the concentration of dissolved species. Rate of flux may be affected by many factors such as total rainfall, seasonal wetting and drying, topography, permeability, position of water table, etc.

# INTRODUCTION

This report presents the results of a three year study on a series of tropical rock weathering profiles collected in Brazil during a sabbatical leave in 1968-69. During this period, over 500 specimens representing more than twenty different rock types, formed in a range of weathering regimes, were collected from many different localities in Brazil. These samples afford an unusual opportunity for a systematic study of tropical weathering processes and the resultant products formed under a variety of conditions. The samples were subjected to chemical, mineralogical and physical analysis including wet chemical, x-ray diffraction, petrographic, cation exchange capacity, bulk and powder density, and surface area and abrasion pH on selected samples. By establishing this data base, it was hoped that some questions concerning tropical weathering could be answered. Among the questions that have interested the author are the following:

1. How are clay minerals formed during weathering from primary tecto- and ino-silicates such as feldspars, amphiboles and pyroxenes?

2. Theoreticians such as Helgeson, Garrels, Paces and others have constructed elaborate models of weathering largely on the basis of laboratory data. Can complete quantitative data from natural systems be used to clarify, confirm or disprove these idealized weathering models?

3. Does the same rock type, e.g., a basalt, always yield the same weathering products even under different conditions of climate, rainfall, topography (drainage), mean annual temperature, etc.?

4. Does rock texture affect the weathering products formed? I.e., do rhyolites weather to the same products as granites under similar conditions?

5. Why in some cases does a kaolinite form during weathering, while in another case, halloysite is formed?

6. What are the weathering products associated with some of the rarer rock types such as charnockite, eudialyte syenite, phonolite, etc.?

## The Problem(s)

Rocks weather because the minerals of which they are composed are not in equilibrium under the surface conditions in which they find themselves. In response to the chemical potentials driving them, reactions take place which decompose the

original minerals and re-distribute the components to form new equilibrium phases, such as, the various clay minerals, hydroxides and oxides, while removing more soluble constituents in solution. Despite extensive study in both field and laboratory, many aspects and phenomena of the weathering process remain poorly understood, because of the complexities involved. A good discussion of the current state of knowledge of weathering may be found in Krinitzsky, Patrick and Townsend (1976).

Many complaints can be found in the literature deploring the "incomplete" nature of many weathering studies that have been made; incomplete in the sense that only one or two parameters, e.g., the chemistry or mineralogy only was studied, to the neglect of other important considerations. Because of the complex nature of the problem, such studies have been criticized as being of limited value. It was one of the present author's original purposes to put an end to some of these complaints by providing data on more parameters. Unfortunately, the problem is still not resolved. There are so many parameters that could be measured on a single weathering profile, that a year or more would probably have to be spent on a single sequence. While this study attempts to provide more data than usual, it can still be faulted for neglecting certain aspects such as particle size distributions, composition of the interstitial waters in contact with the materials undergoing weathering, etc. One of the author's deepest regrets was his failure to obtain analyses of these interstitial or pore waters passing through the weathering profiles in question. In planning the field work, it was intended to measure, in the field, the pH, total carbonate and the activities of mono- and di-valent cations of the waters at each sampling locality, as well as to collect water samples for later analyses of other important elements (Si, Al, etc.) back in the laboratory. Unfortunately, because of import restrictions on electronic equipment used in these field measurements, that aspect had to be abandoned. It is hoped that perhaps sometime in the future the author could arrange a return to

Brazil to complete this part of the study.

Progress to Date

The first year of this study was devoted primarily to the setting up of an analytical laboratory, testing of procedures using U.S.G.S. and other rock standards, automation of procedures, preliminary study, testing and selection of the more promising weathering profiles. The second and third years were devoted to the collection of data. During the three years of support, four papers were presented at national and international scientific meetings (Table 1), and five papers were published (Table 2). Two other papers are now in various stages of completion and enough raw data has been accumulated to eventually produce at least five additional papers. Although this is the final report of this grant, much data remains to be studied. More time was devoted to the acquisition of data than in the analysis of that data, which will eventually be published. As a result, it is not yet possible to try to answer all of the questions raised above.

Table 1. Papers presented at various national and international scientific meetings during the course of this study.

1. Clemency, C. V. (1975). Simultaneous weathering of a granitic gneiss and an intrusive amphibolite dike near São Paulo, Brazil and its bearing on the origin of clay minerals. Paper presented at the 1975 International Clay Conference, Mexico City.

2. _____ (1974). Weathering of contrasting rock types under tropical conditions in Brazil. Paper presented at the 23rd Annual Meeting, Clay Minerals Society, Cleveland, Ohio.

3. _____ and E. Busenberg (1974). The kinetics of dissolution of alkali feldspars at 25°C and 1 atm $P_{CO_2}$. Paper presented at the 1st International Symposium on Water-Rock Interaction, Prague, Czechoslovakia.

4. Busenberg, E. and C. V. Clemency (1974). A comparision of the chemistry and mineralogy of quartz-rich and quartz-free rocks from Brazil. Paper presented at the 1st International Symposium on Water-Rock Interaction, Prague, Czechoslovakia.

Table 2. Papers published as a result of this study. See bibliography for complete reference.

1. Busenberg, E. and C. V. Clemency (1973).
2. Clemency, C. V. (1975).
3. Busenberg, E. and C. V. Clemency (1976b).
4. Busenberg, E. and C. V. Clemency (1976a).
5. Clemency, C. V. and Busenberg, E. (1976).

## The Data and Results

The various data are presented in a series of appendices. Appendix A gives various pertinent field data, such as sampling locality, rock description, sample numbers, etc. Appendix B lists rainfall and elevation data of stations close to or at the sampling localities. Appendix C contains the chemical analyses of some 343 samples of fresh rock and their associated weathering products. The values given are the average of duplicate (two) samples. The samples were run by the single-solution method of Shapiro (1975). In Appendix D may be found measurements of cation exchange capacity, bulk density, powder density, surface area and abrasion pH. For various reasons, not every sample could be run for every parameter. For example, bulk density cannot be measured on an incoherent sample (a powder), and and few surface area measurements made were difficult, time-consuming and were run on "borrowed" apparatus. Appendix E presents an index of rock types by name, and Appendix F, an index of sample numbers in numerical order with rock type and locality. X-ray data was so voluminous, that it was impossible to include in this report. Selected portions will be made available to interested parties.

Because of the magnitude of work involved, some weathering sequences have not yet been worked on at all. An idea of these can be obtained by noting gaps in the numerical sequence listed in Appendix F. Much work still remains on many sequences, where detailed size fractionations, mineral separations and petrographic

work have not yet been done. Probably several years of work remain. Lastly, for many sample sequences there has not been enough time to really study all the mass of data accumulated so far in enough detail to arrive at meaningful conclusions. The next year will be devoted to data analysis only, and several papers will be forthcoming shortly.

## CONCLUSIONS

Under the section "Purpose of Study" several questions were raised which were to be addressed in the course of the research. Unfortunately, definitive answers to all these questions cannot be listed unequivocally at this time, however, certain observations were made which may contribute to better understanding. Because much of the data has not yet been analyzed in detail, and because some x-ray work is in the process of completion, more definitive answers will be forthcoming in future papers. Some observations and conclusions to date regarding some of these points follow.

In order to understand the complex processes of weathering and how clay minerals form, it soon became clear that the problems must be attacked from three directions: 1) by laboratory studies of mineral dissolution under carefully controlled conditions, which produce exact and unequivocal data, which can be used in, 2) theoretical modeling of thermodynamic and kinetic processes to identify those factors important in weathering processes, and 3) field studies to corroborate, refute or choose between alternative models proposed by the theoreticians. No one of these aspects alone can hope to solve the problem.

Shortly after the start of our studies, it was realized that we could not hope to understand our findings without better laboratory data on the dissolution of the feldspar family of minerals. This led to our study on the dissolution kinetics of the feldspars. Until the appearance of the paper by Busenberg and Clemency (1976), which gives complete laboratory data on eight feldspars including orthoclase, microcline and the complete range of composition of plagioclases

(six in all), almost all theoretical work was based on the data of Wollast (1967) who studied only 1 feldspar. In our paper we discuss several criticisms of Wollast's work which we attempted to eliminate in our study. This study, which was done by Busenberg as his Ph.D. dissertation, now provides the most complete and accurate data on the kinetics of dissolution of this most important group of minerals. The principal investigator considers this paper to be the most valuable contribution of this study to date, and it will provide invaluable data for all future theoretical studies as Wollast's has in the past. A brief summary of Busenberg's conclusions follows:

1. Weathering releases silicic acid and cations into the bulk solution by four different processes. The initial reaction is the exchange of surface cations for hydrogen ions from the bulk solution. This stage lasts approximately one minute. In the second stage, large amounts of cations and silicic acid are released into the bulk solutions. The duration of this second stage is very variable for the release of silicic acid, ranging from one hour for albite and potassium feldspars to slightly more than 100 hours for anorthite; the duration varies proportionately with the anorthite content of the feldspar. In the third stage, which lasts approximately 19 days, the release of all species into the bulk solution is diffusion-controlled and follows the parabolic rate law. In the fourth and final stage, the steady-state release of species follows the linear kinetic law.

2. The aluminum concentrations of the bulk solutions reached saturation with amorphous $Al(OH)_3$ in about six minutes and remained at saturation for the rest of the experimental run.

3. Parabolic and linear rate constants and diffusion coefficients for 25°C and pH5 were evaluated for the release of all the major elements of the eight feldspars. These data are tabulated in Busenberg and Clemency (1976).

4. The steady-state Si/Al molecular ratios of the product layers appear to be about 1 :1 for all the members of the plagioclase series. In contrast, this ratio appears to be about 2:] for orthoclase and microcline.

The paper by Clemency (1976) discusses the interesting case of two closely associated, dissimilar rock types in intimate contact with each other that must have undergone long, intense weathering under exactly the same conditions of climate, rainfall, topography, time, vegetation, etc. The original parent rock materials consisted of a host rock (granitic gneiss?) which was crosscut by two parallel basalt dikes about 2 meters and 1 meter thick respectively and a few meters apart. These parent rocks evidently later underwent metamorphism which converted the basalt dikes to amphibolite and the host rock to granitic gneiss. Subsequently, these rocks weathered to a depth of greater than 20 meters and are now exposed in a very large and deep roadcut of striking color aspect. The amphibolite dikes have weathered to an apple-green, smectitic clay containing some unweathered remnants of amphibolite in the center. These green dikes cross-cut the pink (from hematite) granitic gneiss, whose original foliation is still visible, and which consists of mainly kaolinite clay, quartz and mica.

In such a case, it is clear that conditions of weathering affecting these rocks had to be identical on outcrop scale. In order to form the saprolite over 20 m deep, vast quantities of water must have passed through these rocks. One might expect a blurring of contacts and mixing of the green and pink clays formed from each parent rock type, yet this has not occurred. Knife-sharp contacts are preserved between the green, smectitic clay formed from the amphibolite and the pink, kaolinitic clay formed from the gneiss. How long would it take to weather hard rocks to a depth greater than 20 meters? How much water had to pass through these rocks during that time?

It is difficult to account for the clear separation of these weathering products using current popular hypotheses on the mechanism of formation of clay minerals. These mechanisms fall into three categories:

1. Those processes invoking precipitation of crystalline clay minerals directly from ionic or undissociated species in true solution.

2. Those processes involving first the decomposition of the original minerals by removal of some constituents in solution, but leaving a "collapsed", amorphous aluminosilicate "residue" which never went into solution. This amorphous residue later reorganizes or recrystallizes into crystalline clay minerals, perhaps also incorporating some mobile constituents from solution.

3. Combinations of 1 and 2, e.g., adsorption of silicic acid in true solution onto some insoluble substrate, such as proto-gibbsite or amorphous aluminum hydroxide gel to form crystalline alumino-silicates (clay minerals).

In cases 2 and 3, the observed physical separation of the green vein of smectite and the surrounding pink, kaolinitic host rock would result from one or both of the essential constituents of the clays (alumina and silica components) existing in immobile condition throughout the history of the weathering process. In case 1, where both ingredients are in a mobile (dissolved) form, it seems unlikely that knife-sharp contacts and complete separation of clay types could be maintained for very long times. However, this may nevertheless be possible if the green vein material and that of the reddish host rock have greatly different permeabilities. In this connection see Ross and Hendricks (1945, p. 60). The kaolinitic host rock is far more permeable than the green smectitic clay, as evidenced by greatly different filtration rates observed during separation and filtration of the clay fractions.

If the kaolinitic host rock is far more permeable than the smectitic green clay veins, pore water seeping downward would have a far longer "residence time" in contact with the minerals within the impermeable green vein than would water in the more permeable host rock. Since dissolution rates in natural waters of the primary silicate minerals vary greatly, and since the rate of release of individual ions from each mineral also varies greatly (Busenberg and Clemency, 1976), concentration of dissolved species in pore waters is time dependent. A physical factor such as a permeability difference could thus cause a difference

in the length of time of contact between water and primary minerals. This would allow pore water within the green veins to acquire different characteristics (higher pH and silica content, etc.) than pore water within the pink host rock. The pore water characteristics within each rock type thus impresses its own particular equilibrium constraints on the clay minerals forming within each rock type and stability field relationships may be different within each rock type within close proximity in the same outcrop.

The outcrop described is not an uncommon phenomenon in Brazil. The author observed at least three other localities in the state of Parana (the one described was in Sao Paulo) where dikes of green clay cross-cut other rock types usually red or brown in color. Sharp contacts were observed in each case. These other outcrops have not been studied in the detail that the first was.

The author concludes from these observations that the sharp separation of two different clay types is either a result of rock permeability differences, or, clay minerals form from immobile alumino-silicate "residues" rather than being precipitated from dissolved species in solution where they existed in a mobile state.

The paper by Clemency and Busenberg (1976) discusses a striking field feature first pointed out to the author by Brazilian geologists and subsequently observed by him many times in Brazil. This is the observation that quartz-free rocks, such as nepheline syenites, basalt, diabase, gabbro, diorite, phonolite, marble, dolomite, etc., exhibit an extremely narrow and sharply-defined transition zone between the fresh rock and completely weathered saprolite. The width of this transition zone is on the order of one mm to a few cm at most. In contrast, quartz-rich rocks, such as, granite, rhyolite, quartz-bearing gneisses and sediments, seem to exhibit wide, gradational transition zones on the order of several meters or tens of meters thick, with increasingly weathered material upwards.

In addition, the author observed a color correlation between saprolites of the B and C horizons of these quartz-free and quartz-rich rock types that enabled him to usually predict from the color of the saprolite above, whether a quartz-free or quartz-rich rock was present below the saprolites above. Quartz-rich rock types are usually of a light pastel shade of pink or yellow. Saprolites associated with quartz-free rocks exhibit either a white, dark yellow, dark red or purple colors. It is stressed here that the color of the upper soil horizons are of no value for such a prediction, all being usually homogenized to some similar shade of yellow, purple, red or brown. It is in the lower horizons where this color correlation was observed. A deep road-cut, quarry face, trench or shaft is usually necessary for best exposure. It can seldom if ever be observed from the surface alone.

Further, when the mineralogy of the weathering products was later studied in the laboratory, it became apparent that quartz-free rocks invariably weathered directly to gibbsite or smectite, whereas, the quartz-rich rocks weathered to kaolinite or halloysite. The quartz-rich vs. quartz-free phenomenon is not new and has been observed and discussed before by many authors, such as Mohr and van Baren (1954), Gardner (1970), Chesworth (1975) and Weaver (1975). Mohr and van Baren and Weaver do not believe in such a relationship. The present author believes there is one based on repeated observations of this phenomenon in the field.

Several possible reasons suggest themselves as factors that might be important in causing these observed relationships. Among these are: the difference in concentration of silica in leaching waters, pH differences, quantity and quality of water passing through the environment, which depends on climate, topography, permeability, etc., or even the possibliity that the presence of certain minerals ensure the formation of only certain products, e.g., kaolinite.

The author knows of no way at present to solve the problem, identify the critical factors, or even to prove that these phenomena exist. The only ones who can in fact confirm or refute whether this pehnomenon exists are recognized field geologists who have spent many years in field work in tropical climates. In the course of a year in Brazil, the author saw hundreds of outcrops of dozens of different rock types under many different climatic and topographic conditions, yet is not 100 per cent sure that his observations are correct. However, he is certain of one thing, and that is, that definitive pronouncements on the subject by those who spend a week or two in the tropics seeing a few outcrops had best be ignored as they will only lead to confusion, not clarification. One of the Brazilian geologists who directed the author's attention to this phenomenon was Dr. Theodore Knecht, formerly State Geologist for the State of Sao Paulo, now retired. Dr. Knecht has spent his whole life as a field geologist in Brazil and the author has great respect for his opinions.

The author would like to offer the following very tentative hypothesis, based on a laboratory observation, as a possible explanation. Because of certain peculiarities shown by aluminum in solution, which we observed in leaching experiments on feldspars (Busenberg and Clemency, 1976), and which have also been observed by others (Smith and Hem, 1972), it was observed that cryptocrystalline gibbsite can form fairly rapidly (within six minutes!) in certain solutions, and within one or two months can recrystallize into microcrystalline gibbsite (Smith and Hem, 1972). Under certain conditions, aluminum released from minerals by weathering rapidly reaches its saturation concentration in the leaching water, at which point amorphous $Al(OH)_3$ (cryptocrystalline gibbsite) forms. We have observed that, for reasons still not known but probably related to surface electrical charge on the crystals, zero point of charge, pH, etc., two possible phenomena may be observed: 1) the $Al(OH)_3$ particles rapidly coagulate into

aggregates larger than 0.45 microns, or 2) the particles remain peptized and exist as essentially single particles or platelets of less than 0.45 microns in size. (This effect was noted in filtering our leaching solutions through 0.45 and 0.1 micron Millipore filters.) The flat platelets coagulate to form aggregates, probably by joining face-to-face so that one platelet partially covers the face of the other, much as sheets of paper in a pile. Very little of the total surface area is exposed to the bulk solution. Most of the aluminum is thus physically prevented from reacting with (adsorbing) silicic acid to form kaolinite (a slow reaction). These aluminum hydroxide aggregates are large enough (>0.45Å) to be filtered out of percolating waters in the porous weathered saprolite, thus fixing the cryptocrystalline gibbsite near the fresh rock. The silicic acid is flushed out of the environment as fast as it is released from the fresh primary minerals. If the aluminum hydroxide forms large, filterable aggregates, the weathering product consists of gibbsite. If the aluminum hydroxide remains peptized (independent particles with large, reactive surface areas) greater opportunity exists for adsorption and fixation of the silicic acid in solution onto the gibbsite platelets or sheets to eventually recrystallize into a kaolinite-type mineral. The rate of flux of the pore water is of utmost importance in this process because it will affect and control the concentration of all dissolved species.

It has long been observed that in tropical climates the soil mineral commonly found on hilltops (well-drained and above the water table) is gibbsite, whereas in more low-lying areas (valleys, bottom slopes of hills, anywhere <u>below</u> water table) kaolinite and/or kaolinite-gibbsite mixtures are common (Millot, 1970,

p. 122-123; Moniz and Jackson, 1967, p. 34). The explanation given relates the presence of gibbsite to places where the flux of water through the saprolite is high, whereas when water flux is low, kaolinite is present. High rates of water flux enable the concentration of silicic acid in solution to remain low enough so that gibbsite is the stable phase. Low rates of water flux, which may result from a number of factors, such as topographic position, permeability, relationship to water table, seasonal variation of rainfall, etc., enable silicic acid concentration to increase to a point where the kaolinite stability field is entered. Very low or stagnant rates of water flux might result in an increase in silicic acid concentrations high enough to enter the smectite stability field.

The presence of kaolinite in a weathering profile containing both gibbsite and kaolinite may be explained in several ways, one is that it formed directly from weathering of primary minerals; another is that it formed from gibbsite by resilication as a result of an increase in silicic acid concentration in the groundwaters for some reason. The author was guided in the field by Dr. Moniz and has seen his field evidence and laboratory data and agrees with his conclusions that gibbsite can and will resilicate under conditions of poor drainage. Moniz and Jackson (1967, p. 34) state that,

> "Mohr and van Baren (1954) in their review of rock weathering, did <u>not</u> agree with studies that have shown gibbsite to be the main product of the weathering of basic rocks. That conclusion is not tenable here too. <u>Both</u> kaolinite and gibbsite are formed from basic rocks. Which of these predominates depends on how much a particular soil has been weathered."

The present author does not believe that the presence of kaolinite in a weathering profile consisting of both gibbsite and kaolinite necessarily proves that the primary minerals of the parent rock weathered <u>directly</u> to kaolinite. The kaolinite could just as well have been formed by resilication of gibbsite at some time earlier in the saprolite's history, or even contemporaneously, such as during the dry season, when the rate of flux of water is much lower. The present

author believes that the weathering of a fresh parent rock material takes place over a period of time, usually quite long, and that as weathering progresses, the original complex composition tends to approach a very simple composition, a process described succinctly by Chesworth (1973) which he calls the "residua system", consisting of the materials $SiO_2$, $Al_2O_3$ and $Fe_2O_3$. This is defined as "the chemical sink towards which the bulk of earth's surface materials (i.e., the silicate rocks) trend during weathering".

It is interesting to note that Isphording (1975, p. 37), on the basis of multi-variate factor analysis found that "rainfall, contrary to many previous reports, was of minor importance, once a minimum value of 50 inches per year was reached." If his conclusions are correct, the absolute amount of rainfall may not be as important as how long a given volume of water remains in contact with the rock being weathered, i.e., the "rate of flux" of water through the environment. The longer the contact time, the higher the concentrations of various dissolved species will become, which in turn controls the equilibrium assemblage of weathering products formed.

The weathering of a rock to its very final end-product can be thought of as analagous to a long motion picture film with a beginning, a middle and an end. The geologist appears at some moment in time, sees one "frame" of the film, representing one stage in the development of the ultimate product. Some "frames" maybe more significant than others, and some may be misleading, since changes in exterior controls such as topography, climate, permeability, etc. might alter or even reverse the normal course of events. Theoretical studies of stable equilibrium assemblages indicate that the basic process of weathering is fairly simple. However, the picture is clouded because conditions are not static over time, but can change, resulting in stages where mixtures of minerals representative of the old and the new stability assemblages coexist. Soils are not necessarily

equilibrium assemblages of minerals reached instantaneously during all portions of the weathering cycle. The problem of deciphering the whole story is not likely to be solved by any one study in any one locality, but must be a synthesis of many studies.

The present author has found several instances of rocks weathering directly to gibbsite only in rinds or zones close to the parent rock. As distance away from the fresh rock increases, kaolinite begins to appear, and increases in amount away from the fresh rock interface. This probably reflects the fact that material further from the interface is older and has had more time to react with (adsorb?) silicic acid from solution (a slow process). Despite the fact that kaolinite is present along with gibbsite does not prove that kaolinite is forming directly from the parent minerals of the rock. Basalts and diabases were observed to weather directly to gibbsite under good drainage conditions as found on topographic highs, but to appear to be weathering to kaolinite or smectite under poor drainage conditions, and to form mixtures of gibbsite and kaolinite in intermediate cases. As a terrain matures and streams meander and cut laterally and downward, one can easily picture areas where what was once a topographic low becoming a hilltop and vice-versa. The result, especially in ancient terrains such as, for example, the Planalto of Pocos de Caldas, is a confusion of primary weathering products ranging from monominearalic to multi-component mixtures. Secondary processes would mix products from different areas or stages and further confuse the picture. Many areas can be found where age of the rocks is fairly young and fresh, and terrains are immature. Here, good profile exposures should be sought which reveal complete, first-cycle saprolite profiles in situ with fresh rock at the base. Various effects of topography, drainage, water flux variation, the nature of the parent rock type, etc., will affect the concentration of silica and other ions which will determine what product will be formed. In such places, the author predicts that the more simple realtionships will be found and the most fruitful studies will be made.

In trying to answer some of the questions raised in the introduction, the following comments are offered.

1. Does one rock type (e.g., basalt) always yield the same weathering product regardless of different conditions of rainfall, topography, climate, etc.?

   From many observations of weathering products of the same rock type, weathered under different conditions in different localities in Brazil, the answer to this question is definitely no. One rock type can produce different weathering products under different conditions.

2. Does rock texture affect the weathering products formed, i.e., do phonolities (aphanitic) weather to the same products as their coarser-grained phaneric equivalent, foyaite?

   From the author's observation, rock texture is not an important factor and does not affect the product formed. Phonolites and foyaites were found in the Pocos de Caldas area in close proximity whose chemical and mineralogical analyses were virturally identical. They decomposed to the same weathering products. Likewise, basalts, diabases and gabbros seemed to show little difference in weathering products formed. Texture does not appear to be an important controlling factor on what product is formed.

3. What are the weathering products associated with some of the rarer rock types not previously described in the literature?

   Phonolite, tinguaite, foyaite, charnockite, meta-gabbro (metadiorite?) weather to gibbsite and iron oxides. Amphibolites form greenish-colored

smectites close to nontronite in composition. Shonkinite decomposes to vermiculite. Carbonates (marble, dolomite) form chlorite and mica. In one case, rhyolite formed pure halloysite only.

4. How do clay minerals form, i.e., what is the mechanism?

The question cannot be answered by this study, however, some important observations bearing on this problem are discussed elsewhere in the conclusions. The author directs the reader to the excellent paper by Fripiat and Herbillon (1971) which reviews current ideas on these points.

5. Can field information, such as gathered in this study, be useful in evaluating various theoretical models proposed for weathering?

The answer to this is a cautious yes. The phenomena involved in weathering is extremely complex. Important controlling conditions can change through time (i.e., drainage, topography, position of water table, flux rate of leaching water, etc.) which may result in confusing mixtures of weathering products not "normally" associated with each other, i.e., non-equilibrium assemblages. In developing theoretical models it is usually necessary to grossly simplify the parameters and to make assumptions, which may sometimes be unwarranted, in order to be able to attack the problem at all. By keeping a cautious eye on actual conditions found in nature, the theoretician can perhaps avoid the many pitfalls in his path.

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# APPENDIX A

Appendix A contains pertinent field information about the samples, such as, geographic location, rock type, sampling depth, etc. Rainfall and elevation data, being usually unavailable at the exact sampling locality, may be estimated from data presented in Appendix B. Appendix B lists average annual rainfall and elevation data measured at various airfields throughout Brazil. This information was extracted from Anonymous (1968) which also contains additional information on mean annual temperatures, maximum and minimum temperatures, rainfall distribution monthly throughout the year, etc. Information is given as to the closest airfield or two to the sampling location, from which estimates can be made. Similar additional data were gathered from many journals too numerous to cite individually. These are listed at the end of Appendix A.

## SAMPLE DESCRIPTIONS

Samples 8-20-1 through 8-20-21 are samples of tourmaline-rich granite, gneiss, schist and their weathering products collected at a crushed stone quarry known as "Mineraçaõ Peccicacco" near the town of Perus 25 km northwest of the city of Saõ Paulo. The nearest airfields (see Appendix B) are station number 83777 Vira Copos, about 50 km to the north of Saõ Paulo, and 83729 Campinas, about 90 km to the northwest of Saõ Paulo.

The unweathered rocks exposed in this quarry are folded pegmatoid tourmaline granites located in a zone of a syntectonic granite with schistose country rock. Tourmaline is enriched within the pegmatitic granite, especially near the contact with the schist. Weathering has attacked both schist and granite where their contact has been exposed. Cordani et al (1963) say:

> "Rocks in this area include a large granite intrusive which contains black tourmaline, calc-silicate rocks such as amphibolite (containing

tremolite), pyroxenite (diopside) which intrude the muscovite schist country rock. These rocks fall in the classification of "calc-silicate hornfelses of Heinrich."

8-20-1 Partially weathered granite remnant within clay.
8-20-2 Fully weathered granite (clay) six inches from 1.
8-20-3 Granite (white) from 1 meter below contact with intruded weathered schistose country rock. Contact is 3 meters below surface.
8-20-4 Ditto 0.5 meter below contact.
8-20-5 Ditto from within 2.5 cm of contact.
8-20-6 Weathered schist (yellow) country rock 2.5 cm above contact with granite below.
8-20-7 Ditto from 0.5 m above contact (red color).
8-20-8 " " 1.0 m " " (brown color).
8-20-9 " " 1.5 m " " (yellow-brown color).
8-20-10 " " 2.0 m " " (reddish soil).
8-20-11 " " 2.6 m " " and 30 cm below surface (brown soil).
8-20-12 Fresh granite from 3 meters below contact with schist.
8-20-13 Weathered " " 1 " " " " " .
8-20-14 Fresh pegmatitic granite (almost pure feldspar) from 1 meter below contact but 30 meters to left of 8-20-1 through 12.
8-20-15 Weathered pegmatitic granite rich in black tourmaline from 30 cm below contact.
8-20-16 Unconsolidated white "sand" at contact. This white, sandy zone was not observed 30 m to right.
8-20-17 Yellow and black-striped schist from 30 cm above contact.
8-20-18 Fresh, banded gneiss from left end of main quarry face (Jazida #1). This is intruded by what appears to be a dike of pure feldspar (#19 below).
8-20-19 Pure feldspar cleavage flakes from 1 meter away from #18.
8-20-20 Sample of dark, banded gneiss from high above on right side of Jazida #1.
8-20-21 Weathered sample of dark banded gneiss #20.

* * * * * *

Samples 8-22-1 through 8-22-64 are samples of tinguaite, foyaite, chibinite and lujavrite and their weathering products which were collected on the plateau of the alkaline massif of Pocos de Caldas, Minas Gerais State. A description of the rocks, weathering products and bauxites are given in Ellert (1959), Björnberg (1959), de Souza Santos (1937), Weber (1959), Ashry (1962), and Ilchenko and Guimaraes (1954). Moniz (1964) made a detailed study of the clays of this region. The present author wishes to thank Dr. Moniz for his assistance and guidance in collecting the samples described in this study.

The massif is an elliptical, plateau-like body about 35 by 30 km which stands

in topographic relief 600 m above the surrounding plain. The topographic relief is pronounced around the rugged and dissected edges of the massif where elevations vary from 1,678 m at the highest to 1,220 m at the lowest within a horizontal distance of 1,600 m. The depressed, bowl-like center of the massif (the "planalto") is less rugged, formed of low, rolling hills with an average elevation of about 1,300-1,350 m and an average annual rainfall of 2,308 mm (Weber, 1959; Bjornberg, 1959; de Souza Santos, 1965). Bauxitized talus slopes vary from a minimum of 5° to a maximum 27° with an average of 18°. Rapid drainage is a result. Rainfall is cyclic with definite wet and dry seasons (see Weber, 1959).

8-22-1 Fresh black, tinguaite of the ring-dike. Collected at an outcrop 1.6 km outside the city of Pocos de Caldas on the road to the top of the Serra de Pocos where the statue of Christ is located which overlooks the city. (This rock is the same rock type as sample 8-22-22B of which fresh and weathered rinds were analyzed.)

* * * * * *

Samples 8-22-12 through 8-22-18 were collected at "Pedra Balão" (or "Balloon Rock"), a famous tourist attraction, about 4.0 km from Pocos de Caldas. Here an outcrop of the rare alkaline rock type eudialyte syenite is found. Brazilian geologists call this rock "lujavrite" if it shows a dark, gneissic texture, or "chibinite" if it has a lighter more massive texture. Both varieties may be collected within several hundred yards of "Pedra Balao."

Here was found a good weathering sequence on an exfoliating outcrop of lujavrite. The rock varies from fairly fresh inner material (#12) to about 60 cm outward where weathering progresses to almost a soil.

| | |
|---|---|
| 8-22-12 | Fresh, dark foliated, eudialyte syenite (variety "lujavrite"). Much biotite. |
| 8-22-13 | Sample taken 7 cm from #12 of weathered lujavrite. |
| 8-22-14 | Sample more weathered 120 cm from fresh material (#12). |
| 8-22-15 | " " " 300 cm " " " " |
| 8-22-16 | " " " 450 cm " " " " |

8-22-17 Sample more weathered 600 cm from fresh material (#12).
8-22-18 " " " 600 cm " " " "
These are scrapings of highly weathered rock or soil.
8-22-19 Fresh eudialyte syenite ("chibinite") from 100 meters uphill above Pedra Balão. Lighter facies. Less biotite.
8-22-20 Crumbly, white weathering product from about 10 cm from #19.
8-22-21 Brownish soil from 20 cm from #19.
8-22-22B This was a sample of fresh, black tinguaite which was coated with a cream colored weathering rind about 1 cm thick. This was collected at a roadcut about 1 km from Pedra Balão towards the statue of Christ which overlooks the town of Pocos de Caldas. This 1 cm thick weathering rind was visibly zoned. The rind was separated into three crude fractions by careful scraping and peeling, labeled respectively "Inner", "Middle" and "Outer". The fresh, unaltered rock was labeled "Fresh".

8-22-22B (Fresh)
Unaltered black tinguaite.
8-22-22B (Inner)
Inner 2-3 mm of white weathering crust closest to fresh tinguaite.
8-22-22B (Middle)
Middle 3-4 mm of cream-colored weathering crust.
8-22-22B (Outer)
Outer 2-3 mm of tan-colored weathering crust.

* * * * * *

Samples 8-22-23 through 8-22-27 are coarse-grained, white foyaite (nepheline syenite) and its weathering products, collected on the property of Compania Minerio de Aluminio (ALCOMINAS). Samples were collected at the top of a low knoll on the company's prospect located on the road between Caladas and Pocos de Caldas. This is within the foyaite zone mapped on the geologic map. Here was exposed fresh foyaite with thick weathering rinds (5-20 cm thick) and good weathering sequences. Boulders with 3-10 cm thick white bauxite rinds, within which are cores of fresh foyaite, can be found here in the rubble at the top of the hill, as well as in-situ outcrop. Original rock structures are often preserved in the weathered rinds.

8-22-23 Fresh foyaite (nepheline syenite).
8-22-23A Boulder of hard, compact red and white bauxite. These nodules (up to 300 cm in diameter) are found within the soil layer.
8-22-23B Piece of weathered crust with fairly fresh core. Weathering rind still retains the visible texture and structure of the original rock.

| | |
|---|---|
| 8-22-24 | White, weathered rind 2-3 cm from fresh rock. |
| 8-22-25 | A porous crust 10 cm from fresh rock. |
| 8-22-26 | Weathered material 300 cm from fresh rock. |
| 8-22-27 | Fresh foyaite from the main outcrop. Some pieces had a white crust which was selectively removed before the rock was ground up for chemical analysis. |

* * * * * *

Samples 59 through 64 are of fresh fenite and its weathering products. These were collected at an outcrop about 0.75 km outside of the town of Pocinios on the paved road to Caldas. The outcrop is about 100 m northeast of a white concrete bridge over a stream.

| | |
|---|---|
| #59 | Fresh pink fenite. Contains large phenocrysts of potash feldspar. |
| 60 | Partly weathered fenite 30 cm to right of 59. |
| 61 | Highly weathered material 60 cm to right of 59. |
| 62 | Weathered material 50 cm to left of 59. |
| 63 | " " 200 cm " " " ". |
| 64 | " " 500 cm " " " ". |

* * * * * *

Samples 65 through 72 are from a glacial till deposit used as raw material by a company known as "Ceramica Martini" near the town of Mogi Guacu which is located about 65 km north of Campinas. Pocos de Caldas lies about 80 km to the north. The nearest airfield station is number 83729 in Appendix B.

The glacial till is part of a sedimentary sequence called the Tubarão Series of Permo-Carboniferous age. This deposit is believed to be a till because varved deposits have been found here, along with a heterogeneous assortment of particle sizes. The deposit is mostly clay and silt but contains polished and rounded pebbles and boulders within it. Bedrock has been found with glacilly striated surfaces. Samples were taken starting at the bottom of a benched hillside and working up. Much calcite was observed as veins throughout the till which will contribute to high $CO_2$ and CaO.

| | |
|---|---|
| 65 | Dark gray-black tillite. Compact and fine-grained. From floor of pit. Contains many polished pebbles. These were removed before analysis. |
| 66 | Same from top of bench 5 m above 65. |
| 67 | Same from bottom of next bench above about 6 m above 65. |
| 68 | Same from top of next bench about 14 m above 65. |
| 69 | Sample of yellow zone 0.5 m above 68. Weathered tillite (?). |
| 70 | Sample 2 m above 69. Gray with yellow (limonite) surface stains. |
| 71 | Sample of gray, sandy material with yellow surface stains from about 10 m above 70. Contains many pebbles. |
| 72 | A reddish, cross-bedded sandstone from 1 m below original hill-surface. This is a different material than the till and probably has no connection with it. |

Samples 65-71 all bloated severely during water analysis by the Penfield method (fusion in a closed tube). This indicated presence of organic matter or other gas-producing material. Sample 72 was the only one which did not bloat.

* * * * * *

Sample 75-78 are samples of fresh diabase and its weathering products taken from a roadcut 14 km north of the town of Campinas, São Paulo State, on the west side of the highway. There is an airfield at Campinas which is station number 83729 in Appendix B. Here an outcrop of fresh diabase with thick, concentric weathering rinds is well-exposed. The transition between fresh rock and completely weathered material is very sharp, probably no more than 1-2 cm. The weathered material spalls off in concentric, 1 cm thick shells. Immediately adjacent to the fresh rock is a yellow and white (mixed) zone a few cm wide which gradually merges with red terra roxa above. About 2.5 m of soil is present between fresh rock and the surface. A. C. Moniz, who was present when these samples were collected, has studied the terra roxas of this region (Moniz, 1967). He distinguishes between two types of terra roxa: "legitima" which is light, porous, friable and disintegrates when wetted, and "estructura" which is more dense, harder and does not crumble when wetted. Moniz identified the terra roxa at this outcrop as "legitima".

| | |
|---|---|
| 75 | Fresh black diabase |
| 76 | White and yellow weathering rind 1 cm from fresh rock. |
| 77 | Yellow " " 3 cm " " " . |
| 78 | Dark red terra roxa soil 1 m above 75 and 1.5 m below the ground surface. |

* * * * * *

Samples 82 through 89 are samples of shonkinite and its weathering or hydrothermal alteration products collected at the Congonhal vermiculite mine (now abandoned) of the Vermiculita S/A company near the town of Tatui, about 150 km west of São Paulo. This occurence has been described by Maciel and Guimares (1965) as follows:

> The deposit has the structure of a vertical dike striking about 70° NW. The dip is vertical and the thickness varies from 20 to 50 m wide. The country rocks are sandstones and siltstones of the Tubarão Series. The dike has been dug out to a depth of 10-15 meters. The "ore" is made up of rounded, golden-brown vermiculite flakes embedded in a fine-grained, granular, highly altered matrix composed of sericite, calcite, chlorite and amphibole. Xenoliths from the surrounding sandstones and tillites compose 10% of the matrix and vary in size from mm to decimeters in size. The vermiculite flakes compose about 10% of the rock and are strikingly rounded. The intrusive rock of the dike is very much like the shonkinite-porphyrites that occur at the Morro Aracoiaba, Ipanama. This mountain, about 10-20 km away, can be seen from the deposit at Tatui and lies directly along the projection of strike of the dike. The vermiculite may be a product of hydrothermal alteration of the biotite that occurs in those rocks.

The nearest airports are at Campinas and Vira Copos, 100 km to the northeast (Appendix B). The town of Sorocaba, 50 km east of Tatui has an elevation of 540 meters and 1200 mm of rainfall per year.

It could not be determined unequivocally whether the dike material was weathered or hydrothermally altered. The color of the dike rock in the deeper parts of the cut is mostly reddish to reddish-brown indicating an oxidizing environment, although some green material is also present. Evidence of severe heating and baking may be seen in the wall rocks and inclusions. The mineralogy (sericite, calcite, chlorite) suggests hydrothermal alteration. Near the upper parts of the deposit, the colors become yellow-brown to yellow as the original

ground surface is approached. These yellow colors are obviously a result of weathering or leaching near the surface.

| | |
|---|---|
| 82 | Sample from wall 3-4 meters below original surface. Color of material is light brown. |
| 83 | Same as 82, but sun-dried. Gray color. |
| 84 | Green altered material from bottom of cut, 10-15 m below surface. |
| 84A | Weathered mica flakes in 84. |
| 85 | Piece of amygdoloidal basalt inclusion from within wall containing green clay and black includions. Dark gray. |
| 86 | Sample from a dark red zone within wall of dike. Dark red-brown. |
| 87 | Light yellow-brown zone from 30 cm to right of red zone (86). |
| 88 | Hard, indurated green material to right of 86. This material bloats on heating. |
| 88A | In the wall near a small adit at bottom of cut is a xenolith of fresh, hard, black rock which appears to be fresh shonkinite. |
| 89 | Weathered light brown material 2-4 m from top of cut just above sample 82. |

* * * * * *

Samples 90-96 are of a porphyritic granite of a white color with black grains of biotite present in the amount of abour 20%. The samples were collected in an abandoned quarry owned by a Dr. Mendes located near his clay beneficiating plant in the town of Votorantim which lies about 5 km south of Sorocaba which in turn lies about 90 km west of São Paulo. The elevation of Sorocaba is 540 m and the average annual rainfall is 1200 mm. The black and white granite is typical of that found over a wide area of this region. More rare in this area is a pinkish-tan, fine-grained granite which intrudes and contains inclusions of the black and white granite. This pinkish-tan granite may also be seen in this quarry.

| | |
|---|---|
| 90 | Sample of fresh pink and tan granite. |
| 91 | " " " black and white, porphyritic granite. |
| 92 | Partially weathered black and white granite, Feldspar is chalky and rock stained yellow by limonite. |
| 93 | Decomposed granite (mostly white clay) with quartz and feldspar fragments. Crumbles easily. Collected from 5 m below original surface. |
| 94 | Tan-colored clay from 4 m below original surface. |
| 95 | " " " " 3 m " " " . |
| 96 | Crumbly, decomposed granite relict found with the clay at 4.5 m below original surface. Samples crumble easily but feldspar is fairly fresh toward center of crystals. |

* * * * * *

Samples 97-99B were of granite and endellite collected at a roadcut along the Sorocaba-Piedade road at about the 112.5 km post. Here is exposed an altered green and red granite containing veins of coarse endellite which has been described by de Souza Santos et al (1965). Fresh rock is not exposed here, but a piece of red granite float was found (99A).

| | |
|---|---|
| 97 | Tan-colored clay containing red specks of iron oxide. Within this material are found the veins of endellite. The tan clay is a weathering product of red granite similar to 99A. |
| 98 | Coarse endellite from veins in 97. |
| 99A | Red granite float found at base of outcrop. |
| 99B | Fresh red granite exposed at 111.5 km post. |

* * * * * *

Samples 100-104 are samples of a slate-phyllite of the São Roque Series exposed in a roadcut at the 108 km post on the Sorocaba-Piedade road. For a reference discussing the weathering of slate see Moniz (1967).

| | |
|---|---|
| 100 | Fresh silvery-gray slate-phyllite |
| 101 | Most weathered slate-phyllite (white clay) from 10 m to right of 100. Sample is coherent, but white and powdery on the outside. |
| 102 | No sample. Skipped this number. |
| 103 | Partially-weathered gray slate-phyllite material from between 100 and 101. |
| 104 | An apparently fresher piece of gray slate-phyllite than 100. Found embedded in clay as a relict between 100 and 103. |

* * * * * *

Samples 105-108 are completely weathered samples of what once was a shale, slate, phyllite or schist. No fresh rock is visible. Original foliation is visible and is vertical. Weathering is complete. These samples were collected at the "Filito Branco Pit" owned by Dr. Mendes (now abandoned) at La Barreiro, not far from Piedade. A sequence of samples was taken from bottom to top of the exposure.

105 White clay from bottom of pit about 3-4 m below original ground surface
106 Cream-colored clay from top of pit 2 m below original surface.
107 Red clay from horizon 1 m below original surface.
108 Yellow-brown soil from 30 cm below original surface. Contains roots.

* * * * * *

Two clay pits at Boa Vista also owned by Dr. Mendes were sampled. These are called "xisto argilloso" or argillaceous schist. No fresh original rock is visible as it has been completely weathered, however, a piece of float was found of fairly unaltered schist. The original schistosity and texture is preserved and the original rock appears to probably have been a schist or gneissic schist. Clay from these pits is used as a vehicle and diluent for insecticides. According to Dr. Mendes it has a high quartz content and a high potassium content, due to the presence of muscovite, which makes it valuable in ceramics.

109 A composite sample of white clay was taken across a meter of exposed outcrop perpendicular to the foliation and about 5-6 m below the original surface of the now abandoned first pit.

A second pit now being worked was also sampled.

110 A composite sample of white clay from bottom of second pit and 5-6 m below original surface.
110A A gray-green clay zone near top of pit 2-3 m below original surface.
111 Pinkish-tan clay. Near top of pit 2 m below original surface.
112 Cream-colored clay. Near top of pit 1 m below original surface.
113 Brown clay. Near top of pit 30 cm below original surface. Coarse pebbles are present in this zone.
114 A piece of fairly unaltered schist was found as float at the bottom of the pit. Center is fresh, very finely laminated schist of a gray color which is weathered on outside to a cream colored clay.

* * * * * *

Samples 136-142 are from a sequence of fresh to weathered basalt exposed in a crushed stone quarry on the east bank of the Parana River near the hydro-

electric dam at Ilha Solteira-Jupia between the states of São Paulo and Mato Grosso States. The nearest airfield is at Tres Lagoas, station number 83618, about 14 km away. There were 3 "benches" each 3 m high exposed.

| | |
|---|---|
| 136 | Brown soil from 10 cm below original surface of ground. |
| 137A | Yellow-brown soil from 30 cm below original surface of ground. |
| 137B | Brown soil from 30 cm below original surface and 30 cm to left of 137A. Looks different. |
| 138 | Light gray weathered basalt from 1 m below surface. |
| 139 | Red and green speckled weathered basalt from 2 m depth. |
| 140 | " " " " " " 3 m " . |
| 141 | Green-red altered "semi-fresh" basalt from a depth of 6 m below surface. Darker color than 140. |
| 142 | Freshest black basalt from a depth of 9 m. |

* * * * * *

Samples 151-165 are from a shale quarry near the town of Jundiai, 50 km northwest of São Paulo. The nearest airfield is Vira Copos, Station no. 83777 about 40 km to the northwest. This is a bloating shale used to make lightweight aggregate by the CINASA company. Samples 151-160 were collected in the old, abandoned (1968) pit. Samples 161-164 were collected from the new, smaller, working pit.

| | |
|---|---|
| 151 | Variegated, green and red, thinly laminated shale. From lowermost point of pit about 9 m below original ground surface. |
| 152 | Ditto from 7 m depth. |
| 153 | Yellow and pink shale from 6 m depth. |
| 154 | Tan and white shale from 5 m depth. |
| 154A | All red shale from 30 cm away from 154. |
| 155 | Red and white variegated shale from 4 m depth. |
| 156 | Ditto from 3 m depth. |
| 156A | Yellow and red shale from near 156 (30 cm) but different color. |
| 157 | No sample. Skipped this number. |
| 158 | Red and white clayey soil from 2 m below surface. |
| 159 | Light red soil from 1 m below surface. |
| 160 | Dark red soil from 30 cm below surface. |
| 161 | (New pit.) Sample of a mass of black clay. |
| 162 | Brown soil 30 cm below original surface. This sample was <u>lost</u>! |
| 163 | Yellowish shale, soft, moist, slakes readily from 1 m below original surface. |
| 164 | Ditto from 2 m depth. |
| 165 | Ditto from 3 m depth. |

* * * * * *

Samples 166-172 are of green nontronite veins formed from weathering of amphibolite dikes which cross-cut a pink, weathered gneissic host rock near the town of Jundiai, São Paulo State. These rocks and clays are completely described in the paper by Clemency (1976). The nearest airfield is at Vira Copos about 40 km to the northwest.

* * * * * *

Samples 180-186 are from a Tertiary oil shale deposit called "Mineracão Santa Fe" near the town of Tremembé, about 140 km northeast of São Paulo on the main highway to Rio de Janeiro. The nearest airfield is at Cumbica, station number 83778, about 100 km to the southwest. Here a green, petroliferous shale is found which is part of the "Xisto do Vale do Paraiba" (Paiva Netto and Nascimento, 1956). Although the shale is not now being utilized as an oil shale at the nearby oil shale pilot plant, it is being used as a decolorizing agent and as a foundry sand. Samples were collected in and around the adit of a small, underground working. See reference by J. E. Paiva Netto and A. C. Nascimento (1956).

| | |
|---|---|
| 180 | Soft, bluish-green clay or shale from lowermost part of the deposit. This is not as petroliferous (only 2-3% organics) as sample 181. From a depth of about 5.5 m below surface. |
| 181 | Hard green shale 1 m above 180. This is the "oil shale" of the "Xisto do Vale do Paraiba" formation. This contains 8.4% oil and 2.4% gas. |
| 182 | Brown-red soil from 30 cm below original ground surface. There is a color "unconformity" at a depth of about 1-2 m separating the green shales and clays below it and more red and yellow material above. This may be an effect of the water table and resulting oxidation or reduction zones. |
| 183 | Yellow-red soil from 1 m below 182. Above "unconformity". |
| 184 | Greenish clay with yellow limonitic patches. From below the "unconformity" and at a depth of about 2.3 m. |
| 185 | Greenish-gray clay from a more yellow zone <u>above</u> the unconformity. This is probably the same as 184 but has more limonitic staining. |
| 186 | "Weathered" gray-green shale from a depth of 3 m and between 184 and 181. Not as coherent as 181 which is "fresher" looking. |

* * * * * *

Samples 187-199 are samples of pegmatite, gneiss and their kaolintic weathering products from the Empresa Caulim Company kaolin deposit at the village of Linhares, about 5 km from the city of Juiz de Fora (State of Minas Gerais) which lies about 150 km due north of Rio de Janeiro. Nearest airfield is at Barbecena New, Station number 83689, about 75 km northwest of Juiz de Fora. Because of a hard rain and unpleasant conditions, collection was cut short and a close examination of the pegmatite was not possible. Samples 187, 188, and 189 were given to me by the company geologist from his office collection and were not collected personally by me.

| | |
|---|---|
| 187 | Sample of fresh gneissic country rock around pegmatite from drill core. The pegmatite itself has been drilled to about 40 m and they have not found fresh rock. |
| 188 | Altered gneiss from drill core. Depth 5 m. |
| 189 | Sample of fresh kaolin. |
| 190 | Purest white kaolinite found. |
| (191) | Altered gneissic wall rock. (This sample is missing and probably was lost.) |
| 192 | Kaolin - 1 m from wall rock. |
| 193 | " 3 m " " " |
| 194 | " 3 m from bull quartz core of pegmatite. (Sieved out coarse quartz and mica fragments before chemical analysis. Coarse fraction composed about 50% of the sample.) |
| 195 | Kaolin - 30 cm from bull quartz core |
| 196 | A relict of partially-weathered feldspar (large, shiny, cleavage fragments) was found about 2-3 m from quartz core. Fragments are friable and can be broken up in the fingers. |
| 197 | Kaolinized, highly decomposed feldspar 10 cm from 196. |
| 198 | Mixture of white and green micaceous material found within the kaolinite near 191. X-ray shows presence of a smectite peak at 19.6A which on glycolation collapses to 17.6A. |
| 199 | Three samples of fresh biotite augen gneiss which encloses the pegmatite. The samples were collected in a small stream about 1 km down the hill from the pit. Here the fresh host rock is exposed, whereas fresh gneiss is not exposed in the pit itself. |

* * * * * *

Along the highway between the towns of Juiz de Fora and São João del Rei, Minas Gerais, can be seen many lime kilns used in making whitewash and stucco that is used to cover the crude bricks from which the houses are built. Near the

town of Barroso is located a large cement plant, the Compania de Cimento Barroso, whose smoke can be seen from many kilometers away. We were given permission to visit the quarry, from which their raw material comes, which lies about 2-3 km from the plant. Here is exposed a deep pit (about 50 m) from which a fairly fine-grained marble is quarried. Judging from the fine-grained texture, metamorphism was probably fairly low-grade. At the top of the quarry was an excellent exposure of fresh marble grading upward through a soil profile about 6-7 m thick to the original forested hillside. There exists no transition zone of partially weathered rock (C horizon). Within 1 mm above the fresh marble, which shows a roughened water-etched surface, it contacts an overlying greenish-gray clay. The nearest airport is at Barbacena New, station number 83689.

| | |
|---|---|
| 200 | Fresh marble from top of the quarry pit, taken just a few inches below marble-clay soil contact. |
| 201 | A greenish, micaceous-looking soil or clay lying immediately above the marble surface. This forms a distinct greenish layer all along the exposure. |
| 202 | Altered (?) marble a few meters from 200. |
| 203 | Another sample of greenish soil 10 cm above 202. |
| 204 | Yellowish clay - 30 cm above green clay layer (201). |
| 205 | Yellowish clay - 1 m above 204. |
| 206 | Brownish-red clay - 1 m above 205. |
| 207 | " " " 1 m above 206. |
| 208 | Red soil - 1 m above 207 and 1 m below original tree-covered surface of hill. |

About 100 meters from the exposure sampled (above), bulldozers were removing overburden from the marble surface. Where the soil was removed, the marble was seen to be sculptured into smooth, graceful, planar swirls and shapes, about 30-60 cm in height. This effect is no doubt due to meteoric waters passing through the soil and over the marble surface which is on a hillside and hence well drained. Again no C horizon (partially-wearthered rock) was observed. Here again the fresh rock grades immediately above into the greenish clay layer. Another sample of fresh marble (209) and a fragment of sculptured surface (210) was taken here. We were told that the greenish layer above the marble causes

trouble in the kilns and must be removed as completely as possible before quarrying. The rock surface is washed free of this mica which leaves the sculptured surface of the marble exposed to view.

At one place nearby, there was showing above the marble a pocket of a black and yellow mixture of what appeared to be a yellow clay with zones rich in black humus or organic matter.

| | |
|---|---|
| 211 | Black material |
| 212 | Yellow and black material. (There was no pure yellow). |

* * * * * *

Samples 230-232 are samples of a green clay derived from weathering of an amphibolite dike cross-cutting a gneissic rock. These are exposed in a roadcut on Highway BR-116 which runs between São Paulo and the city of Curitiba in the state of Parana to the south. In a roadcut at the 377 km post is exposed a green dike cross-cutting a gneissic (now weathered to clay) host rock. Relicts of amphibolite ranging from decomposed to semi-hard were found in the green clay. The nearest airport is at Curitiba, station number 83842.

| | |
|---|---|
| 230 | Freshest amphibolite; semi-hard but still weathered. |
| 231 | Semi-decomposed amphibolite; rotted and soft. |
| 232 | Green clay. |

* * * * * *

Samples 233-235 are also of green clay dikes cutting a weathered gneissic host rock (now clay). These rocks are exposed in a roadcut about 28 km east of Curitiba on Highway BR-468. Within the green clay dike are visible relict textures of white (clay) phenocrysts and fresh-looking brown mica flakes. It looks like it might have been a porphyritic andesite or dacite originally. Andesite and dacite dikes are found in this area. Alongside the vertical dike a few meters away are round, green clay masses of similar aspect that appear as

"inclusions" within the gneissic (?) (now weathered) country rock. No fresh rock was found here. The nearest airport is at Curitiba, station number 83842.

| | |
|---|---|
| 233 | "Pure" green clay from one of the inclusions near the dike. |
| 234 | Sample of the green clay dike. Relict tectures still visible. |
| 235 | Impure green clay with brown mica. |

* * * * * *

On Highway BR-468 at about 54 km from Curitiba, just before the entrance to the rhyolite quarry at Morro Redondo, is a roadcut exposure where an outcrop of "fresh" amphibolite (?) shows a weathering sequence. The freshest material is green in color and appears to be residual boulders within the reddish-brown soil, and shows spheroidal, concentric weathering and exfoliation. The original rock may have been some basic rock which was metamorphosed to amphibolite which then underwent weathering. The original ground surface is about 2-3 m above the rock exposed.

| | |
|---|---|
| 236 | "Freshest" amphibolite (?). |
| 237 | More weathered material (green clay) from a concentric exfoliation shell about 2-4 cm from the fresh core (236). |
| 238 | Ditto from 7-9 cm out. |
| 239 | Ditto from 15 cm out. Yellowish color. |
| 240 | Ditto from 30 cm out. Reddish color. |

* * * * * *

About 54 km from Curitiba on Highway BR-468 is a rhyolite quarry on Morro Redondo, on the north side of the road. The quarry is visible from the highway. The rock quarried from the hillside has uncovered a semi-circular exposure perhaps 25-30 m high. Fresh, hard, gray rhyolite is exposed in the center and grades outward to maroon shades, then light pink to almost white clay, then begins to get hematite-red near the original soil surface. The top of the hill above is heavily wooded. Concentric color variation can be seen in the semi-circular exposure. The outcrop was too steep to collect a profile vertically upwards, so

samples were collected starting at the center of the fresh rhyolite and moving to the left where the hill slopes down. This path also cuts across the weathering profile.

| | |
|---|---|
| 241A | Fresh, gray rhyolite. |
| 241B | More red (maroon?) zone 2 m outward from the gray. |
| 241C | Pinker and more weathered than B. 4 m outward from A. |
| 241D | Whiter, softer. 2 m from C. |
| 241E | Pink clay 2 m further outward than D. |
| 241F | 2 m further outward than E. Whitish clay. |
| 241G | Whitest, softest. From near top of quarry. This is not part of the A-F sequence. Estimated 12 m from A. |

The weathering sequence at F was interrupted by a slab of fairly unweathered rhyolite which beyond, again became more weathered. Three more samples (H, I and J) were collected between this fresh slab and the original soil surface.

| | | |
|---|---|---|
| 241H | Looks more weathered than F and G. | Pinker color..4 m from F. |
| 241I | " " " " H (?) . | Light gray. .2 m from H. |
| 241J | " " " " I (?) . | Light pink. .2 m from I. |

* * * * * *

Samples 244-250 were dolomite and its weathering products collected in a large dolomite quarry located near the town of Tranqueira about 20 km north of Curitiba on Highway PR-R-12. Most of the dolomite exposed is pure white and very fine grained. There are some patches of gray (graphite ?), some pink (a weathering effect?), and some with pea-sized, concentric pisolitic structures present. The fresh white dolomite makes a very sharp contact with the soil above with no C horizon discernible. This soil is about 2-3 m thick and grades from a yellowish-brown color in contact with the dolomite to dark red to maroon near the original soil surface. It appears to be a typical terra roxa soil. On the left side of the quarry was a fractured zone where the dolomite appeared weathered and crumbly (245). Also here a narrow fissure was found filled with a yellow, sandy clay (244). At the surface of the dolomite where it contacts the soil are arcuate solution surfaces and pits from 10 to 70 cm in relief. For details of the geology see Marini and Bigarella (1967).

| | |
|---|---|
| 244 | Yellow, sandy clay from fracture zone. |
| 244AA | White, fresh dolomite. |
| 244AB | Gray, " " . |
| 244AC | White dolomite with pisolitic structures. |
| 244AD | Pink and powdery (weathered ?) dolomite. |
| 245 | Weathered dolomite. White and friable. |
| 246 | Red soil 1 m below original surface. |
| 247 | Brown " 2 m " " " . |
| 248 | Yellowish soil. 3 m below original surface and 15 cm above dolomite-soil contact. |
| 249 | Sample of rough, weathered dolomite surface where it contacts the soil from the right side of the quarry. |
| 250 | Sample of a tan-colored, sandy residue zone (weathering residue ?) from right side of quarry. |

* * * * * *

Samples 251-256 are of a large diabase dike and its weathering products. Just outside the town of Rio Branco do Sul, 25 km north of Curitiba, a large (100-200 m wide) diabase dike is exposed. The diabase weathers in a box-work pattern resulting from the passage of water along vertical and horizontal joints, creating "cells" of about 30-40 cm on a side. These are sometimes called "diaclases" (Daubree) by Brazilian geologists. This box-work weathering pattern is common in Brazil and is characteristic of basalts and diabases. In the center of some cells are round, cannon-ball-like relicts of fresh diabase with exfoliating shells or layers of more weathered material surrounding the fresh core, like layers of an onion-skin. The ophitic texture of the orignal diabase can be seen preserved in the weathered material.

| | |
|---|---|
| 251 | "Fresh" diabase (cannonball). |
| 252 | Weathered diabase 10 cm from fresh. |
| 253 | More weathered material 30 cm from fresh. |
| 254 | Weathered material (brown soil) 1 m from fresh. |
| 255 | Red soil from near original surface about 3-4 m above fresh diabase. This appears to be the most weathered phase of the diabase. A zone of white bauxite pebble concretions was observed in the red soil about 30-40 cm below the original surface. |
| 256 | Another weathering stage of the diabase, but quite white in color. Collected about 1 m from fresh rock. |

* * * * * *

Highway BR-277 from Curitiba towards Ponta Grossa is known as the "Via do Cafe". At the 34 km post is an outcrop of dark, foliated rock containing pink metacrysts of small size. The rock may be a schist, gneiss or amphibolite. A weathering sequence was collected.

| | |
|---|---|
| 260 | Fresh rock. Dark Gray |
| 261 | Weathered rock 30 cm from 260. |
| 262 | More weathered than 261. Three m from 261. Light yellowish-brown. |
| 263 | More weathered than 262. One m from 262. " " " |
| 264 | May be more weathered than 263. One m from 263. " " " |

* * * * * *

Samples 291-297 are samples of dark green granite (known as the "green granites of Ubatuba") and their weathering products and have been described as charnockites by various authors. They occur in bands which are some tens to several hundred meters wide concordant to the regional structures of the adjoining biotite gneisses. The samples were collected at a roadcut along the coast road about 15 km south of the town of Ubatuba near a beach called Praia das Toninhas. Here a differentiated vertical diabase dike is exposed directly on the road, and in contact with it is the green granite. Freshest granite is in contact with the diabase and becomes more weathered as one moves away from the contact. The elevation is about 10-15 m above sea-level and the average annual rainfall at the town of São Sebastião, about 55 km to the southeast and also on the coast, is 4-500 mm in the dry season, 1000-1100 mm in the wet season, with an average annual rainfall of 1500 mm.

| | |
|---|---|
| 291 | Very fresh, dark green granite from 3 m away from granite-diabase contact. |
| 292 | Same granite 15 m further from contact. Looks different (weathering?). |
| 293 | Weathered green granite 15 cm from 292. |
| 294 | More weathered green granite 30 cm from 292. |
| 295 | " " " " 60 cm " ". |
| 296 | " " " " 130 cm " ". |
| 297 | A yellow-brown clay showing relict texture, with white clay phenocrysts. It is not certain that this is weathered granite. From 11 m away from 292. |

* * * * * *

Samples 302-304 are samples of fresh and weathered diabase from a dike exposed on the beach of the Marine Biology Laboratory of University of São Paulo at São Sebastião which lies 80 km northeast of Santos on the coast. Here a diabase dike is exposed at the water's edge on a small, rocky promontory on the right side of the beach. The dike is only a meter above sea-level at the waters edge and is worn and rounded by abrasive action of waves and is constantly subject to salt-water spray and is inundated during storms and high tides. The dike varies from 1-2 m wide. Weathering, inward along joints and cracks has caused a cell-like pattern (diaclases) of knobs and depressions to develop. In the center of some of the cells one can find fresh cores which are more resistant and protrude, knob-like, above the softer, weathered matrix. The fresher, central cores are surrounded by concentric, shell-like rinds which can be individually peeled off.

| | |
|---|---|
| 302 | Center nodule with fresh dark gray diabase in center. |
| 303A | Inner, more dense rind. |
| 303B | Outer, less dense rind. |
| 304 | Soft, yellow clay. Weathered basalt. (Note. The samples have been continuously soaked in sea-water and spray for a long time.) |

* * * * * *

(Moraes Rego and de Souza Santos, 1938)

Samples 311-320 are samples of "Granito Pirituba", a porphyritic granitized gneiss and its weathering products. The samples were collected at km post 70.5 on the Rodovia Castelo Branco (Estrada do Oeste) which runs west from the city of São Paulo. Nearest airports are at Congonhas, station number 83780, 70 km east, and Vira Copos, station number 83777, 60 km to the north. In addition, this location is only about 25 km from the town of Sorocaba. Climatic data for Sorocaba is given in Appendix B. The roadcut here is large (about 70 m wide) and is apparently an example of granitization. As one faces the outcrop, the left and center parts consist of a dark green, fine-grained rock (greenstone ?)

which is essentially featureless. As one walks to the right, increasing amounts of orange and, to a lesser degree, white phenocrysts (potash feldspar and plagioclase) appear in the green matrix until the green material is only a minor component. It would be impossible to say what composition would be most representative. As one approaches the right side of the outcrop, the original ground surface of the hill 10 m above slopes down towards the level of the road, i. e., you approach the original ground surface. Samples were collected from left to right and represent a series of fresh rock to more weathered gneiss.

| | |
|---|---|
| 311 | Unweathered dark green rock with about 50% of small orange phenocrysts. Little or no white phenocrysts. |
| 312 | Fresh granitized gneiss with about 75% orange and white phenocrysts. Reference point is here at 0 meters. |
| 313 | Slightly weathered porphyritic gneiss about 10-15 m below original ground surface (above). 3 m to right of 312. |
| 314 | Ditto. More weathered. 4 m to right. |
| 315 | " . " " . 5 m " " . |
| 316 | " . " " . 6 m " " . |
| 317 | " . " " . 7 m " " . |
| 318 | " . " " . 8 m " " . |
| 319 | Very weathered. 9 m to right and about 3-4 m below original surface. |
| 320 | Soil. 15 m to right and 1-2 m below original surface. |

* * * * * *

Samples 321-325 are of diabase and its weathering products. They were collected at a large roadcut exposing a very good example of columnar jointing about 3-5 km west of the Tatuí exit of the Rodovia Castelo Branco. (See climatic data for Sorocaba in Appendix B.) Brazilian geologists use the term "diabase" to denote an intrusive nature (dike or sill), and the term "basalt" to denote an extrusive nature, rather than to imply textural connotation.

| | |
|---|---|
| 321 | Fresh gray diabase from about 8-9 m below original surface. |
| 322 | Weathered diabase with texture still visible or actually accentuated by the weathering. From 3-4 cm above the fresh rock. |
| 323 | Two zoned relict nodules were collected in the weathered zone. One of these was "peeled" into an inner, middle and outer portion and analyzed separately. |

324 A yellow and white clay "concretion" with relict structure still visible. From about 5-6 m below original surface. This was split into two portions: 324A is the outer 1 cm crust of the concretion, and 324B is the inner core of the concretion (about 5 cm in diameter). This inner core is also visibly zoned, but not well enough to separate. The whole core was ground up for analysis. Sample 324 (unlettered) is light, fluffy, yellow powder which separated from the concretion in the bag. This was analyzed separately from 324A and 324B.

325 Red soil from 1 m below original surface. No texture or structure visible.

* * * * * *

Samples 326-329 were collected at a roadcut about 20 km west of the Tatui exit on the Rodovia Castelo Branco (see climatic data for town of Sorocaba about 60 km to the southeast, Appendix B). The outcrop consists of a striking cyclic alternation of layers of black shale and black, dense, blocky, dolomite.

326 Soft, gray, clay weathering product from above fresh rock and 1 m below original surface.

327 Weathered shale from about 3 m below surface. White and tan color.

328 Black shale from between dolomite layers about 5m below original surface.

329 Fresh black dolomite from about 5.5 m below original surface.

* * * * * *

Samples 330-333 are of weathered basalt or diabase. They were collect high on a hillside known as "Serra Geral", where a road was being constructed (in 1969) about 2-3 km north of the western terminus of the Rodovia Castelo Branco near the town of Torro de Pedra. High on the side of a hill a bulldozer had exposed some layers of vesicular basalt and/or diabase which had weathered along joints to create cell-like structures (diaclases) containing fresh "cannonball" cores as described under samples 251-256.

| | |
|---|---|
| 330 | A concentrically weathered nodule about 15 cm in diameter. This was "peeled" and divided into inner, middle and outer parts for analysis. The inner, fresh-looking material showed the presence of many cracks when it was sawed. The cracks show as wet lines when the flat sawed surface is dried. |
| 331 | Weathered rinds of concretions. These were divided into 331A the inner shell, 331B the middle shell and 331C the outer shell. |
| 332 | Red soil above the weathered diabase. |
| 333 | Green clay above 333A. |
| 333A | Fresh vesicular and amygdaloidal basalt. Sample has so many vari-colored, crystal-lined vugs and amygdules that it makes no sense to analyze this sample. |

* * * * * *

Samples 338-346 are of pink, porphyritic granite which was collected in a quarry called "Pedreira Km 66" of the "Estrada do Ferro Sorocabana" railroad. This quarry is visible from the highway Rodovia Raposo Tavares as it passes by the town of São Roque about 55 km west of São Paulo. See climatic data for Sorocaba, which is about 30 km west of São Roque, in Appendix B. In the quarry walls is displayed a spectacular maze of cross-cutting and faulted dikes of light pink, fine-grained granite in darker, coarse-grained, migmatitic granite or augen gneiss. It appears as if a pink, potash feldspar has granitized a darker rock such as a biotite schist in varying degrees. The rock is referred to as "toad's eye granite" because of the large phenocrysts or "augen". This rock is described in detail by Coutinho (1953) and Franco (1958).

| | |
|---|---|
| 338 | Fresh, pink, light-colored dike rock. |
| 338A | Weathered, pink, light-colored dike rock. |
| 339A | Fresh, hard "toad's eye" (augen) granite rich in dark minerals (dark facies). |
| 339B | Lighter colored, potash feldspar-rich facies. |
| 340 | Slightly weathered, coarse-grained granite from 8-10 cm above fresh rock. |
| 341 | Ditto from 1 m above fresh rock. |
| 342 | Ditto from 2 m above fresh rock. |
| 343 | Weathered rind 1.5 m above fresh rock. |
| 344 | Completely (?) weathered material from 4 m above fresh rock. |
| 345 | Outer crust of a highly weathered boulder with a deeply etched outer crust. This crust was about 2-4 cm thick with fresh toad's eye granite below. |

346 Soil taken from within a fracture or fissure between two highly weathered boulders of granite. It is yellow-brown and shows no texture or structure.

346A A minus 60 mesh fraction of 346. Sample 346 contained many fresh fragments of potash feldspar. These were sieved out so that a better idea could be obtained of the composition of the clay weathering product.

(Note. The distances estimated from fresh rock to weathered are almost surely highly in error because the rock is fractured at the weathered surface and there are many boulders and pieces in the soil above. There may be fresh pieces in soil above (C horizon) and weathered material in a fissure far below the so-called "fresh surface". Therefore none of the estimated distances are to be taken very seriously.)

* * * * * *

Samples 347-353 are of granite and its weathering products collected near the town of Itapevi, about 40 km west of São Paulo. Here a series of three samall abandoned quarries called A, B and C, known as "Pedreira Itapevi" are owned by the "Prefeitura de São Paulo". There is a small pit ("Rochinha") near the office building which contains pink, porphyritic "toad's eye" granite exactly like that at São Roque (samples 338-346) complete with cross-cutting pink dikes. No samples were collected at "Rochinha". Quarry A, which we did not visit, was said to be the same as B, from which our samples were collected. In quarry B is exposed a medium-grained, gray granite of extremely massive texture. No joints or fractures can be seen on the walls. The rock is much more fine-grained and homogeneous and also of a different color than at São Roque or at the "Rochinha" pit.

347 Fresh medium-grained, gray granite from pit B.

348 Weathered, but still coherent granite 10-15 cm from 347.

349 Weathered, very friable granite 30 cm from fresh rock. Textures still visible.

350 Weathered, completely soft, texture still visible, one meter from fresh rock.

(Samples 347-350 were all of a "salt and pepper" gray color.)

351 Completely soft and weathered clay material. Color is a mixture of pink and brown (weathered biotite?). Taken about 5 m below original ground surface.

352 Red soil from 3 m below original surface.

353 Yellow-brown soil from about 1 m below original surface.

* * * * * *

Samples 365-369 are of a white gneiss and its weathering products collected at the Pedreira Mongagua near the town of the same name which is located on the coast about 35 km southwest of Santos. There is an airfield at Santos, station number 83782, in Appendix B.

| | |
|---|---|
| 365 | Fresh, white gneiss showing parallel streaks of black mafic minerals. |
| 366 | Weathered, coherent gneiss. |
| 367 | More weathered than 366 but still coherent. |
| 368 | More weathered than 367 but still coherent. |
| 369 | More weathered than 368. Non-coherent. |

* * * * * *

Samples 377-386 are of vesicular basalt and its weathering products collected at an outcrop on a small side road 8 km east of the town of Riberaõ Preto which lies 340 km north north-west of São Paulo. Elevation of Riberaõ Preto is 525 m and the average annual rainfall is 1400 mm. Exposed here is an outcrop of weathered maroon-colored basaltic lava and its weathering products which grade into a red soil of the type called terra roxa "legitima" (see test below) by Moniz and Jackson (1967). (See samples 75-78.) No fresh basalt is exposed. The freshest material is red-maroon in color and has been substantially weathered. Many agate-filled amygdules, films and fractures are present giving evidence of much silica present in ground-water passing through the soil and rock. A roadcut through a small hill exposes an outcrop of some 7 m in height from road to top of cut at the original ground surface.

| | |
|---|---|
| 377 | Sample of coherent, slightly weathered, dark gray basalt essentially free of vesicles and amygdules. This is the freshest material exposed. |
| 378 | Slightly softer, more weathered brown basalt from about 30 cm above 377. This sample had some hard, silicified, agate nodules present in vugs lined with a green clay which were very noticeable when crushing the sample. |
| 379 | More weathered material, light gray with brown films from 30 cm above 378. Contains agate-filled amygdules. |

| | |
|---|---|
| 380 | More weathered, from 30 cm above 379 and about 5-6 m below original ground surface. Brown with red patches. |
| 381-2 | See below. |
| 383 | More weathered red soil material from 2 m above 380 and 3 m below original surface. Brown with yellow patches. |
| 384 | Ditto from 1 m above 383. Looks like terra roxa estructurada. Material is harder than 383, is a light tan color and has some white pellet-like nodules present (bauxite?). |
| 385 | Ditto from 1 m above 384. Has agate nodules present as do also all the previous samples. Light brown color with brown films. |
| 386 | Reddish-brown soil from 1 m below original surface but from 20-25 m to right of where other samples were collected because could not climb cliff at that original site. |
| 381 | Sample of hard red soil taken from 75-100 m to right of 377 where hill slopes down to approach road level. This sample was later tested by Moniz and pronounced to be terra roxa "legitima". The test consists of placing a lump of soil about 5-6 cm in diameter in a dish containing 1 cm of water. Terra roxa "legitima" soaks up water and disintegrates into mud within a minute or so. In contrast, terra roxa "estructurada" remains coherent when placed in water. |
| 382 | This sample of red soil was taken about 30-40 m further to the right of 381 where there is no longer any slope present, but a flat valley bottom. This material, when tested as was 381 above, quickly disintegrated and thus appears to be terra roxa "legitima" also. |

* * * * * *

Samples 387-410 are of varied rock types collected in a wild and uninhabited region of difficult access near the Billings Reservoir, which lies about 30-40 km south of São Paulo along the Via Anchieta, the highway to Santos. The author was guided by Dr. Theodore Knecht, formerly State Geologist of the State of São Paulo. Exact locations by measured mileages was impossible. Nearest airfield is at Congonhas, station number 83780.

Stop 1 was at "Pedreira Sabeu" about 3-4 km beyond the ferry across the reservoir. Exposed here in a small quarry is a small white pegmatite vein about 4-5 m wide in a red colored, weathered muscovite mica schist (now clay) host rock. The pegmatite is rich in black tourmaline, and at the contact, the pegmatite has tourmalinized the mica schist. Also at the contact one can see a zone

enriched in coarse muscovite mica flakes 1-2 cm in diameter within the mica schist within 1-2 m of the contact. The mica was either introduced by the pegmatite or is recrystallized mica from the schist. The mica schist itself contains small (1 mm or less) mica flakes. The contact is not sharp but transitional over about 30 cm from white pegmatite to reddish (hematite) mica schist. Large crystals and masses of black tourmaline have weathered out and lie on the ground. The black tourmaline appears completely fresh, coherent and unaltered. The pegmatite feldspars and the surrounding mica schist host rock are either deeply weathered or hydrothermally altered. Although it would probably be impossible to prove either weathering or hydrothermal alteration, this author prefers the former, based on its similarity to many other occurrences of undoubted weathering. No fresh rock of any kind is present, except the black tourmaline.

| | |
|---|---|
| 387 | Reddish colored (hematite) muscovite mica schist. Taken 6 m from right side of contact with pegmatite. |
| 388 | Ditto from 4 m from contact. |
| 389 | Ditto but from within coarse mica zone 1 m from contact. Coarse mica was sieved out before chemical analysis. |
| 390 | White, decomposed pegmatite. |
| (391) | Samples of black tourmaline crystals. Not analyzed. |
| 392 | Reddish mica schist 1 m from left edge of pegmatite vein. |
| 393 | Ditto (darker red color) about 5 m from left edge of pegmatite. |
| 394 | Ditto (lighter red color) about 10 m from left edge of pegmatite. |
| 395 | Yellow-brown soil about 15 m from left edge of pegmatite and 1-2 m below original ground surface. |

* * * * * *

We then drove many kilometers on a very winding, rough, dirt track to find a bauxite deposit (Stop 2) or claim owned by a Dr. Jesuino Felicissimo, former Director of the Instituto Geographico and Geologico. Because Knecht had not been there for 20 years, he had trouble finding the place, and I became completely disoriented. Finally we found the hillside which is underlain by a dike of olivine gabbro of considerable width which Knecht referred to as the "Curucutu

Olivine Gabbro" (Stop 2). This rock, along with the bauxite deposit, is discussed in detail in Gomes (1956), Felicissimo and Franco (1956), Knecht (1943) and Knecht (1945). There is no outcrop of fresh rock exposed anywhere, but there are some residual boulders near the road which obviously are remnants within the soil. There is a bauxite prospect pit further up the hill, but no fresh rock is exposed there. In a small excavation at the roadside were two large olivine gabbro boulders with weathered outer crusts. Chips of the weathered crust were obtained fairly easily, but the rounded fresh rock underneath was extremely tough and hard and could not be broken with the rock hammers we had. A few chips of this fresher material (samples 399 and 400) was all that could be obtained from each boulder. Within the red soil could be seen abundant white bauxite nodules. Thin section examination showed the fresh rock to be an olivine gabbro exactly as described in Gomes (1956) and Felicissimo and Franco (1956).

| | |
|---|---|
| 396 | Porous weathered crust chipped off outer part of boulder #1. |
| 397 | Hard, white bauxite nodules found in red soil about 1.5 m below original surface. |
| 398 | Red-brown soil from vicinity of white nodules. |
| 399 | Chips of fresh (?) olivine gabbro from boulder #2. |
| 400 | Ditto from boulder #1. (Some 1-2 mm of weathered crust is present on samples 399 and 400 and this had to be ground up and analyzed along with the olivine gabbro fragments.) |

* * * * * *

According to Knecht (1969, personal communication; Knecht 1943 and 1945), there is apparently some correlation between the bauxite deposits in this area and the north slope of hillsides. The bauxite deposits are always found on northern-exposure slopes. Perhaps the dip of underlying schists has some effect on drainage and permeability. Although north slopes get more direct sunlight, vegetation appears the same on both slopes (Knecht, 1969, personal communication). These were the personal observations of Dr. Knecht over many years of field observation in this area. In this same connection, see Cooper (1960).

Precambrian mica schists are the common rock type underlying most of this area. The schists strike about N60°E and dip to the north. Rarely, if ever, do bauxite deposits develop from mica schists; usually the mother rock is a basic rock type (gabbro, basalt, diorite, etc.).

Stop 3 was at the "Pedreira Dom Miguel," an abandoned quarry once used as a source of crushed stone by the Sorocabana-Santos-Mayrink Railroad. The quarry is between the village of Evangelista de Souza and the small dam (barragem). It is on the opposite side of the tracks from the dam and is overgrown and could not be seen from 50 m away. The rock exposed here was identified as a diorite by Dr. Knecht. It is a black, blasto-porphyritic rock composed mostly of hornblende and plagioclase feldspar, but is not a typical diorite. It has a peculiar texture in thin section which shows a coarse-grained igneous rock (gabbro?) which has undergone an incomplete metamorphism. Hornblende is abundant. Large phenocrysts now appear highly corroded (poikiloblastic?) and feldspars are partially sericitized. The term "epidiorite" or metadiorite may be appropriate. Gomes (1956) and Felicissimo and Franco (1956) described an "amphibolite" from this immediate area that is probably this same rock. For lack of a more certain term, the rock will be called a "metadiorite".

| | |
|---|---|
| 401 | Fresh black, porphyritic metadiorite. |
| 402 | Weathered crust from within 1 cm of fresh rock. |
| 403 | " " " " 2-3 cm " " " . |
| 404 | Completely weathered material 1 m above fresh rock. Fairly hard and indurated and structure still visible. |
| 405 | Soft soil adjacent to 404. |
| 406 | Sticky clay 2 m above fresh rock. |
| 407 | " " 3 m " " " . |
| 408 | Brown-red soil 4-5 m above fresh rock and 30 cm below original surface. |
| 409 | White bauxite nodules in yellowish clay on a level with 407, but 8 m to the right. |
| 410 | Weathered crust 5-8 cm from fresh rock. Appears perhaps more weathered than 403. |

* * * * * *

Samples 418-421 are of a bituminous (oil) shale similar to the oil shale deposit at Taubaté (see samples 180-186). These samples were not collected by me but were collected for me by Dr. Jefferson V. de Souza at the Companía Industrial de Rochas Bituminosas, Fazenda Mombaca, Pindamonhagaba, State of São Paulo. This material is heated at about 300°C and gas and oil are distilled off.

| | |
|---|---|
| 418 | "Xisto Papiraceo" (paper shale) above "xisto pedra" (rock shale), 65 cm thick, Gallery #7, Fazenda Mombaca. |
| 419 | Xisto Pedra (rock shale) 17 m below 418, Gallery #23. |
| 420 | Powdery, residual black material remaining after distilling off oil and gas at about 300°C. |
| 421 | Green clay, 2 m thick, from Gallery #7, above the xisto Papiraceo. |

* * * * * *

Samples 430-432 are samples of terra roxa estructurada collected by Dr. A. C. Moniz from a hillside along the road between the towns of Jaguariuna and Pedreira which lie about 30 km north and east of Campinas. There is an asphalt road between the towns. Going from Jaguariuna towards Pedreira, there is a small, dirt farm road going off to the left and up a low hill. The samples were collected on this hilltop.

| | |
|---|---|
| 430 | Tan colored weathering material from the C horizon containing remnants of fresh rock. |
| 431 | Remnants of fresh rock (diabase) within diaclases at 418. |
| 432 | Red terra roxa estructurada soil from just below original ground surface. |

* * * * * *

Samples CP-1 through CP-6 were samples of perthitic white feldspar collected at the Cascavel Pegmatite mine near Governador Valadares, Minas Gerais, in 1966. Here a tunnel enters the hillside and feldspar is quarried for the ceramics industry. From within the tunnel one can observe a weathering profile of the pegmatite. The fresh unweathered feldspar is pure white in the central part of the deposit deep within the tunnel. As the tunnel mouth is approached (toward

the ground surface and increased weathering), the feldspar takes on a pink color, which increases to dark red as one gets closer to the soil surface. Simultaneously the feldspar loses its shiny aspect and becomes dull and chalky, until finally a dark red, soft clay is encountered that can be crushed in the fingers.

| | |
|---|---|
| CP-1 | Fresh, hard, shiny, white feldspar cleavages (perthite). |
| CP-2 | Ditto but slightly pink. |
| CP-3 | Darker pink or red. Still shiny. Coherent. |
| CP-4 | More weathered, darker red, still shiny. Coherent. |
| CP-5 | " " , " " , dull and chalky. Friable. |
| CP-6 | Soft, dark red clay. Contains some muscovite flakes which could not be separated completely. |

# APPENDIX B

Rainfall and elevation data for several towns and cities near the sampling localities are listed in this table. The data for the numbered stations was obtained from "U. S. Naval Weather Service, World-wide Airfield Summaries, Vol. VI, Part I, South America (Argentina, Brazil, Uruguay)". Besides the included data on elevation and mean annual precipitation, much other data is available on the individual data sheets for each station, such as, monthly distribution of precipitation throughout the year; maximum, minimum and mean temperatures; humidity and other information. Data for many other cities throughout Brazil are available that are not listed here. These data are available from: U. S. Department of Commerce, National Oceanic and Atmospheric Administration, Environmental Data Service, National Climatic Center, Federal Building, Asheville, North Carolina 28801.

Data for towns without a station number were obtained from a variety of sources, such as, journal articles on geology of the area and personal communications.

| Station Number | Name | Elevation (ft) | Elevation (m) | Mean Annual Precipitation (in) | Mean Annual Precipitation (mm) |
|---|---|---|---|---|---|
| 83492 | Teofilo Otoni | 1079 | 329 | 47.9 | 1217 |
| 83525 | Uberlandia | 3025 | 922 | 52.3 | 1328 |
| 83538 | Diamantina | 4183 | 1275 | 63.4 | 1610 |
| 83577 | Uberaba | 2657 | 810 | 58.8 | 1494 |
| 83587 | Belo Horizonte | 1812 | 552 | 58.9 | 1496 |
| 83618 | Tres Lagoas | 1030 | 314 | 52.9 | 1344 |
| 83689 | Barbacena New | 3635 | 1108 | Data not available | |
| 83729 | Campinas | 2182 | 665 | 34.4 | 874 |
| 83743 | Rio de Janeiro | 89 | 27 | 42.7 | 1085 |
| 83777 | Vira Copos | 2126 | 648 | 34.4 | 874 |
| 83778 | Cumbica | 2457 | 749 | 57.3 | 1455 |
| 83780 | Congonhas | 2631 | 802 | 57.3 | 1455 |
| 83781 | São Paulo | 2628 | 801 | 57.3 | 1455 |
| 83782 | Santos | 10 | 3 | 88.2 | 2240 |
| 83842 | Curitiba | 2979 | 908 | 55.2 | 1402 |
| | Ribeirão Preto | 1722 | 525 | 55.1 | 1400 |
| | São Sebastião | 49 | 15 | 59.1 | 1500 |
| | Sorocaba | 1771 | 540 | 47.2 | 1200 |

# APPENDIX C

## Results of Chemical Analyses

Results of chemical analyses are presented in tabular form in appendix C. Analytical procedures followed were according to the "rapid methods" of Shapiro (1975). However, because of frequent problems with the quinalizarin method for aluminum, that method was replaced by the pyrocatechol violet method of Dougan and Wilson (1974). About half the aluminum results were obtained by the alizarin and half by the pyrocatechol violet method. Occasionally, difficulties were experienced with the FeO titration. For some unknown reason the indicator turned purple upon addition of the sample to the indicator solution. FeO could not be obtained for these samples and this is noted in the tables. It will be noted that occasionally very low sums for the oxides is obtained. This is correlated with unusually high contents of one or more of the following constituents: $H_2O+$, $TiO_2$, MnO, $CO_2$ and sulfur. Occasionally, the low sum may be attributed to presence of an appreciable amount of a rare constituent (e.g., $ZrO_2$) not normally determined. Ferric oxide is determined by difference by subtracting the amount of FeO (converted to $Fe_2O_3$) from total iron, expressed as $Fe_2O_3$.

All samples were run in duplicate. If good checks were not obtained, a third or perhaps even a fourth sample was run. All percentages are therefore an average of at least two determinations.

Analysts were Mr. David Borden, Mrs. Carol Clemency and Charles V. Clemency.

RESULTS OF CHEMICAL ANALYSES

Rock Type Granite Locality Perus, São Paulo

| Sample Number | 8-20-1 | -2 | -3 | -4 | -5 | -6 | -7 | -8 | -9 | -10 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 72.4 | 74.6 | 72.0 | 68.8 | 70.9 | 43.9 | 49.0 | 49.9 | 56.1 | 61.4 |
| $Al_2O_3$ | 16.2 | 16.1 | 20.3 | 23.2 | 18.8 | 28.9 | 24.9 | 24.5 | 24.1 | 22.6 |
| Total Iron | 0.08 | 0.09 | - | - | 1.31 | 12.2 | 13.0 | 12.7 | 7.42 | 5.95 |
| $Fe_2O_3$ | 0.02 | 0.02 | - | - | 1.13 | 12.1 | 12.9 | 12.7 | 7.26 | 5.82 |
| FeO | 0.05 | 0.06 | 0.02 | 0.03 | 0.16 | 0.11 | 0.06 | - | 0.14 | 0.12 |
| MgO | - | - | 0.01 | 0.01 | 0.04 | 0.88 | 0.28 | 0.15 | 0.87 | 0.20 |
| CaO | 0.07 | 0.78 | - | - | - | 0.21 | 0.03 | 0.01 | 0.23 | - |
| $Na_2O$ | 2.39 | 4.61 | 0.02 | - | 0.15 | 0.12 | - | 0.03 | 0.11 | 0.02 |
| $K_2O$ | 9.91 | 1.31 | 0.03 | 0.02 | 0.03 | 0.21 | 0.34 | 0.10 | 0.59 | 0.48 |
| $P_2O_5$ | 0.04 | 0.03 | - | - | 0.02 | 0.09 | 0.09 | 0.18 | 0.07 | 0.07 |
| $TiO_2$ | - | 0.01 | 0.01 | 0.01 | 0.07 | 1.07 | 1.13 | 1.16 | 1.03 | 0.60 |
| MnO | 0.02 | 0.01 | 0.03 | 0.02 | 0.06 | 0.09 | 0.13 | 0.31 | 0.03 | 0.10 |
| $H_2O+$ | 0.47 | 1.91 | 7.33 | 8.47 | 5.88 | 10.8 | 9.67 | 10.2 | 8.61 | 7.04 |
| $CO_2$ | 0.03 | 0.01 | 0.04 | 0.04 | 0.08 | 0.11 | 0.11 | 0.08 | 0.11 | 0.04 |
| | | | | | | | | | | |
| Total | 101.57 | 99.45 | 99.79 | 100.60 | 97.32 | 98.59 | 98.64 | 99.32 | 99.25 | 98.49 |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Granite Locality Perus, São Paulo

| Sample Number | 8-20-11 | -12 | -13 | -14 | -15 | -16 | -17 | -18 | -19 | -20 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 66.4 | 73.6 | 66.6 | 79.9 | 70.9 | 67.6 | 48.0 | 75.6 | 66.5 | 78.1 |
| $Al_2O_3$ | 18.6 | 15.50 | 19.7 | 12.2 | 20.3 | 19.8 | 24.0 | 14.0 | 18.9 | 13.0 |
| Total Iron | 5.13 | 1.06 | 0.09 | 0.28 | 0.11 | 1.54 | 11.9 | 0.06 | - | 0.34 |
| $Fe_2O_3$ | 4.65 | 0.78 | 0.03 | 0.20 | 0.09 | 1.34 | * | - | - | 0.24 |
| FeO | 0.43 | 0.25 | 0.05 | 0.07 | 0.02 | 0.18 | * | 0.06 | 0.05 | 0.09 |
| MgO | 0.21 | 0.04 | 0.01 | 0.02 | 0.02 | 0.22 | 2.21 | 0.02 | 0.01 | 0.04 |
| CaO | 0.17 | 0.38 | 0.02 | 0.74 | 0.05 | 0.14 | 0.22 | 1.40 | 0.11 | 0.83 |
| $Na_2O$ | 0.10 | 3.61 | 0.33 | 4.55 | 0.17 | 0.89 | 0.08 | 5.98 | 3.05 | 4.45 |
| $K_2O$ | 0.40 | 5.90 | 9.57 | 2.95 | 3.27 | 4.66 | 1.15 | 1.27 | 11.9 | 3.05 |
| $P_2O_5$ | 0.06 | 0.03 | 0.07 | 0.05 | 0.09 | 0.06 | 0.34 | 0.03 | 0.06 | 0.08 |
| $TiO_2$ | 0.54 | 0.03 | 0.02 | - | - | 0.10 | 1.18 | 0.02 | - | 0.02 |
| MnO | 0.07 | 0.32 | 0.03 | 0.02 | 0.02 | 0.13 | 0.98 | 0.03 | - | 0.02 |
| $H_2O+$ | 7.59 | 0.32 | 2.99 | 0.24 | 5.72 | 4.14 | 8.65 | 0.11 | 0.11 | 0.18 |
| $CO_2$ | 0.03 | 0.03 | 0.09 | 0.05 | 0.03 | 0.11 | 0.13 | 0.10 | 0.03 | 0.05 |
| | | | | | | | | | | |
| Total | 99.25 | 100.79 | 99.51 | 101.02 | 100.66 | 99.37 | 98.84 | 98.62 | 100.66 | 100.14 |

Comments: * Could not be determined. Interference in FeO titration.

RESULTS OF CHEMICAL ANALYSES

Rock Type Lujavrite Locality Poços de Caldas, Minas Gerais

| Sample Number | * 8-22-1 | | ** (17-6) | 8-22-12 | -13 | -14 | -15 | -16 | -17 | -18 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | | | 53.5 | 53.8 | 49.7 | 41.3 | 40.9 | 50.2 | 47.0 | 40.6 |
| $Al_2O_3$ | | | 15.2 | 15.4 | 18.1 | 22.5 | 23.6 | 19.4 | 21.7 | 25.3 |
| Total Iron | | | 10.95 | 10.10 | 12.35 | 13.93 | 13.22 | 11.29 | 11.95 | 13.06 |
| $Fe_2O_3$ | | | 8.63 | 8.18 | 11.23 | 13.62 | 13.01 | 10.34 | 11.17 | @ |
| FeO | | | 2.09 | 1.73 | 1.01 | 0.28 | 0.19 | 0.86 | 0.70 | @ |
| MgO | | | 0.53 | 0.45 | 0.48 | 0.37 | 0.31 | 0.35 | 0.20 | 0.12 |
| CaO | | | 1.73 | 1.36 | 1.40 | 1.04 | 0.93 | 1.01 | 0.87 | 0.32 |
| $Na_2O$ | | | 9.04 | 8.24 | 4.37 | 3.40 | 2.79 | 3.28 | 2.67 | 1.11 |
| $K_2O$ | | | 5.34 | 5.63 | 6.14 | 5.24 | 5.23 | 7.18 | 6.73 | 5.32 |
| $P_2O_5$ | | | 0.01 | 0.02 | 0.02 | 0.01 | 0.02 | 0.01 | 0.01 | 0.02 |
| $TiO_2$ | | | 0.56 | 0.80 | 0.78 | 1.22 | 1.43 | 0.65 | 0.95 | 1.05 |
| MnO | | | 0.45 | 0.44 | 0.69 | 1.29 | 0.69 | 0.42 | 0.34 | 0.94 |
| $H_2O+$ | | | 2.89 | 2.63 | 4.81 | 6.94 | 8.92 | 4.92 | 6.76 | 9.46 |
| $CO_2$ | | | | | | | | | | |
| $ZrO_2$ † | | | 0.28 | 0.56 | 0.29 | 1.62 | 0.48 | 0.21 | - | 2.15 |
| Total | | | 100.25 | 99.24 | 99.02 | 98.83 | 98.50 | 98.83 | 99.10 | 99.45 |

Comments:

* See data sheet for 8-22-22 series.

** Sample 17-6 and 8-22-12 are both fresh rock specimens of the dark facies of eudialyte syenite known as "lujavrite". Sample 17-6 is equivalent to 8-22-12 but was collected on an earlier trip to the same locality. Analyses of both are given for comparison.

† $ZrO_2$ was determined by x-ray fluorescence using synthetic standards with added $ZrO_2$.

@ FeO could not be determined because of an interference with the indicator color.

RESULTS OF CHEMICAL ANALYSES

Rock Type Chibinite Locality Poços de Caldas, M.G.

| Sample Number | (17-7)** | | 8-22-19 | -20 | -21 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 53.2 | | 56.4 | 40.2 | 31.0 | | | | | |
| $Al_2O_3$ | 18.9 | | 20.0 | 36.4 | 35.8 | | | | | |
| Total Iron | 6.42 | | 4.02 | 4.48 | 8.75 | | | | | |
| $Fe_2O_3$ | 4.72 | | 2.65 | 4.44 | 8.54 | | | | | |
| FeO | 1.53 | | 1.23 | 0.04 | 0.19 | | | | | |
| MgO | 0.20 | | 0.06 | - | 0.07 | | | | | |
| CaO | 1.17 | | 0.56 | 0.04 | 0.09 | | | | | |
| $Na_2O$ | 7.82 | | 5.38 | 0.05 | 0.40 | | | | | |
| $K_2O$ | 7.24 | | 11.86 | 0.05 | 2.49 | | | | | |
| $P_2O_5$ | 0.04 | | 0.02 | 0.05 | 0.05 | | | | | |
| $TiO_2$ | 0.68 | | 0.44 | 0.54 | 1.12 | | | | | |
| MnO | 0.34 | | 0.29 | 0.34 | 0.27 | | | | | |
| $H_2O+$ | 3.52 | | 0.82 | 14.9 | 15.9 | | | | | |
| $CO_2$ | - | | - | - | - | | | | | |
| $ZrO_2$ † | 0.04 | | 0.04 | 2.39 | 1.49 | | | | | |
| Total | 99.40 | | 99.75 | 99.44 | 97.41 | | | | | |

Comments: ** Sample 17-7 and 8-22-19 are both fresh rock specimens of the light facies of eudialyte syenite known as "chibinite". Sample 17-7 is equivalent to 8-22-19 but was collected on an earlier trip to the same locality. Analyses of both are given for comparison.

† $ZrO_2$ was determined by x-ray fluorescence using synthetic standards with added $ZrO_2$.

RESULTS OF CHEMICAL ANALYSES

Rock Type Tinguaite (var. Phonolite) Locality Poços de Caldas, Minas Gerais

| Sample Number | 8-22-1 | 8-22-22A | Fresh 8-22-22B | Inner -22B | Middle -22B | Outer -22B | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 54.7 | 55.6 | 54.0 | 33.1 | 34.0 | 20.2 | | | | |
| $Al_2O_3$ | 21.6 | 21.2 | 20.0 | 30.0 | 29.9 | 30.9 | | | | |
| Total Iron | 3.67 | 3.57 | 5.57 | 6.81 | 6.95 | 8.20 | | | | |
| $Fe_2O_3$ | 3.02 | nil | 1.85 | 6.45 | 6.44 | 8.08 | | | | |
| FeO | 0.59 | 3.35 | 3.35 | 0.32 | 0.45 | 0.11 | | | | |
| MgO | 0.15 | 0.21 | 0.20 | - | 0.08 | - | | | | |
| CaO | 1.10 | 1.57 | 1.48 | 0.03 | 0.27 | 0.27 | | | | |
| $Na_2O$ | 9.67 | 8.29 | 8.32 | 1.27 | 1.40 | 0.67 | | | | |
| $K_2O$ | 8.87 | 8.60 | 8.10 | 6.32 | 6.50 | 3.34 | | | | |
| $P_2O_5$ | 0.05 | 0.05 | 0.05 | 0.09 | 0.08 | 0.10 | | | | |
| $TiO_2$ | 0.35 | 0.55 | 0.06 | 1.09 | 1.06 | 1.11 | | | | |
| MnO | 0.26 | 0.23 | 0.26 | 0.13 | 0.11 | 0.25 | | | | |
| $H_2O+$ | 0.99 | 0.47 | 0.80 | 19.4 | 19.5 | 33.1 | | | | |
| $CO_2$ | 0.21 | -- | 0.21 | 0.18 | 0.18 | 0.15 | | | | |
| | | | | | | | | | | |
| Total | 101.56 | 100.1 | 298.68 | 98.38 | 99.97 | 98.28 | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Foyaite Locality Poços de Caldas, M.G.

| Sample Number | 8-22-23 | -23A | -24 | -24A | -24B | -25 | -26 | -27 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 54.5 | 12.2 | 47.1 | 16.6 | 24.4 | 0.89 | 0.57 | 54.4 | | |
| $Al_2O_3$ | 23.1 | 57.9 | 29.3 | 55.4 | 46.1 | 75.5 | 79.8 | 23.3 | | |
| Total Iron | 2.14 | 2.92 | 3.95 | 9.64 | 3.93 | 6.30 | 7.02 | 2.27 | | |
| $Fe_2O_3$ | 1.21 | 2.79 | 3.26 | 8.25 | 3.16 | 5.16 | 5.88 | 1.33 | | |
| FeO | 0.84 | 0.12 | 0.62 | 1.25 | 0.69 | 1.03 | 1.03 | 0.85 | | |
| MgO | 0.18 | - | 0.09 | 0.08 | 0.03 | - | - | 0.16 | | |
| CaO | 1.20 | 0.02 | 0.36 | 0.09 | 0.11 | - | - | 1.04 | | |
| $Na_2O$ | 8.88 | 0.30 | 2.39 | 0.52 | 1.28 | 0.24 | 0.26 | 8.70 | | |
| $K_2O$ | 8.28 | 1.72 | 8.51 | 2.50 | 4.81 | 0.22 | 0.21 | 8.41 | | |
| $P_2O_5$ | 0.06 | 0.05 | 0.07 | 0.13 | 0.08 | 0.10 | 0.11 | 0.06 | | |
| $TiO_2$ | 0.51 | 0.58 | 0.82 | 2.48 | 0.82 | 1.60 | 1.69 | 0.50 | | |
| MnO | 0.11 | 0.10 | 0.17 | 0.34 | 0.12 | 0.19 | 0.19 | 0.11 | | |
| $H_2O+$ | 2.04 | 25.9 | 6.86 | 15.2 | 18.6 | 17.5 | 15.9 | 1.96 | | |
| $CO_2$ | 0.40 | 0.10 | 0.08 | 0.23 | 0.18 | 0.17 | 0.18 | 0.30 | | |
| | | | | | | | | | | |
| Total | 101.63* | 101.78* | 99.45 | 103.07* | 100.38 | 102.60* | 105.82* | 103.39* | | |

Comments: * High totals are primarily due to high $Al_2O_3$ or $H_2O+$ or both in these samples.

RESULTS OF CHEMICAL ANALYSES

Rock Type Phonolite or Leucite Phonolite(?) Locality Poços de Caldas, M.G.

| Sample Number | 53 | 54 | | 55 | 56 | 57 | 58 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 55.4 | 56.1 | | 54.6 | 51.4 | 48.4 | 45.3 | | | |
| $Al_2O_3$ | 21.6 | 21.6 | | 22.5 | 23.2 | 26.4 | 31.9 | | | |
| Total Iron | 5.15 | 2.54 | | 3.88 | 6.63 | 6.98 | 3.99 | | | |
| $Fe_2O_3$ | 4.81 | 2.36 | | 3.48 | 6.63 | 6.86 | 3.89 | | | |
| FeO | 0.31 | 0.16 | | 0.36 | - | 0.11 | 0.09 | | | |
| MgO | 0.35 | 0.23 | | 0.38 | 0.26 | 0.38 | 0.34 | | | |
| CaO | - | - | | - | - | - | - | | | |
| $Na_2O$ | 0.17 | 0.19 | | 0.20 | 0.34 | 0.25 | 0.08 | | | |
| $K_2O$ | 11.11 | 11.69 | | 11.30 | 8.33 | 6.41 | 4.55 | | | |
| $P_2O_5$ | 0.13 | 0.20 | | 0.14 | 0.09 | 0.11 | 0.12 | | | |
| $TiO_2$ | 1.07 | 1.03 | | 1.11 | 1.15 | 1.23 | 1.35 | | | |
| MnO | 0.02 | - | | 0.02 | 0.34 | 0.25 | 0.42 | | | |
| $H_2O+$ | 2.39 | 2.59 | | 2.56 | 4.79 | 6.32 | 9.13 | | | |
| $CO_2$ | 0.03 | - | | 0.03 | 0.06 | 0.06 | 0.06 | | | |
| | | | | | | | | | | |
| Total | 97.39 | 96.15 | | 96.68 | 96.59 | 96.78 | 97.23 | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Fenite Locality Poços de Caldas, M.G.

| Sample Number | 59 | 60 | 61 | 62 | 63 | 64 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 54.5 | 57.9 | 57.6 | 55.7 | 56.4 | 51.0 | | | | |
| $Al_2O_3$ | 13.0 | 14.2 | 15.6 | 15.1 | 15.5 | 20.3 | | | | |
| Total Iron | 6.42 | 6.29 | 6.31 | 7.11 | 7.49 | 8.55 | | | | |
| $Fe_2O_3$ | 3.09 | 3.85 | 4.71 | 5.49 | 6.25 | 7.60 | | | | |
| FeO | 3.00 | 2.20 | 1.44 | 1.46 | 1.12 | 0.86 | | | | |
| MgO | 3.98 | 3.19 | 1.96 | 3.11 | 2.38 | 2.35 | | | | |
| CaO | 6.10 | 3.66 | 2.35 | 3.09 | 2.06 | 0.16 | | | | |
| $Na_2O$ | 2.88 | 3.08 | 3.13 | 2.80 | 2.56 | 0.46 | | | | |
| $K_2O$ | 6.71 | 7.03 | 7.24 | 7.06 | 7.77 | 7.64 | | | | |
| $P_2O_5$ | 1.25 | 1.22 | 1.10 | 1.39 | 1.37 | 0.54 | | | | |
| $TiO_2$ | 1.49 | 1.46 | 1.49 | 1.67 | 1.77 | 2.13 | | | | |
| MnO | 0.10 | 0.07 | 0.09 | 0.10 | 0.11 | 0.11 | | | | |
| $H_2O+$ | 0.46 | 0.34 | 0.67 | 0.77 | 0.97 | 4.98 | | | | |
| $CO_2$ | 1.58 | 0.06 | 0.06 | 0.06 | 0.06 | 0.07 | | | | |
| | | | | | | | | | | |
| Total | 98.14 | 98.26 | 97.44 | 97.80 | 98.32 | 98.20 | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Tillite Locality Mogi Guaçu, São Paulo

| Sample Number | 65 | 66 | 67 | 68 | 69 | 70 | 71 | 72 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 71.4 | 71.1 | 70.7 | 70.7 | 70.7 | 70.5 | 80.6 | 81.8 | | |
| $Al_2O_3$ | 11.71 | 11.75 | 11.81 | 12.76 | 13.30 | 11.55 | 8.63 | 9.47 | | |
| Total Iron | 4.08 | 4.11 | 4.14 | 4.55 | 4.66 | 3.58 | 2.33 | 1.78 | | |
| $Fe_2O_3$ | 1.67 | 1.65 | 1.65 | 2.84 | 4.11 | 2.36 | 1.42 | 1.52 | | |
| FeO | 2.17 | 2.22 | 2.24 | 1.54 | 0.50 | 1.10 | 0.82 | 0.23 | | |
| MgO | 2.14 | 2.14 | 2.13 | 2.15 | 1.73 | 1.68 | 1.01 | 0.84 | | |
| CaO | 1.79 | 1.83 | 1.81 | 0.94 | 0.52 | 2.69 | 0.89 | 0.34 | | |
| $Na_2O$ | 2.14 | 2.14 | 2.17 | 2.10 | 1.83 | 1.84 | 1.29 | 1.14 | | |
| $K_2O$ | 2.81 | 2.80 | 2.85 | 2.96 | 3.03 | 2.75 | 2.15 | 2.30 | | |
| $P_2O_5$ | 0.16 | 0.17 | 0.16 | 0.18 | 0.18 | 0.16 | 0.08 | 0.08 | | |
| $TiO_2$ | 0.63 | 0.67 | 0.66 | 0.72 | 0.73 | 0.62 | 0.52 | 0.56 | | |
| MnO | 0.10 | 0.10 | 0.11 | 0.11 | 0.06 | 0.10 | 0.04 | 0.04 | | |
| $H_2O+$ | 2.11 | 2.28 | 2.58 | 3.12 | 2.54 | 2.43 | 1.66 | 2.06 | | |
| $CO_2$ | 1.05 | 1.12 | 1.11 | 0.34 | 0.05 | 1.71 | 0.42 | 0.02 | | |
| | | | | | | | | | | |
| Total | 99.88 | 99.97 | 99.98 | 100.46 | 99.28 | 99.49 | 99.53 | 100.40 | | |

Comments: All samples except 72 bloated severely when fused for $H_2O+$ determination in the Penfield tube.

RESULTS OF CHEMICAL ANALYSES

Rock Type Diabase Locality Campinas, São Paulo

| Sample Number | 75 Fresh | 75 Inner | 75 Outer | 76 | 77 | 78 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 48.4 | 41.4 | 17.7 | 42.7 | 13.6 | 26.5 | | | | |
| $Al_2O_3$ | 11.8 | 15.0 | 22.9 | 14.2 | 26.2 | 25.5 | | | | |
| Total Iron | 16.4 | 19.4 | 32.0 | 20.7 | 32.4 | 26.8 | | | | |
| $Fe_2O_3$ | 5.16 | 13.6 | 28.2 | 14.4 | 29.4 | 23.9 | | | | |
| FeO | 10.10 | 5.19 | 3.42 | 5.73 | 2.64 | 2.57 | | | | |
| MgO | 4.96 | 3.01 | 0.69 | 3.36 | 0.30 | 0.14 | | | | |
| CaO | 9.36 | 5.49 | 0.64 | 5.82 | 0.12 | 0.07 | | | | |
| $Na_2O$ | 2.26 | 1.77 | 0.24 | 1.62 | - | - | | | | |
| $K_2O$ | 1.10 | 1.38 | 0.26 | 1.16 | 0.08 | 0.01 | | | | |
| $P_2O_5$ | 0.44 | 0.62 | 0.67 | 0.45 | 0.67 | 0.13 | | | | |
| $TiO_2$ | 3.39 | 4.19 | 6.89 | 4.20 | 7.11 | 5.76 | | | | |
| MnO | 0.24 | 0.19 | 0.18 | 0.20 | 0.15 | 0.08 | | | | |
| $H_2O+$ | 0.66 | 3.75 | 13.8 | 4.35 | 13.2 | 7.00 | | | | |
| $CO_2$ | 0.11 | 0.16 | 0.16 | 0.14 | 0.07 | 0.18 | | | | |
| | | | | | | | | | | |
| Total | 97.98 | 95.77 | 95.77 | 98.33 | 93.54 | 91.84 | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Shonkinite Locality Tatui, São Paulo

| Sample Number | 81 | 82 | 83 | 84 | 85 | 86 | 87 | 88 | 88A Fresh | 88A Rind | 89 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 47.3 | 50.0 | 54.0 | 52.2 | 50.3 | 38.3 | 48.5 | 51.5 | 49.6 | 50.7 | 66.0 |
| $Al_2O_3$ | 15.7 | 10.5 | 8.76 | 12.1 | 14.4 | 12.7 | 12.8 | 7.54 | 13.1 | 11.5 | 12.8 |
| Total Iron | 6.05 | 10.04 | 7.71 | 11.49 | 11.77 | 15.71 | 11.08 | 7.60 | 12.66 | 10.97 | 8.10 |
| $Fe_2O_3$ | 5.50 | 9.52 | 6.99 | - | 10.74 | - | - | 6.66 | 8.10 | 9.06 | 7.94 |
| FeO | 0.50 | 0.47 | 0.65 | ** | 0.93 | ** | ** | 0.85 | 4.11 | 1.72 | 0.14 |
| MgO | 19.6 | 12.1 | 11.5 | 3.48 | 4.05 | 12.7 | 3.42 | 11.5 | 5.10 | 6.95 | 2.28 |
| CaO | 1.77 | 3.39 | 3.75 | 5.01 | 1.30 | 6.17 | 5.55 | 7.13 | 5.89 | 3.35 | 0.42 |
| $Na_2O$ | 0.29 | 1.12 | 2.00 | 0.23 | 0.25 | 0.12 | 0.14 | 1.63 | 2.71 | 1.88 | 0.16 |
| $K_2O$ | 1.41 | 5.75 | 6.11 | 7.15 | 8.51 | 3.06 | 9.48 | 4.93 | 4.28 | 5.79 | 3.70 |
| $P_2O_5$ | 0.03 | 2.26* | 1.77* | 3.55* | 0.87 | 4.13* | 4.20* | 3.04* | 0.54 | 0.67 | 0.22 |
| $TiO_2$ | 0.81 | 0.95 | 0.75 | 0.98 | 3.87* | 1.24 | 1.09 | 0.72 | 3.46* | 4.04* | 0.80 |
| MnO | 0.18 | 0.18 | 0.20 | 0.40 | 0.15 | 0.53 | 0.34 | 0.20 | 0.29 | 0.30 | 0.29 |
| $H_2O+$ | 6.27 | 2.85 | 2.11 | 2.17 | 2.85 | 4.94 | 2.15 | 2.30 | 1.35 | 2.23 | 4.03 |
| $CO_2$ | 0.17 | 0.17 | 0.10 | 0.11 | 0.02 | 0.14 | 0.06 | 0.24 | 0.11 | 0.06 | 0.03 |
| C.E.C. meq/100g | 133.2 | 57.5 | 30.3 | 34.2 | 32.7 | 60.8 | 28.0 | 35.1 | ___ | 27.3 | 21.9 |
| Total | 99.53 | 99.26 | 98.69 | 98.87 | 98.24 | 99.74 | 98.81 | 98.24 | 98.64 | 98.25 | 98.81 |

Comments: * Note high $TiO_2$ and $P_2O_5$

** Solutions turn purple before titration.

RESULTS OF CHEMICAL ANALYSES

Rock Type Granite Locality Sorocaba, São Paulo

| Sample Number | 90 | 91 | 92 | 93 | 94 | 95 | 96 | 97 | 99a | 99b |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 77.1 | 70.7 | 65.4 | 68.5 | 67.4 | 63.9 | 70.5 | 73.2 | 68.9 | 75.6 |
| $Al_2O_3$ | 12.14 | 14.39 | 15.26 | 16.69 | 16.14 | 18.60 | 13.95 | 17.68 | 15.47 | 12.73 |
| Total Iron | 2.13 | 3.88 | 5.86 | 3.12 | 4.58 | 4.05 | 4.05 | 1.17 | 2.24 | 1.37 |
| $Fe_2O_3$ | 0.54 | 0.56 | 0.84 | 2.21 | 4.04 | 3.34 | 1.33 | 1.07 | 0.95 | 0.36 |
| FeO | 1.43 | 2.99 | 4.52 | 0.82 | 0.49 | 0.64 | 2.45 | 0.09 | 1.16 | 0.91 |
| MgO | 0.14 | 0.66 | 1.05 | 0.43 | 0.47 | 0.45 | 0.62 | 0.09 | 0.81 | 0.09 |
| CaO | 0.50 | 2.42 | 1.20 | 0.39 | 0.09 | 0.19 | 1.33 | 0.10 | 1.61 | 0.59 |
| $Na_2O$ | 3.08 | 4.27 | 2.93 | 1.46 | 0.27 | 0.39 | 2.81 | 0.02 | 3.23 | 3.21 |
| $K_2O$ | 5.04 | 2.58 | 5.83 | 6.96 | 5.64 | 7.65 | 4.97 | 0.58 | 6.90 | 5.40 |
| $P_2O_5$ | 0.05 | 0.23 | 0.27 | 0.06 | 0.11 | 0.05 | 0.19 | 0.01 | 0.10 | 0.02 |
| $TiO_2$ | 0.15 | 0.56 | 0.93 | 0.45 | 0.68 | 0.59 | 0.61 | 0.18 | 0.40 | 0.18 |
| MnO | 0.08 | 0.06 | 0.05 | - | 0.04 | 0.02 | 0.04 | 0.03 | 0.04 | 0.04 |
| $H_2O+$ | 0.36 | 0.46* | 1.06* | 2.64 | 3.76 | 4.06 | 0.87 | 6.17* | 0.23* | 0.55 |
| $CO_2$ | 0.02 | 0.12 | 0.02 | 0.02 | 0.05 | 0.02 | 0.05 | 0.02 | 0.14 | 0.05 |
| | | | | | | | | | | |
| Total | 100.63 | 100.00 | 99.36 | 100.63 | 99.18 | 99.90 | 99.72 | 99.24 | 99.94 | 99.73 |

Comments: * Samples bloated on heating in Penfield tube.

RESULTS OF CHEMICAL ANALYSES

Rock Type Phyllites Locality Sorocaba, São Paulo

| Sample Number | 100 | 101 | 103 | 104 | 105 | 106 | 107 | 108 | 109 | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 63.73 | 64.89 | 62.73 | 78.19 | 60.33 | 60.33 | 50.89 | 48.80 | 71.00 | |
| $Al_2O_3$ | 19.58 | 18.28 | 19.69 | 10.51 | 23.30 | 23.50 | 27.65 | 27.37 | 17.89 | |
| Total Iron | 7.65 | 8.28 | 8.22 | 4.43 | 2.46 | 2.52 | 6.66 | 7.71 | 0.88 | |
| $Fe_2O_3$ | 7.18 | 8.18 | 7.63 | 4.00 | 2.24 | 2.22 | 6.40 | 7.38 | 0.61 | |
| FeO | 0.42 | 0.09 | 0.53 | 0.39 | 0.20 | 0.27 | 0.23 | 0.30 | 0.24 | |
| MgO | 0.90 | 0.21 | 1.80 | 0.99 | 0.50 | 0.57 | 0.45 | 0.42 | 0.14 | |
| CaO | 0.28 | 0.01 | 0.10 | 0.10 | - | - | - | - | 0.06 | |
| $Na_2O$ | 1.43 | 0.65 | 0.98 | 0.57 | 0.31 | 0.21 | 0.30 | 0.19 | 0.32 | |
| $K_2O$ | 2.47 | 3.77 | 2.27 | 1.76 | 4.96 | 4.69 | 3.49 | 3.08 | 4.94 | |
| $P_2O_5$ | 0.15 | 0.04 | 0.08 | 0.08 | 0.02 | 0.01 | 0.03 | 0.04 | 0.02 | |
| $TiO_2$ | 0.91 | 0.86 | 0.85 | 0.81 | 1.08 | 1.07 | 1.33 | 1.33 | 0.12 | |
| MnO | 0.05 | 0.04 | 0.08 | 0.03 | - | - | 0.03 | - | 0.06 | |
| $H_2O+$ | 2.62 | 2.75 | 2.92 | 1.54 | 4.91 | 5.26 | 8.10 | 8.66 | 3.82 | |
| $CO_2$ | 0.04 | 0.02 | 0.06 | 0.03 | 0.03 | 0.03 | 0.06 | 0.04 | 0.02 | |
| | | | | | | | | | | |
| Total | 99.76 | 99.79 | 99.72 | 99.00 | 97.88 | 98.16 | 98.96 | 97.61 | 99.24 | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Phyllites Locality Sorocaba, São Paulo

| Sample Number | 110 | 110-A | 111 | 112 | 113 | 114 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 71.16 | 60.40 | 68.84 | 66.59 | 60.33 | 73.55 | | | | |
| $Al_2O_3$ | 17.54 | 19.07 | 18.91 | 20.37 | 18.76 | 14.33 | | | | |
| Total Iron | 0.76 | 5.54 | 1.47 | 1.80 | 5.66 | 1.25 | | | | |
| $Fe_2O_3$ | 0.45 | 3.78 | 1.25 | 1.63 | 5.17 | 0.82 | | | | |
| FeO | 0.28 | 1.59 | 0.20 | 0.15 | 0.44 | 0.39 | | | | |
| MgO | 0.17 | 2.42 | 0.30 | 0.23 | 2.55 | 0.16 | | | | |
| CaO | - | 0.16 | - | - | 0.28 | 0.86 | | | | |
| $Na_2O$ | 0.28 | 0.44 | 0.13 | 0.17 | 0.23 | 3.01 | | | | |
| $K_2O$ | 5.11 | 4.28 | 3.95 | 4.23 | 3.73 | 5.24 | | | | |
| $P_2O_5$ | 0.02 | 0.04 | 0.02 | 0.02 | 0.04 | 0.03 | | | | |
| $TiO_2$ | 0.13 | 1.22 | 0.42 | 0.28 | 1.36 | 0.18 | | | | |
| MnO | 0.01 | 0.06 | - | - | 0.07 | - | | | | |
| $H_2O+$ | 3.70 | 5.11 | 5.13 | 5.58 | 5.79 | 0.82 | | | | |
| $CO_2$ | 0.01 | 0.03 | 0.02 | 0.02 | 0.02 | 0.01 | | | | |
| | | | | | | | | | | |
| Total | 98.86 | 98.60 | 99.17 | 99.27 | 98.77 | 99.40 | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Basalt Locality Near Jupia, Mato Grasso

| Sample Number | 136 | 137A | 137B | 138 | 139 | 140 | 141 | 142 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 45.1 | 46.6 | 47.1 | 48.7 | 48.5 | 49.4 | 50.0 | 50.2 | | |
| $Al_2O_3$ | 15.7 | 13.5 | 15.0 | 13.4 | 13.4 | 13.3 | 13.3 | 13.4 | | |
| Total Iron | 17.6 | 15.7 | 15.5 | 14.3 | 14.4 | 14.2 | 14.5 | 14.7 | | |
| $Fe_2O_3$ | 15.2 | 9.92 | 10.5 | 7.21 | 6.46 | 6.21 | 6.05 | 3.90 | | |
| FeO | 2.20 | 5.24 | 4.52 | 6.42 | 7.13 | 7.23 | 7.59 | 9.74 | | |
| MgO | 3.67 | 5.65 | 5.25 | 6.38 | 6.48 | 6.77 | 6.28 | 6.06 | | |
| CaO | 3.76 | 6.83 | 6.04 | 9.80 | 10.12 | 10.27 | 9.95 | 9.95 | | |
| $Na_2O$ | 0.84 | 1.31 | 1.31 | 2.10 | 2.18 | 2.22 | 2.24 | 2.24 | | |
| $K_2O$ | 0.77 | 0.79 | 0.78 | 0.78 | 0.70 | 0.76 | 1.02 | 0.80 | | |
| $P_2O_5$ | 0.11 | 0.13 | 0.13 | 0.21 | 0.21 | 0.15 | 0.24 | 0.24 | | |
| $TiO_2$ | 2.13 | 1.93 | 1.90 | 1.80 | 1.77 | 1.82 | 1.81 | 1.89 | | |
| MnO | 0.32 | 0.37 | 0.28 | 0.24 | 0.24 | 0.23 | 0.23 | 0.23 | | |
| $H_2O+$ | 7.23 | 4.69 | 5.63 | 1.67 | 1.14 | 1.26 | 0.84 | 0.44 | | |
| $CO_2$ | 0.12 | 0.03 | 0.03 | 0.03 | 0.06 | 0.03 | 0.02 | 0.03 | | |
| | | | | | | | | | | |
| Total | 97.15 | 96.99 | 98.47 | 98.74 | 98.39 | 99.65 | 99.55 | 99.12 | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Bloating Shale Locality Jundiaí, São Paulo

| Sample Number | 151 | 152 | 153 | 154 | 154-A Red | 154-A White | 155 | 156 | 156A | 158 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 59.6 | 58.9 | 71.6 | 57.3 | 56.7 | 63.7 | 67.7 | 58.7 | 48.5 | 43.4 |
| $Al_2O_3$ | 17.1 | 18.6 | 14.7 | 20.3 | 21.0 | 21.8 | 19.8 | 21.7 | 23.4 | 28.8 |
| Total Iron | 7.46 | 7.88 | 5.83 | 9.21 | 8.63 | 2.90 | 3.11 | 6.98 | 14.5 | 12.3 |
| $Fe_2O_3$ | 6.56 | 7.29 | 5.79 | 8.89 | 8.30 | 2.71 | 3.03 | 6.76 | 14.3 | 12.1 |
| FeO | 0.81 | 0.53 | 0.04 | 0.29 | 0.30 | 0.17 | 0.07 | 0.20 | 0.23 | 0.22 |
| MgO | 2.85 | 2.01 | 0.69 | 1.25 | 0.84 | 0.86 | 0.26 | 0.78 | 0.84 | 0.80 |
| CaO | 0.13 | 0.14 | 0.11 | 0.12 | 0.05 | 0.10 | 0.10 | 0.05 | - | 0.09 |
| $Na_2O$ | 0.01 | - | - | - | - | - | - | - | - | - |
| $K_2O$ | 4.55 | 3.95 | 1.70 | 3.70 | 3.98 | 2.58 | 0.75 | 2.59 | 3.00 | 2.87 |
| $P_2O_5$ | 0.17 | 0.21 | 0.17 | 0.25 | 0.09 | 0.07 | 0.23 | 0.05 | 0.15 | 0.06 |
| $TiO_2$ | 0.85 | 0.89 | 0.68 | 0.89 | 1.13 | 0.83 | 0.52 | 0.95 | 0.97 | 1.33 |
| MnO | 0.05 | 0.03 | 0.13 | 0.10 | 0.07 | 0.08 | 0.08 | 0.08 | 0.07 | 0.08 |
| $H_2O+$ | 5.31 | 6.22 | 5.36 | 6.89 | 6.87 | 7.36 | 7.29 | 7.26 | 8.11 | 9.54 |
| $CO_2$ | 0.03 | 0.03 | 0.03 | 0.07 | 0.09 | 0.09 | 0.03 | 0.09 | 0.10 | 0.12 |
| | | | | | | | | | | |
| Total | 98.02 | 98.80 | 101.0 | 100.05 | 99.42 | 100.35 | 99.86 | 99.21 | 99.67 | 99.41 |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Bloating Shale Locality Jundiaí, São Paulo

| Sample Number | 159 | 160 | 163 | 164 | 165 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 42.8 | 37.9 | 52.2 | 52.5 | 55.8 | | | | | |
| $Al_2O_3$ | 29.8 | 36.7 | 21.9 | 21.0 | 20.3 | | | | | |
| Total Iron | 12.8 | 14.1 | 9.69 | 10.9 | 7.90 | | | | | |
| $Fe_2O_3$ | 12.7 | 14.0 | 9.28 | 10.5 | 7.33 | | | | | |
| FeO | 0.13 | 0.09 | 0.37 | 0.32 | 0.51 | | | | | |
| MgO | 0.48 | 0.15 | 2.57 | 2.93 | 2.99 | | | | | |
| CaO | 0.03 | 0.06 | 0.05 | 0.09 | 0.09 | | | | | |
| $Na_2O$ | - | - | - | 0.05 | 0.06 | | | | | |
| $K_2O$ | 1.78 | 0.40 | 4.65 | 4.59 | 4.85 | | | | | |
| $P_2O_5$ | 0.05 | 0.07 | 0.13 | 0.15 | 0.14 | | | | | |
| $TiO_2$ | 1.64 | 2.16 | 1.02 | 1.02 | 1.05 | | | | | |
| MnO | 0.06 | 0.07 | 0.14 | 0.12 | 0.10 | | | | | |
| $H_2O+$ | 9.98 | 9.07 | 6.35 | 5.86 | 5.35 | | | | | |
| $CO_2$ | 0.14 | 0.17 | 0.07 | 0.10 | 0.10 | | | | | |
| | | | | | | | | | | |
| Total | 99.59 | 100.84 | 98.73 | 99.23 | 98.67 | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Amphibolite and Schist (?) Locality Jundiaí, São Paulo

| Sample Number | 166 | 167 | 168 | 169 | 170 | 171 | 172A | 172B | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 52.6 | 57.9 | 53.4 | 70.6 | 48.4 | 51.2 | 51.3 | 46.6 | | |
| $Al_2O_3$ | 17.2 | 28.4 | 24.12 | 15.6 | 17.7 | 14.7 | 14.6 | 18.3 | | |
| Total Iron | 11.98 | 0.96 | 8.37 | 4.69 | 15.11 | 10.96 | 11.55 | 12.90 | | |
| $Fe_2O_3$ | 11.38 | 0.82 | 7.94 | 4.45 | * | 1.19 | 1.01 | 5.37 | | |
| FeO | 0.54 | 0.13 | 0.39 | 0.22 | * | 8.80 | 9.50 | 6.78 | | |
| MgO | 6.76 | 0.65 | 2.81 | 1.20 | 2.87 | 9.16 | 8.84 | 7.97 | | |
| CaO | 0.81 | 0.43 | 0.09 | 0.01 | 3.37 | 10.46 | 11.06 | 6.50 | | |
| $Na_2O$ | 0.07 | 0.33 | 0.05 | 0.06 | 0.06 | 1.30 | 0.89 | 0.15 | | |
| $K_2O$ | 1.71 | 0.53 | 2.27 | 2.35 | 0.93 | 0.81 | 0.39 | 0.41 | | |
| $P_2O_5$ | 0.04 | 0.05 | 0.02 | 0.04 | 0.02 | 0.02 | 0.02 | 0.01 | | |
| $TiO_2$ | 0.39 | 0.07 | 1.21 | 0.62 | 0.32 | 0.20 | 0.20 | 0.25 | | |
| MnO | 0.31 | 0.06 | 0.06 | 0.07 | 1.61 | 0.22 | 0.19 | 0.18 | | |
| $H_2O+$ | 7.58 | 9.50 | 8.36 | 4.44 | 6.53 | 1.74 | 1.80 | 6.46 | | |
| $CO_2$ | 0.07 | 0.06 | 0.09 | 0.04 | 0.10 | 0.03 | 0.03 | 0.05 | | |
| | | | | | | | | | | |
| Total | 99.45 | 98.94 | 100.81 | 99.67 | 97.02 | 99.84 | 99.79 | 98.98 | | |

Comments: * FeO could not be determined because of an interference with the indicator color, probably by the high manganese content.

RESULTS OF CHEMICAL ANALYSES

Rock Type Amphibolite and Schist (?) Locality Jundiaí, São Paulo

| Sample Number | 166MP† | 167P† | 168P† | 169P† | 166-3A† | 166-3D† | 166-6† | 166-S† | 170-A† | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 51.0 | 45.2 | 45.0 | 46.5 | 42.8 | 61.3 | 51.8 | 53.2 | 48.7 | |
| $Al_2O_3$ | 16.1 | 37.6 | 35.0 | 35.9 | 19.5 | 16.3 | 21.0 | 14.1 | 18.0 | |
| Total Iron | 15.33 | 0.68 | 3.07 | 2.27 | 11.12 | 6.89 | 8.93 | 20.32 | 15.29 | |
| $Fe_2O_3$ | 13.84 | - | - | - | 9.98 | - | 8.62 | 20.25 | 14.89 | |
| FeO | 1.34 | - | - | - | 1.03 | - | 0.28 | 0.06 | 0.36 | |
| MgO | 5.62 | 0.29 | 0.79 | 0.41 | 12.01 | 4.04 | 3.38 | 1.61 | 2.96 | |
| CaO | 1.51 | 0.07 | 0.03 | 0.04 | 0.23 | 0.43 | 0.34 | 0.05 | 2.46 | |
| $Na_2O$ | 0.04 | 0.08 | 0.20 | 0.21 | - | - | 0.05 | 0.43 | 0.09 | |
| $K_2O$ | 0.93 | 0.62 | 1.44 | 1.77 | 2.38 | 2.31 | 0.40 | 0.17 | 1.02 | |
| $P_2O_5$ | 0.07 | 0.39 | 0.02 | 0.06 | - | 0.04 | 0.04 | 0.09 | 0.02 | |
| $TiO_2$ | 0.34 | 0.09 | 1.69 | 0.70 | 0.65 | 0.17 | 0.11 | 0.35 | 0.29 | |
| MnO | 0.11 | 0.02 | 0.02 | 0.01 | 0.07 | 0.06 | 0.06 | 0.02 | 0.29 | |
| $H_2O+$ | 8.16 | 13.0 | 11.3 | 11.3 | 8.0 | * | 8.2 | 8.8 | 6.9 | |
| $CO_2$ | - | - | - | - | - | - | - | - | - | |
| | | | | | | | | | | |
| Total | 99.03 | 98.04 | 98.58 | 99.13 | 96.68 | 91.54 | 94.29 | 99.14 | 95.96 | |

Comments:

* Not enough sample to run $H_2O+$.

† Sample 166-MP is the most purified fraction of the green clay that we could obtain. Samples 167-P, 168-P and 169-P are the purified, less than 2 micron fraction of white clay separated from the crude schist composing the host rock. Number 166-3A is purified brown mica separated from the crude green clay of 166. Sample 166-3D consisted of a single sample of 0.0500 g of a clear white mineral (?) separated from the brown mica in 166. Sample 166-6 is the last (purest?) fraction of green clay left floating on bromoform. Sample 166-S is a purified fraction of 166 separated by settling and decantation only. Sample 170A was a clay sample purified using a vibrator table only.

RESULTS OF CHEMICAL ANALYSES

Rock Type Oil Shale ("Paraiba Valley Shale") Locality Taubaté, São Paulo

| Sample Number | 180 | 181 | 182 | 183 | 184 | 185 | 186 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49.4 | 48.0 | 68.2 | 41.9 | 53.3 | 50.3 | 49.7 | | | |
| $Al_2O_3$ | 20.5 | 21.8 | 16.0 | 23.0 | 25.8 | 25.2 | 25.5 | | | |
| Total Iron | 8.90 | 8.95 | 6.34 | 22.4 | 6.88 | 9.51 | 9.60 | | | |
| $Fe_2O_3$ | 8.01 | 7.70 | 6.08 | 22.24 | 6.70 | 9.10 | 9.24 | | | |
| FeO | 0.80 | 1.13 | 0.23 | 0.16 | 0.16 | 0.37 | 0.32 | | | |
| MgO | 2.91 | 2.50 | 0.41 | 0.79 | 1.20 | 1.57 | 1.94 | | | |
| CaO | 3.00 | 3.09 | - | - | - | - | - | | | |
| $Na_2O$ | 0.66 | 0.35 | 0.02 | 0.05 | 0.15 | 0.22 | 0.29 | | | |
| $K_2O$ | 3.97 | 3.37 | 0.81 | 1.65 | 2.17 | 2.46 | 2.96 | | | |
| $P_2O_5$ | 0.27 | 0.16 | 0.13 | 0.18 | 0.24 | 0.11 | 0.08 | | | |
| $TiO_2$ | 0.93 | 1.02 | 1.14 | 1.05 | 1.09 | 1.21 | 1.18 | | | |
| MnO | 0.15 | 0.12 | 0.09 | 0.03 | 0.03 | 0.04 | 0.05 | | | |
| $H_2O+$ | 7.34 | 7.93 | 6.14 | 9.23 | 8.61 | 9.30 | 9.23 | | | |
| $CO_2$ | 2.00 | 2.05 | 0.12 | - | 0.10 | - | - | | | |
| Loss on Ignition | 9.1 | 10.6 | 6.5 | 8.4 | 8.9 | 9.6 | 8.8 | | | |
| Total * | 99.94 | 99.22 | 99.37 | 100.28 | 99.55 | 99.88 | 100.49 | | | |

Comments: * Does not include loss on ignition

RESULTS OF CHEMICAL ANALYSES

Rock Type Gneiss and Kaolin Locality Linhares, Minas Gerais

| Sample Number | 187 | 188 | 189 | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 65.2 | 7.10 | 65.2 | | | | | | | |
| $Al_2O_3$ | 13.0 | 12.1 | 24.4 | | | | | | | |
| Total Iron | 7.62 | 6.75 | 0.72 | | | | | | | |
| $Fe_2O_3$ | 3.30 | 5.27 | 0.65 | | | | | | | |
| FeO | 3.89 | 1.33 | 0.06 | | | | | | | |
| MgO | 3.30 | 1.92 | 0.08 | | | | | | | |
| CaO | 2.85 | 1.29 | - | | | | | | | |
| $Na_2O$ | 2.12 | 1.03 | 0.22 | | | | | | | |
| $K_2O$ | 3.25 | 2.53 | 0.98 | | | | | | | |
| $P_2O_5$ | 0.17 | 0.49 | 0.07 | | | | | | | |
| $TiO_2$ | 1.04 | 0.92 | 0.07 | | | | | | | |
| MnO | 0.09 | 0.07 | 0.03 | | | | | | | |
| $H_2O+$ | 0.68 | 2.01 | 9.58 | | | | | | | |
| $CO_2$ | 0.32 | - | 0.08 | | | | | | | |
| | | | | | | | | | | |
| Total | 99.21 | 99.96 | 101.42 | | | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Pegmatite Locality Linhares, Minas Gerais

| Sample Number | 190 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 47.1 | 50.0 | 67.8 | 47.6 | 49.3 | 65.8 | 74.0 | 45.5 | 61.0 | |
| $Al_2O_3$ | 38.78 | 35.82 | 24.22 | 37.03 | 37.36 | 18.81 | 16.28 | 24.62 | 15.99 | |
| Total Iron | - | 0.53 | 0.21 | 1.28 | 0.49 | 0.09 | 0.30 | 10.1 | 6.70 | |
| $Fe_2O_3$ | - | 0.49 | 0.15 | - | 0.43 | 0.02 | 0.23 | - | 5.36 | |
| FeO | 0.04 | 0.04 | 0.05 | ** | 0.05 | 0.06 | 0.06 | ** | 1.21 | |
| MgO | - | 0.51 | 0.06 | 0.12 | 0.02 | 0.008 | 0.29 | 1.64 | 3.38 | |
| CaO | 0.02 | 0.23 | 0.02 | - | 0.04 | - | 1.74 | 0.23 | 4.66 | |
| $Na_2O$ | 0.04 | 0.51 | 0.03 | 0.09 | 0.08 | 2.60 | 5.15 | 0.58 | 2.75 | |
| $K_2O$ | 0.08 | 0.77 | 0.14 | 2.36 | 0.39 | 13.1 | 0.96 | 0.75 | 3.95 | |
| $P_2O_5$ | 0.03 | <0.01 | <0.01 | 0.01 | 0.03 | <0.01 | <0.01 | 0.06 | 0.20 | |
| $TiO_2$ | <.01 | - | <.01 | 0.02 | - | - | - | 0.03 | 0.58 | |
| MnO | - | 0.16 | 0.004 | 0.40 | 0.08 | - | - | 5.41* | 0.10 | |
| $H_2O+$ | 13.7 | 11.8 | 8.55 | 11.19 | 12.3*** | 0.25 | 1.44 | 9.18 | 0.62 | |
| $CO_2$ | 0.05 | 0.03 | 0.05 | 0.07 | 0.07 | 0.03 | 0.03 | 0.10 | 0.45 | |
| | | | | | | | | | | |
| Total | 99.80 | 100.36 | 101.07 | 100.17 | 100.15 | 100.68 | 100.18 | 98.20 | 100.25 | |

Comments: * Far out of range of standards

** Could not be determined. Soln. turned purple before titration.

*** Large variation in $H_2O+$ results

9.57, 12.43 } 1 g. samp.
14.40, 12.86 } 0.5 g samp. } Av=12.3

RESULTS OF CHEMICAL ANALYSES

Rock Type Marble Locality Barroso, Minas Gerais

| Sample Number | 200 | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 2.40 | 59.7 | 54.7 | 60.6 | 63.7 | 58.0 | 47.3 | 64.1 | 59.2 | |
| $Al_2O_3$ | 0.28 | 16.51 | 21.71 | 17.86 | 17.37 | 22.19 | 28.08 | 18.56 | 20.13 | |
| Total Iron | 0.29 | 7.45 | 9.78 | 8.61 | 8.21 | 7.93 | 10.89 | 7.48 | 8.56 | |
| $Fe_2O_3$ | - | 7.39 | - | - | 8.14 | 7.56 | 10.62 | 7.17 | 8.16 | |
| FeO | - | 0.05 | *- | *- | 0.06 | 0.33 | 0.24 | 0.28 | 0.36 | |
| MgO | 0.42 | 3.25 | 0.59 | 1.12 | 0.48 | 0.33 | 0.37 | 0.35 | 0.34 | |
| CaO | 55.72 | 2.37 | 0.13 | 0.22 | 0.09 | 0.12 | 0.20 | 0.11 | 0.10 | |
| $Na_2O$ | 0.48 | 0.88 | 0.06 | 0.07 | 0.05 | 0.06 | 0.03 | 0.03 | 0.03 | |
| $K_2O$ | 0.24 | 3.29 | 2.19 | 2.30 | 1.90 | 1.57 | 1.17 | 1.02 | 1.06 | |
| $P_2O_5$ | 0.05 | 0.92 | 0.31 | 0.33 | 0.21 | 0.10 | 0.10 | 0.13 | 0.14 | |
| $TiO_2$ | 0.02 | 0.95 | 1.19 | 1.08 | 1.25 | 1.29 | 1.19 | 1.12 | 1.21 | |
| MnO | 0.01 | 0.25 | 0.31 | 0.46 | 0.16 | 0.05 | - | 0.005 | 0.04 | |
| $H_2O+$ | - | 4.00 | 7.12 | 5.56 | 5.37 | 7.34 | 9.48 | 6.33 | 7.23 | |
| $CO_2$ | 41.83 | 0.12 | 0.13 | 0.09 | 0.08 | 0.13 | 0.14 | 0.09 | 0.12 | |
| | | | | | | | | | | |
| Total | 101.74 | 99.68 | | | 98.86 | 99.07 | 98.92 | 99.29 | 98.12 | |

Comments: * Could not be determined. Interference with indicator color.

RESULTS OF CHEMICAL ANALYSES

Rock Type Marble Locality Barroso, Gerais Minas

| Sample Number | 209 | 210 | 211 | 212 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 0.61 | 1.03 | 67.0 | 63.2 | | | | | | |
| $Al_2O_3$ | 0.14 | 0.13 | 7.12 | 13.23 | | | | | | |
| Total Iron | 0.16 | 0.13 | 6.06 | 7.21 | | | | | | |
| $Fe_2O_3$ | - | - | - | - | | | | | | |
| FeO | - | - | -* | -* | | | | | | |
| MgO | 0.40 | 0.43 | 6.09 | 0.67 | | | | | | |
| CaO | 56.84 | 56.70 | 2.35 | 0.08 | | | | | | |
| $Na_2O$ | 0.08 | 0.07 | 0.09 | 0.06 | | | | | | |
| $K_2O$ | 0.05 | 0.03 | 1.51 | 2.35 | | | | | | |
| $P_2O_5$ | 0.06 | 0.06 | 1.98 | 0.33 | | | | | | |
| $TiO_2$ | 0.01 | 0.01 | 0.44 | 0.77 | | | | | | |
| MnO | 0.01 | 0.01 | 1.57 | 5.0 | | | | | | |
| $H_2O+$ | - | - | 2.80 | 3.80 | | | | | | |
| $CO_2$ | 43.67 | 41.65 | 0.82 | 0.05 | | | | | | |
| | | | | | | | | | | |
| Total | 102.03 | 100.25 | | | | | | | | |

* Could not be determined. Interference with indicator color.

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Amphibolites Locality vicinity Curitiba, Parana'

| Sample Number | 230 | 231 | 232 | 233 | 234 | 235 | 236 | 237 | 238 | 239 | 240 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 53.6 | 52.2 | 52.2 | 56.8 | 46.0 | 52.3 | 54.3 | 60.7 | 57.1 | 54.6 | 54.5 |
| $Al_2O_3$ | 4.41 | 5.16 | 9.07 | 15.09 | 12.41 | 11.59 | 15.35 | 16.28 | 17.56 | 21.77 | 21.95 |
| Total Iron | 11.84 | 13.48 | 19.64 | 16.44 | 15.28 | 14.14 | 10.16 | 8.28 | 9.95 | 11.05 | 12.12 |
| $Fe_2O_3$ | 3.73 | 6.33 | 17.43 | 16.41 | 14.89 | 10.01 | 1.47 | 5.97 | 9.51 | 11.05 | 12.06 |
| FeO | 7.31 | 6.44 | 1.99 | 0.02 | 0.04 | 3.72 | 7.83 | 2.08 | 0.40 | 0.00 | 0.06 |
| MgO | 16.18 | 14.57 | 6.28 | 2.91 | 12.27 | 12.34 | 5.67 | 3.22 | 3.29 | 1.20 | 0.84 |
| CaO | 11.05 | 9.90 | 4.12 | 1.28 | 2.33 | 2.82 | 7.27 | 3.34 | 2.86 | 0.92 | 0.11 |
| $Na_2O$ | 0.41 | 0.34 | 0.39 | 0.13 | 0.41 | 0.64 | 3.21 | 3.65 | 3.18 | 0.39 | 0.14 |
| $K_2O$ | 0.44 | 0.52 | 1.68 | 1.27 | 1.65 | 0.13 | 0.94 | 1.24 | 1.26 | 0.53 | 1.06 |
| $P_2O_5$ | 0.03 | 0.04 | 0.03 | 0.02 | 1.10 | 0.02 | 0.23 | 0.22 | 0.29 | 0.25 | 0.20 |
| $TiO_2$ | 0.27 | 0.37 | 1.11 | 0.35 | 2.59 | 0.28 | 0.64 | 0.66 | 0.74 | 0.87 | 0.92 |
| MnO | 0.26 | 0.32 | 0.32 | 0.25 | 0.40 | 0.28 | 0.22 | 0.10 | 0.19 | 0.30 | 0.15 |
| $H_2O+$ | 2.65 | 3.52 | 5.19 | 6.51 | 6.07 | 5.75 | 2.95 | 3.32 | 5.11 | 8.79 | 9.34 |
| $CO_2$ | 0.06 | 0.06 | 0.07 | 0.10 | 0.13 | 0.13 | 1.09 | 0.10 | 0.06 | 0.07 | 0.08 |
| | | | | | | | | | | | |
| Total | 100.4 | 99.77 | 99.88 | 101.14 | 100.29 | 100.01 | 101.17 | 100.88 | 101.55 | 100.74 | 101.31 |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Rhyolite Locality Curitiba, Parana

| Sample Number | 241A | 241B | 241C | 241D | 241E | 241F | 241G | 241H G | 241HY | 241I | 241J |
|---|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 75.1 | 75.3 | 74.1 | 74.9 | 74.6 | 73.9 | 73.2 | 72.4 | 73.1 | 72.0 | 72.0 |
| $Al_2O_3$ | 12.6 | 12.6 | 13.2 | 13.8 | 14.1 | 14.2 | 15.9 | 16.7 | 14.8 | 17.1 | 17.2 |
| Total Iron | 1.67 | 1.72 | 2.31 | 1.99 | 1.90 | 2.49 | 1.49 | 1.36 | 3.87 | 3.03 | 2.55 |
| $Fe_2O_3$ | 0.77 | 1.05 | 2.24 | 1.82 | 1.70 | 2.28 | 1.29 | 1.20 | 3.81 | 2.74 | 2.31 |
| FeO | 0.81 | 0.60 | 0.06 | 0.15 | 0.18 | 0.19 | 0.18 | 0.14 | 0.05 | 0.26 | 0.22 |
| MgO | 0.01 | 0.02 | 0.03 | 0.03 | 0.03 | 0.04 | 0.01 | 0.01 | 0.02 | 0.03 | 0.03 |
| CaO | 0.49 | 0.48 | 0.01 | - | - | - | 0.01 | 0.01 | 0.02 | - | - |
| $Na_2O$ | 4.24 | 4.24 | 3.39 | 2.15 | 1.55 | 0.32 | 0.25 | 0.04 | 0.04 | - | - |
| $K_2O$ | 4.60 | 4.50 | 5.18 | 4.96 | 5.29 | 5.71 | 5.36 | 3.84 | 3.03 | 1.43 | 1.50 |
| $P_2O_5$ | 0.011 | 0.009 | 0.014 | 0.009 | 0.008 | 0.004 | 0.007 | 0.007 | 0.022 | 0.017 | 0.017 |
| $TiO_2$ | 0.11 | 0.11 | 0.11 | 0.11 | 0.12 | 0.13 | 0.13 | 0.14 | 0.16 | 0.16 | 0.15 |
| MnO | 0.05 | 0.04 | 0.18 | 0.03 | <0.01 | 0.01 | - | - | 0.01 | 0.02 | - |
| $H_2O+$ | 0.28 | 0.27 | 0.83 | 1.67 | 2.18 | 2.56 | 3.62 | 4.68 | 4.53 | 5.57 | 5.58 |
| $CO_2$ | 0.33 | 0.14 | 0.16 | 0.09 | 0.09 | 0.07 | 0.07 | - | 0.07 | 0.12 | 0.07 |
| | | | | | | | | | | | |
| Total | 99.40 | 99.36 | 99.50 | 99.72 | 99.85 | 99.41 | 100.03 | 99.17 | 99.66 | 99.45 | 99.08 |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Dolomite Locality Tranqueira, Parana

| Sample Number | 244 | 244AA | 244AB | 244AC | 244AD | 245 | 246 | 247 | 248 | 249A |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 3.15 | 0.50 | 0.50 | 0.86 | 0.47 | 1.62 | 73.4 | 97.0 | 81.2 | 0.39 |
| $Al_2O_3$ | 0.15 | 0.10 | 0.09 | 0.08 | 0.09 | 0.20 | 12.20 | 9.75 | 6.67 | 0.09 |
| Total Iron | 0.28 | 0.15 | 0.16 | 0.16 | 0.19 | 0.24 | 5.50 | 3.95 | 4.82 | 0.15 |
| $Fe_2O_3$ | - | - | - | - | - | - | 5.19 | 3.69 | - | - |
| FeO | - | - | - | - | - | - | 0.28 | 0.23 | - * | - |
| MgO | 20.36 | 22.10 | 22.38 | 22.46 | 22.36 | 21.36 | 0.25 | 0.22 | 0.21 | 22.13 |
| CaO | 30.70 | 30.58 | 30.39 | 29.78 | 30.12 | 29.81 | 0.09 | 0.05 | 0.07 | 31.34 |
| $Na_2O$ | 0.05 | 0.88 | 0.10 | 0.42 | 0.01 | 0.04 | 0.02 | 0.03 | - | 0.02 |
| $K_2O$ | - | 0.02 | 0.06 | 0.08 | - | - | 0.05 | 0.16 | 0.11 | - |
| $P_2O_5$ | t | t | - | t | - | t | 0.08 | 0.04 | 0.04 | t |
| $TiO_2$ | 0.01 | 0.01 | t | t | 0.01 | 0.01 | 0.75 | 0.73 | 0.36 | 0.01 |
| MnO | t | 0.01 | t | 0.01 | 0.01 | 0.03 | 0.12 | 0.07 | 0.53 | t |
| $H_2O+$ | - | - | - | - | - | - | 5.77 | 4.74 | 3.23 | - |
| $CO_2$ | 43.94 | 46.81 | 45.52 | 48.67 | 45.09 | 46.47 | 0.06 | 0.10 | 0.09 | 46.93 |
| | | | | | | | | | | |
| Total | 98.64 | 101.16 | 99.20 | 102.52 | 98.35 | 99.78 | 98.26 | 98.81 | 97.33 | 101.06 |

Comments: *Could not be determined. Indicator interference.
t mean trace; i.e., less than 0.005 but greater than 0.000.

RESULTS OF CHEMICAL ANALYSES

Rock Type Dolomite Locality Tranqueira, Parana

| Sample Number | 249B | 250 | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 23.29 | 23.29 | | | | | | | | |
| $Al_2O_3$ | 0.11 | 0.31 | | | | | | | | |
| Total Iron | 0.15 | 0.30 | | | | | | | | |
| $Fe_2O_3$ | - | - | | | | | | | | |
| FeO | - | - | | | | | | | | |
| MgO | 21.90 | 17.57 | | | | | | | | |
| CaO | 28.86 | 22.28 | | | | | | | | |
| $Na_2O$ | 0.10 | 0.07 | | | | | | | | |
| $K_2O$ | 0.02 | - | | | | | | | | |
| $P_2O_5$ | 0.01 | t | | | | | | | | |
| $TiO_2$ | 0.01 | 0.02 | | | | | | | | |
| MnO | 0.01 | 0.03 | | | | | | | | |
| $H_2O+$ | - | - | | | | | | | | |
| $CO_2$ | 45.58 | 35.44 | | | | | | | | |
| | | | | | | | | | | |
| Total | 99.65 | 99.31 | | | | | | | | |

Comments: t mean trace; i.e., less than 0.005 but greater than 0.000.

RESULTS OF CHEMICAL ANALYSES

Rock Type Diabase Locality Rio Branco do Sul, Parana'

| Sample Number | 251 | 252 | 253 | 254 | 255 | 256 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 51.8 | 51.0 | 40.0 | 39.1 | 39.1 | 39.3 | | | | |
| $Al_2O_3$ | 12.98 | 13.50 | 20.14 | 20.80 | 21.25 | 21.46 | | | | |
| Total Iron | 14.39 | 14.17 | 20.85 | 20.65 | 21.03 | 20.56 | | | | |
| $Fe_2O_3$ | 3.13 | 6.22 | 19.45 | 18.81 | 19.41 | 19.26 | | | | |
| FeO | 10.14 | 7.16 | 1.26 | 1.66 | 1.46 | 1.17 | | | | |
| MgO | 5.89 | 5.31 | 0.69 | 0.58 | 0.45 | 0.41 | | | | |
| CaO | 9.72 | 8.58 | 0.50 | 0.45 | 0.22 | 0.28 | | | | |
| $Na_2O$ | 2.19 | 2.16 | 0.15 | 0.13 | 0.04 | 0.06 | | | | |
| $K_2O$ | 0.99 | 1.04 | 1.10 | 0.65 | 0.33 | 0.37 | | | | |
| $P_2O_5$ | 0.24 | 0.26 | 0.37 | 0.43 | 0.29 | 0.35 | | | | |
| $TiO_2$ | 1.98 | 1.96 | 3.11 | 3.22 | 3.39 | 3.27 | | | | |
| MnO | 0.22 | 0.20 | 0.41 | 0.34 | 0.28 | 0.38 | | | | |
| $H_2O+$ | 0.67 | 1.37 | 8.79 | 9.22 | 9.50 | 9.97 | | | | |
| $CO_2$ | 0.06 | 0.11 | 0.04 | 0.05 | 0.05 | 0.05 | | | | |
| | | | | | | | | | | |
| Total | 100.01 | 98.87 | 96.01 | 95.44 | 95.77 | 96.33 | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Amphibolite Schist Locality Alto do Serra, Parana'

| Sample Number | 260 | 262 | 263 | 264 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 63.9 | 62.9 | 61.5 | 62.5 | | | | | | |
| $Al_2O_3$ | 15.36 | 15.94 | 16.05 | 16.34 | | | | | | |
| Total Iron | 5.48 | 6.33 | 6.44 | 6.62 | | | | | | |
| $Fe_2O_3$ | 2.15 | 5.72 | 5.40 | 5.97 | | | | | | |
| FeO | 3.00 | 0.54 | 0.94 | 0.59 | | | | | | |
| MgO | 2.01 | 2.03 | 2.43 | 2.15 | | | | | | |
| CaO | 3.86 | 4.84 | 3.75 | 3.66 | | | | | | |
| $Na_2O$ | 4.16 | 3.56 | 2.01 | 2.23 | | | | | | |
| $K_2O$ | 2.77 | 2.25 | 3.66 | 2.72 | | | | | | |
| $P_2O_5$ | 0.24 | 0.15 | 0.11 | 0.03 | | | | | | |
| $TiO_2$ | 0.53 | 0.57 | 0.59 | 0.60 | | | | | | |
| MnO | 0.07 | 0.08 | 0.09 | 0.12 | | | | | | |
| $H_2O+$ | 0.79 | 1.65 | 2.17 | 2.75 | | | | | | |
| $CO_2$ | 0.33 | 0.03 | 0.07 | 0.05 | | | | | | |
| | | | | | | | | | | |
| Total | 99.17 | 100.26 | 98.77 | 99.71 | | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Riebeckite schist Locality Castro, Parana

| Sample Number | 269F | 269W | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 53.5 | 54.15 | | | | | | | | |
| $Al_2O_3$ | 4.29 | 5.04 | | | | | | | | |
| Total Iron | 11.2 | 13.1 | | | | | | | | |
| $Fe_2O_3$ | 2.75 | 6.20 | | | | | | | | |
| FeO | 7.61 | 6.22 | | | | | | | | |
| MgO | 15.89 | 15.39 | | | | | | | | |
| CaO | 10.93 | 6.69 | | | | | | | | |
| $Na_2O$ | 0.60 | 0.39 | | | | | | | | |
| $K_2O$ | 0.29 | 0.19 | | | | | | | | |
| $P_2O_5$ | 0.08 | 0.17 | | | | | | | | |
| $TiO_2$ | 0.43 | 0.42 | | | | | | | | |
| MnO | 0.18 | 0.14 | | | | | | | | |
| $H_2O+$ | 2.06 | 3.99 | | | | | | | | |
| $CO_2$ | 0.05 | 0.08 | | | | | | | | |
| | | | | | | | | | | |
| Total | 98.70 | 99.14 | | | | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Charnockite ("Green Granite") Locality Ubatuba, São Paulo

| Sample Number | (23-2)† | (23-3)† | 291 | 291WR* | 292 | 293 | 294 | 295 | 296 | 297 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 66.0 | 65.4 | 65.0 | 66.5 | 65.3 | 64.2 | 62.7 | 64.0 | 56.7 | 61.2 |
| $Al_2O_3$ | 15.7 | 14.6 | 15.3 | 14.0 | 14.5 | 15.7 | 19.1 | 16.2 | 18.8 | 20.3 |
| Total Iron | 5.41 | 5.58 | 6.99 | 4.56 | 6.60 | 6.41 | 6.21 | 5.79 | 8.64 | 6.95 |
| $Fe_2O_3$ | 1.14 | 1.25 | 1.74 | 2.01 | 1.47 | 3.17 | 4.67 | 2.92 | 7.05 | 6.04 |
| FeO | 3.85 | 3.90 | 4.73 | 2.30 | 4.62 | 2.92 | 1.39 | 2.59 | 1.43 | 0.82 |
| MgO | 0.51 | 0.52 | 0.64 | 0.34 | 0.64 | 0.43 | 0.04 | 0.37 | 0.30 | 0.14 |
| CaO | 2.41 | 2.21 | 2.77 | 1.73 | 2.78 | 2.27 | 0.64 | 1.83 | 0.56 | 0.07 |
| $Na_2O$ | 3.78 | 3.45 | 3.74 | 3.49 | 3.79 | 3.67 | 1.58 | 3.12 | 1.48 | 0.42 |
| $K_2O$ | 5.27 | 4.82 | 4.56 | 6.29 | 4.68 | 4.95 | 5.49 | 5.92 | 4.97 | 3.74 |
| $P_2O_5$ | 0.18 | 0.18 | 0.26 | 0.15 | 0.26 | 0.21 | 0.16 | 0.15 | 0.16 | 0.12 |
| $TiO_2$ | 0.60 | 0.58 | 0.78 | 0.56 | 0.75 | 0.79 | 0.65 | 0.70 | 1.07 | 0.79 |
| MnO | 0.10 | 0.10 | 0.12 | 0.05 | 0.11 | 0.06 | 0.08 | 0.05 | 0.11 | 0.07 |
| $H_2O+$ | 0.18 | 0.38 | 0.30 | 0.57 | 0.29 | 0.83 | 4.11 | 1.56 | 6.05 | 6.89 |
| $CO_2$ | 0.09 | 0.34 | 0.07 | 0.07 | 0.07 | 0.07 | 0.06 | 0.07 | 0.03 | 0.06 |
| | | | | | | | | | | |
| Total | 99.81 | 97.73 | 100.01 | 98.06 | 99.26 | 99.24 | 101.06 | 99.48 | 98.71 | 100.64 |

Comments:
* Light-colored (cream) weathering rind separated from 291. Impure.
† Samples 23-2 and 23-3 were collected on a previous trip (1966) to Ubatuba. Sample 23-2 is fresh charnockite collected at a commercial quarry near Praia de Enseada, about 1.5 km from where 23-3 and 291-297 were collected. Sample 23-2 is also fresh charnockite collected in the same outcrop as 291-297 at Praia das Toninhas.

RESULTS OF CHEMICAL ANALYSES

Rock Type Basalt Locality São Sebastião, São Paulo

| Sample Number | 302 | 303A | 303B | 304 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 43.12 | 43.92 | 44.97 | 46.18 | | | | | | |
| $Al_2O_3$ | 11.64 | 13.77 | 13.46 | 12.26 | | | | | | |
| Total Iron | 10.95 | 11.89 | 12.69 | 11.91 | | | | | | |
| $Fe_2O_3$ | 4.31 | 7.08 | 9.13 | 8.99 | | | | | | |
| FeO | 5.98 | 4.33 | 3.21 | 2.63 | | | | | | |
| MgO | 9.52 | 8.87 | 8.17 | 8.80 | | | | | | |
| CaO | 14.20 | 10.87 | 10.54 | 10.91 | | | | | | |
| $Na_2O$ | 1.75 | 2.32 | 2.34 | 2.23 | | | | | | |
| $K_2O$ | 1.91 | 2.37 | 1.96 | 1.69 | | | | | | |
| $P_2O_5$ | 0.37 | 0.48 | 0.43 | 0.38 | | | | | | |
| $TiO_2$ | 2.15 | 2.37 | 2.61 | 2.32 | | | | | | |
| MnO | 0.18 | 0.13 | 0.15 | 0.20 | | | | | | |
| $H_2O+$ | 2.03 | 2.38 | 2.37 | 2.21 | | | | | | |
| $CO_2$ | 1.86 | 0.26 | 0.13 | 0.16 | | | | | | |
| | | | | | | | | | | |
| Total | 99.02 | 99.15 | 99.47 | 98.96 | | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type "Pirituba" Granite Locality vicinity Sorocaba, São Paulo

| Sample Number | 311 | 312 | 313 | 314 | 315 | 316 | 317 | 318 | 319 | 320 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 68.6 | 67.2 | 70.9 | 71.5 | 68.7 | 68.8 | 69.4 | 66.1 | 65.9 | 45.2 |
| $Al_2O_3$ | 12.21 | 14.03 | 14.11 | 13.46 | 14.83 | 14.16 | 14.60 | 15.52 | 16.83 | 20.36 |
| Total Iron | 5.61 | 4.51 | 3.93 | 4.10 | 4.17 | 4.82 | 4.69 | 5.56 | 4.82 | 6.04 |
| $Fe_2O_3$ | 1.06 | 0.51 | 1.38 | 3.20 | 3.10 | 3.94 | 4.00 | 5.10 | 4.50 | 5.70 |
| FeO | 4.10 | 3.60 | 2.30 | 0.81 | 0.96 | 0.79 | 0.62 | 0.41 | 0.29 | 0.31 |
| MgO | 0.97 | 0.70 | 0.58 | 0.48 | 0.53 | 0.68 | 0.59 | 1.02 | 0.58 | 0.35 |
| CaO | 1.87 | 1.78 | 0.87 | 0.15 | 0.43 | 0.18 | 0.07 | 0.03 | 0.00 | 0.01 |
| $Na_2O$ | 2.91 | 3.88 | 3.07 | 1.77 | 2.65 | 2.47 | 2.02 | 0.28 | 0.19 | 0.09 |
| $K_2O$ | 4.38 | 4.81 | 5.15 | 5.20 | 6.05 | 5.21 | 5.36 | 5.59 | 5.85 | 3.81 |
| $P_2O_5$ | 0.24 | 0.20 | 0.18 | 0.08 | 0.18 | 0.10 | 0.06 | 0.05 | 0.04 | 0.075 |
| $TiO_2$ | 0.81 | 0.64 | 0.58 | 0.59 | 0.58 | 0.70 | 0.66 | 0.81 | 0.72 | 0.82 |
| MnO | 0.13 | 0.05 | 0.08 | 0.07 | 0.06 | 0.06 | 0.06 | 0.08 | 0.03 | 0.04 |
| $H_2O+$ | 1.52 | 1.26 | 1.10 | 1.68 | 1.29 | 1.94 | 2.11 | 3.86 | 3.88 | 5.92 |
| $CO_2$ | 1.00 | 1.13 | 0.03 | <.03 | <.03 | <.03 | 0.03 | <.03 | <.03 | 0.03 |
| | | | | | | | | | | |
| Total | 99.80 | 99.79 | 100.33 | 99.02 | 99.39 | 99.06 | 99.58 | 98.88 | 98.84 | 82.715 |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Diabase Locality Tatuí, São Paulo

| Sample Number | 321 | 322 | 323 Inner | 323 Middle | 323 Outer | 324 | 324A | 324B | 325 | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49.80 | 48.84 | 49.97 | 41.75 | 27.24 | 41.77 | 31.43 | 44.24 | 38.44 | |
| $Al_2O_3$ | 14.00 | 13.55 | 11.76 | 16.66 | 23.98 | 20.27 | 22.02 | 15.88 | 23.82 | |
| Total Iron | 14.46 | 15.16 | 15.96 | 21.59 | 28.83 | 21.34 | 26.00 | 17.58 | 22.35 | |
| $Fe_2O_3$ | 2.93 | 7.06 | 6.10 | 16.10 | 25.00 | 17.97 | 21.73 | 10.22 | 20.21 | |
| FeO | 10.39 | 7.30 | 8.88 | 4.95 | 3.45 | 3.04 | 3.85 | 6.63 | 1.93 | |
| MgO | 6.04 | 5.83 | 4.21 | 2.50 | 0.76 | 1.27 | 1.56 | 4.21 | 0.36 | |
| CaO | 10.52 | 9.38 | 9.17 | 4.61 | 0.71 | 0.47 | 1.24 | 6.50 | 0.20 | |
| $Na_2O$ | 2.40 | 2.06 | 2.50 | 1.39 | 0.19 | 0.30 | 0.40 | 1.49 | - | |
| $K_2O$ | 1.11 | 1.09 | 1.37 | 1.37 | 0.52 | 1.07 | 0.90 | 1.21 | 0.05 | |
| $P_2O_5$ | 0.30 | 0.31 | 0.44 | 0.55 | 0.66 | 0.21 | 0.62 | 0.39 | 0.18 | |
| $TiO_2$ | 2.34 | 2.43 | 3.15 | 4.28 | 5.73 | 3.51 | 4.50 | 3.02 | 3.89 | |
| MnO | 0.22 | 0.23 | 0.27 | 0.22 | 0.19 | 0.29 | 0.17 | 0.20 | 0.14 | |
| $H_2O+$ | 0.49 | 1.41 | 0.46 | 3.85 | 8.49 | 7.61 | 7.19 | 3.46 | 9.58 | |
| $CO_2$ | 0.12 | 0.11 | 0.21 | 0.15 | 0.15 | 0.15 | 0.15 | 0.15 | 0.13 | |
| | | | | | | | | | | |
| Total | 100.66 | 99.60 | 98.49 | 98.38 | 97.07 | 97.93 | 95.76 | 97.60 | 98.93 | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Black Shale and dolomite (329) Locality Tatuí, São Paulo

| Sample Number | 326 | 327 | 328 | 329 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 68.5 | 67.3 | 56.9 | 10.5 | | | | | | |
| $Al_2O_3$ | 13.14 | 16.51 | 7.87 | 2.35 | | | | | | |
| Total Iron | 6.95 | 4.71 | 7.56 | 2.42 | | | | | | |
| $Fe_2O_3$ | 6.58 | 4.43 | 6.31 | 1.73 | | | | | | |
| FeO | 0.33 | 0.25 | 1.13 | 0.62 | | | | | | |
| MgO | 1.21 | 1.11 | 1.72 | 13.99 | | | | | | |
| CaO | 0.27 | 0.04 | 2.27 | 28.25 | | | | | | |
| $Na_2O$ | 0.17 | - | 1.78 | 0.21 | | | | | | |
| $K_2O$ | 2.01 | 1.50 | 2.31 | 0.31 | | | | | | |
| $P_2O_5$ | 0.33 | 0.14 | 0.34 | 0.11 | | | | | | |
| $TiO_2$ | 0.72 | 0.56 | 0.46 | 0.10 | | | | | | |
| MnO | - | - | 0.03 | 1.65 | | | | | | |
| $H_2O+$ | 4.80 | 6.19 | 4.49 | 1.46 | | | | | | |
| $CO_2$ | 0.08 | 0.13 | 0.13 | 34.47 | | | | | | |
| | | | | | | | | | | |
| Total | 98.14 | 98.16 | 85.74* | 98.18 | | | | | | |

Comments: * 328 is a black, powdery shale which gave off a strong sulfur odor when fused in the Penfield tube during determination of $H_2O+$. The low total is probably due to sulfur which was not determined.

RESULTS OF CHEMICAL ANALYSES

Rock Type Basalt Locality Serra Geral, Torro de Pedra, São Paulo

| Sample Number | 330 Inner | 330 Middle | 330 Outer | 331A | 331B | 331C | 332 | 333 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 51.7 | 51.7 | 50.1 | 49.9 | 50.0 | 48.9 | 48.3 | 48.9 | | |
| $Al_2O_3$ | 13.39 | 13.35 | 13.85 | 13.95 | 13.86 | 14.55 | 15.75 | 14.80 | | |
| Total Iron | 13.38 | 13.50 | 14.46 | 14.81 | 14.31 | 15.94 | 15.21 | 14.57 | | |
| $Fe_2O_3$ | 6.81 | 7.10 | 8.57 | 8.87 | 8.02 | 10.51 | 10.48 | 9.82 | | |
| FeO | 5.92 | 5.77 | 5.31 | 5.35 | 5.67 | 4.89 | 4.26 | 4.28 | | |
| MgO | 4.14 | 4.09 | 4.07 | 3.88 | 4.06 | 3.37 | 3.19 | 3.75 | | |
| CaO | 7.72 | 7.40 | 6.02 | 5.66 | 6.17 | 4.72 | 3.96 | 6.76 | | |
| $Na_2O$ | 2.56 | 2.84 | 1.73 | 1.72 | 1.90 | 1.72 | 1.38 | 2.03 | | |
| $K_2O$ | 1.95 | 2.05 | 2.00 | 2.04 | 2.06 | 2.22 | 1.95 | 0.97 | | |
| $P_2O_5$ | 0.52 | 0.51 | 0.54 | 0.52 | 0.51 | 0.49 | 0.43 | 0.55 | | |
| $TiO_2$ | 3.84 | 3.76 | 4.02 | 4.03 | 3.89 | 4.41 | 3.88 | 4.00 | | |
| MnO | 0.14 | 0.17 | 0.18 | 0.20 | 0.19 | 0.23 | 0.18 | 0.22 | | |
| $H_2O+$ | 1.09 | 1.04 | 2.55 | 2.79 | 2.50 | 3.49 | 4.71 | 2.83 | | |
| $CO_2$ | 0.12 | 0.10 | 0.12 | 0.14 | 0.12 | 0.10 | 0.13 | 0.10 | | |
| | | | | | | | | | | |
| Total | 99.90 | 99.88 | 99.06 | 99.05 | 98.95 | 99.60 | 98.60 | 99.01 | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Granite Locality São Roque, São Paulo

| Sample Number | 338 | 338A | 339A | 339B | 340 | 341 | 342 | 343 | 344 | 345 |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 73.8 | 74.3 | 67.3 | 67.0 | 71.0 | 67.5 | 66.0 | 65.2 | 67.5 | 66.9 |
| $Al_2O_3$ | 13.90 | 13.83 | 14.19 | 13.98 | 13.22 | 15.09 | 15.07 | 15.00 | 14.25 | 15.38 |
| Total Iron | 1.11 | 0.81 | 4.01 | 4.36 | 3.01 | 3.75 | 4.47 | 4.58 | 3.97 | 3.34 |
| $Fe_2O_3$ | 0.28 | 0.35 | 1.36 | 1.37 | 1.27 | 1.94 | 2.47 | 2.57 | 2.31 | 1.50 |
| FeO | 0.75 | 0.41 | 2.39 | 2.69 | 1.57 | 1.63 | 1.80 | 1.81 | 1.50 | 1.66 |
| MgO | 0.12 | 0.08 | 1.43 | 1.31 | 1.01 | 1.21 | 1.51 | 1.43 | 1.20 | 0.96 |
| CaO | 0.88 | 0.78 | 1.66 | 2.49 | 0.43 | 0.78 | 0.49 | 0.94 | 0.53 | 0.28 |
| $Na_2O$ | 4.39 | 3.25 | 3.20 | 3.71 | 3.31 | 3.32 | 2.04 | 1.94 | 1.85 | 0.88 |
| $K_2O$ | 4.22 | 5.56 | 4.86 | 5.10 | 4.60 | 4.96 | 5.19 | 5.40 | 5.37 | 8.41 |
| $P_2O_5$ | 0.07 | 0.04 | 0.27 | 0.24 | 0.17 | 0.19 | 0.15 | 0.17 | 0.11 | 0.05 |
| $TiO_2$ | 0.05 | 0.06 | 0.68 | 0.63 | 0.62 | 0.61 | 0.78 | 0.79 | 0.69 | 0.49 |
| MnO | 0.05 | 0.08 | 0.05 | 0.09 | 0.05 | 0.08 | 0.06 | 0.08 | 0.08 | 0.05 |
| $H_2O+$ | 0.54 | 1.14 | 0.98 | 0.54 | 1.47 | 1.60 | 2.45 | 2.58 | 2.18 | 1.92 |
| $CO_2$ | 0.23 | 0.10 | 0.31 | 0.51 | 0.05 | 0.05 | 0.03 | 0.03 | 0.05 | 0.07 |
| | | | | | | | | | | |
| Total | 99.28 | 99.98 | 98.68 | 99.66 | 98.77 | 98.96 | 98.04 | 97.94 | 97.62 | 98.55 |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Granite Locality São Roque, São Paulo

| Sample Number | 346 | 346A | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 62.4 | 50.9 | | | | | | | | |
| $Al_2O_3$ | 18.20 | 24.86 | | | | | | | | |
| Total Iron | 4.41 | 5.95 | | | | | | | | |
| $Fe_2O_3$ | 3.87 | 5.15 | | | | | | | | |
| FeO | 0.49 | 0.72 | | | | | | | | |
| MgO | 0.95 | 1.18 | | | | | | | | |
| CaO | 0.66 | 0.78 | | | | | | | | |
| $Na_2O$ | 0.63 | 0.74 | | | | | | | | |
| $K_2O$ | 4.81 | 4.27 | | | | | | | | |
| $P_2O_5$ | 0.07 | 0.10 | | | | | | | | |
| $TiO_2$ | 0.71 | 0.86 | | | | | | | | |
| MnO | 0.06 | 0.05 | | | | | | | | |
| $H_2O+$ | 4.77 | 8.78 | | | | | | | | |
| $CO_2$ | 0.07 | 0.07 | | | | | | | | |
| | | | | | | | | | | |
| Total | 97.69 | 98.46 | | | | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Granite Locality Itapevi, São Paulo

| Sample Number | 347 | 348 | 349 | 350 | 351 | 352 | 353 | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 71.46 | 68.10 | 69.90 | 68.22 | 58.07 | 66.68 | 64.21 | | | |
| $Al_2O_3$ | 14.22 | 15.60 | 15.53 | 18.06 | 19.45 | 17.86 | 18.41 | | | |
| Total Iron | 2.91 | | | 2.40 | | | 3.87 | | | |
| $Fe_2O_3$ | 0.67 | 1.21 | 1.28 | 1.67 | 4.76 | 3.60 | 3.44 | | | |
| FeO | 2.02 | 2.47 | 1.45 | 0.66 | 0.65 | 0.27 | 0.39 | | | |
| MgO | 0.40 | 0.53 | 0.47 | 0.38 | 1.97 | 0.11 | 0.10 | | | |
| CaO | 1.45 | 0.02 | 0.05 | 0.02 | 0.01 | 0.01 | 0.02 | | | |
| $Na_2O$ | 3.12 | 0.20 | 0.38 | 0.19 | 0.17 | 0.05 | 0.06 | | | |
| $K_2O$ * | 5.36 | 6.87 | 7.14 | 5.26 | 5.52 | 1.53 | 1.39 | | | |
| $P_2O_5$ | 0.07 | 0.10 | 0.08 | 0.07 | 0.17 | 0.06 | 0.06 | | | |
| $TiO_2$ | 0.31 | 0.46 | 0.40 | 0.40 | 0.93 | 0.65 | 0.61 | | | |
| MnO | 0.08 | 0.04 | 0.04 | 0.05 | 0.09 | 0.03 | 0.03 | | | |
| $H_2O+$ | 0.38 | 3.88 | 2.91 | 4.45 | 7.81 | 7.80 | 9.00 | | | |
| $CO_2$ | | | | | | | | | | |
| | | | | | | | | | | |
| Total | 99.54 | 99.50 | 99.79 | 99.96 | 99.60 | 98.30 | 97.72 | | | |

Comments: * Biotite present.

RESULTS OF CHEMICAL ANALYSES

Rock Type Gneiss Locality Mongongua, São Paulo

| Sample Number | 365 | 366 | 367 | 368 | 369 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 68.1 | 69.9 | 65.6 | 62.5 | 59.7 | | | | | |
| $Al_2O_3$ | 14.53 | 14.48 | 16.71 | 18.27 | 20.90 | | | | | |
| Total Iron | 4.89 | 3.76 | 4.61 | 5.24 | 4.86 | | | | | |
| $Fe_2O_3$ | 3.03 | 2.48 | 3.41 | 3.96 | 4.28 | | | | | |
| FeO | 1.68 | 1.15 | 1.08 | 1.15 | 0.52 | | | | | |
| MgO | 0.33 | 0.27 | 0.27 | 0.32 | 0.38 | | | | | |
| CaO | 2.14 | 1.26 | 0.19 | 0.27 | 0.07 | | | | | |
| $Na_2O$ | 3.32 | 2.98 | 0.83 | 0.94 | 0.43 | | | | | |
| $K_2O$ | 5.28 | 5.90 | 6.27 | 6.14 | 4.69 | | | | | |
| $P_2O_5$ | 0.12 | 0.08 | 0.01 | 0.02 | 0.02 | | | | | |
| $TiO_2$ | 0.55 | 0.42 | 0.49 | 0.53 | 0.64 | | | | | |
| MnO | 0.10 | 0.07 | 0.07 | 0.07 | 0.06 | | | | | |
| $H_2O+$ | 0.28 | 0.56 | 4.06 | 4.89 | 6.96 | | | | | |
| $CO_2$ | 0.18 | 0.08 | 0.05 | 0.05 | 0.03 | | | | | |
| | | | | | | | | | | |
| Total | 99.64 | 99.63 | 99.04 | 99.11 | 98.68 | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Vesicular Basalt Locality Ribeirão Preto, São Paulo

| Sample Number | 377 | 378 | 379 | 380 | 381 | 382 | 383 | 384 | (cont'd) | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 49.4 | 48.9 | 44.2 | 44.0 | 34.3 | 26.6 | 47.7 | 47.2 | | |
| $Al_2O_3$ | 12.46 | 12.92 | 15.97 | 17.55 | 24.08 | 25.80 | 16.85 | 16.08 | | |
| Total Iron | 15.39 | 15.05 | 18.28 | 19.16 | 22.58 | 25.41 | 17.82 | 17.79 | | |
| $Fe_2O_3$ | 7.36 | 9.00 | 15.53 | 16.07 | 22.20 | 22.09 | 15.40 | 15.33 | | |
| FeO | 7.23 | 5.45 | 2.48 | 2.78 | 0.34 | 2.99 | 2.18 | 2.22 | | |
| MgO | 4.18 | 3.71 | 1.83 | 1.90 | 0.40 | 0.33 | 1.63 | 1.88 | | |
| CaO | 8.11 | 7.03 | 2.77 | 1.52 | 0.29 | 0.23 | 1.51 | 2.02 | | |
| $Na_2O$ | 2.60 | 2.28 | 0.67 | 0.10 | - | 0.03 | 0.16 | 0.45 | | |
| $K_2O$ | 1.54 | 1.61 | 0.38 | 0.64 | 0.18 | 0.14 | 0.83 | 1.02 | | |
| $P_2O_5$ | 0.47 | 0.55 | 0.61 | 0.68 | 0.32 | 0.24 | 0.51 | 0.59 | | |
| $TiO_2$ | 3.60 | 3.61 | 4.50 | 4.77 | 5.35 | 6.41 | 4.15 | 4.29 | | |
| MnO | 0.21 | 0.19 | 0.20 | 0.25 | 0.11 | 0.17 | 0.19 | 0.22 | | |
| $H_2O+$ | 1.08 | 1.89 | 6.40 | 7.77 | 10.9 | 11.5 | 7.46 | 6.65 | | |
| $CO_2$ | 0.04 | - | 0.03 | 0.02 | 0.03 | - | 0.07 | - | | |
| | | | | | | | | | | |
| Total | 98.28 | 97.14 | 95.57 | 98.05 | 98.50 | 96.53 | 98.64 | 97.95 | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Vesicular Basalt Locality Ribeirão Preto, São Paulo

| Sample Number | 385 | 385A | 385B | 386 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 40.6 | 37.7 | 38.4 | 39.2 | | | | | | |
| $Al_2O_3$ | 19.91 | 20.61 | 20.88 | 19.82 | | | | | | |
| Total Iron | 20.53 | 20.63 | 20.47 | 22.03 | | | | | | |
| $Fe_2O_3$ | 17.77 | 17.56 | 17.66 | 18.32 | | | | | | |
| FeO | 2.49 | 2.77 | 2.53 | 3.34 | | | | | | |
| MgO | 1.96 | 1.73 | 1.74 | 1.09 | | | | | | |
| CaO | 0.90 | 0.82 | 0.78 | 0.73 | | | | | | |
| $Na_2O$ | - | - | - | 0.03 | | | | | | |
| $K_2O$ | 0.22 | 0.30 | 0.32 | 0.27 | | | | | | |
| $P_2O_5$ | 0.30 | 0.32 | 0.33 | 0.41 | | | | | | |
| $TiO_2$ | 4.94 | 4.92 | 4.50 | 5.65 | | | | | | |
| MnO | 0.19 | 0.22 | 0.25 | 0.25 | | | | | | |
| $H_2O+$ | 9.02 | 9.97 | 9.87 | 9.13 | | | | | | |
| $CO_2$ | - | - | - | - | | | | | | |
| | | | | | | | | | | |
| Total | 98.30 | 96.92 | 97.26 | 98.24 | | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Pegmatite and Mica schist host rock  Locality Pedreira Sabeu, Billings Reservoir, São Paulo

| Sample Number | 387 | 388 | 389 | 390 | 392 | 393 | 394 | 395 | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 53.3 | 55.0 | 55.2 | 51.1 | 54.5 | 52.5 | 58.4 | 50.5 | | |
| $Al_2O_3$ | 22.98 | 22.73 | 21.37 | 33.48 | 23.17 | 24.32 | 19.99 | 24.41 | | |
| Total Iron | 10.9 | 9.03 | 11.6 | 0.64 | 9.35 | 9.64 | 10.3 | 10.6 | | |
| $Fe_2O_3$ | 10.6 | 8.89 | 11.6 | - | - | 9.64 | 10.2 | 10.3 | | |
| FeO | 0.25 | 0.13 | 0.02 | * | * | - | 0.05 | 0.25 | | |
| MgO | 0.42 | 0.23 | 0.19 | 0.10 | 0.34 | 0.50 | 0.17 | 0.47 | | |
| CaO | 0.03 | 0.04 | 0.02 | - | 0.02 | 0.02 | - | 0.05 | | |
| $Na_2O$ | 0.19 | 0.11 | 0.10 | 0.09 | 0.56 | 0.53 | 0.18 | 0.31 | | |
| $K_2O$ | 2.86 | 1.44 | 0.69 | 2.39 | 4.03 | 3.99 | 1.81 | 1.89 | | |
| $P_2O_5$ | 0.23 | 0.75 | 0.29 | 0.05 | 0.12 | 0.10 | 0.11 | 0.04 | | |
| $TiO_2$ | 1.12 | 0.99 | 0.85 | 0.01 | 1.01 | 1.09 | 0.90 | 1.23 | | |
| MnO | 0.02 | 0.03 | 0.45 | 0.28 | 0.37 | 0.48 | 0.15 | 0.15 | | |
| $H_2O+$ | 6.36 | 7.81 | 8.15 | 9.25 | 4.37 | 4.58 | 5.94 | 7.72 | | |
| $CO_2$ | 0.03 | 0.03 | 0.05 | 0.03 | 0.05 | 0.04 | 0.04 | <0.03 | | |
| | | | | | | | | | | |
| Total | 98.39 | 98.18 | 98.98 | 97.42 | 97.89 | 97.79 | 97.94 | 97.34 | | |

Comments: * FeO could not be dermined. Solution turned purple before titration.

RESULTS OF CHEMICAL ANALYSES

Rock Type Olivine Gabbro Locality Curucutu, São Paulo

| Sample Number | 396 | 397 | 398 | 399 | 400 | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 3.43 | 5.49 | 25.4 | 48.5 | 47.6 | | | | | |
| $Al_2O_3$ | 43.9 | 51.0 | 35.5 | 15.8 | 15.5 | | | | | |
| Total Iron | 26.9 | 19.89 | 23.9 | 8.35 | 9.33 | | | | | |
| $Fe_2O_3$ | 26.2 | 19.56 | 23.8 | 0.51 | 2.96 | | | | | |
| FeO | 0.68 | 0.30 | 0.09 | 7.06 | 5.74 | | | | | |
| MgO | 0.81 | 0.04 | 0.08 | 12.09 | 11.28 | | | | | |
| CaO | 0.03 | - | 0.01 | 12.73 | 12.66 | | | | | |
| $Na_2O$ | 0.04 | - | 0.02 | 1.57 | 1.36 | | | | | |
| $K_2O$ | 0.02 | 0.02 | 0.02 | 0.11 | 0.12 | | | | | |
| $P_2O_5$ | 0.11 | 0.07 | 0.03 | 0.03 | 0.03 | | | | | |
| $TiO_2$ | 1.53 | 1.08 | 1.31 | 0.47 | 0.61 | | | | | |
| MnO | 0.05 | 0.03 | 0.18 | 0.14 | 0.14 | | | | | |
| $H_2O+$ | 23.1 | 20.5 | 14.3 | 0.58 | 1.55 | | | | | |
| $CO_2$ | 0.15 | 0.12 | 0.14 | 0.18 | 0.15 | | | | | |
| | | | | | | | | | | |
| Total | 100.05 | 98.21 | 100.88 | 99.77 | 99.70 | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Metadiorite (?) or Metagabbro (?) Locality Pedreira do Dom Miguel, Evangelista de Souza, S.P.

| Sample Number | 401 | 402 | 403 | 404 | 405 | 406 | 407 | 408 | 409 | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 47.08 | 14.16 | 26.16 | 6.80 | 21.11 | 33.00 | 31.36 | 29.43 | 6.02 | |
| $Al_2O_3$ | 14.17 | 40.15 | 35.11 | 42.11 | 42.13 | 36.67 | 40.05 | 30.87 | 56.01 | |
| Total Iron | | | | | | | | | | |
| $Fe_2O_3$ | 0.83 | 20.03 | 17.83 | 24.71 | 12.76 | 12.89 | 7.82 | 19.85 | 5.36 | |
| FeO | 7.86 | 0.72 | 0.58 | 0.58 | 0.53 | 0.08 | 0.42 | 0.71 | 0.13 | |
| MgO | 13.54 | 1.60 | 1.95 | 0.85 | 0.57 | 0.11 | 0.23 | 0.29 | 0.11 | |
| CaO | 12.61 | 0.84 | 0.78 | 0.04 | 0.03 | 0.02 | 0.01 | <0.005 | <0.005 | |
| $Na_2O$ | 1.46 | 0.08 | 0.07 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | <0.02 | |
| $K_2O$ | 0.48 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | <0.05 | |
| $P_2O_5$ | 0.04 | 0.12 | 0.11 | 0.15 | 0.08 | 0.06 | 0.04 | 0.05 | 0.02 | |
| $TiO_2$ | 0.45 | 0.94 | 0.92 | 1.52 | 1.43 | 1.18 | 1.29 | 1.63 | 0.36 | |
| MnO | 0.09 | 0.01 | 0.16 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | |
| $H_2O+$ | 1.41 | 21.94 | 17.10 | 23.56 | 21.94 | 16.66 | 18.78 | 16.90 | 31.36 | |
| $CO_2$ | | | | | | | | | | |
| | | | | | | | | | | |
| Total | 100.02 | 100.59 | 100.77 | 100.32 | 100.57 | 100.67 | 99.77 | 99.73 | 99.36 | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Oil Shale Locality Pindamonhagaba, São Paulo

| Sample Number | 418 | 419 | 420 | 421 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 38.6 | 46.2 | 48.5 | 56.8 | | | | | | |
| $Al_2O_3$ | 17.4 | 19.4 | 18.7 | 17.4 | | | | | | |
| Total Iron | 7.80 | 10.09 | 12.29 | 8.68 | | | | | | |
| $Fe_2O_3$ | 4.93 | 6.14 | * | 7.70 | | | | | | |
| FeO | 2.59 | 3.56 | * | 0.88 | | | | | | |
| MgO | 1.50 | 2.04 | 1.54 | 1.89 | | | | | | |
| CaO | 0.53 | 1.25 | 0.19 | 1.46 | | | | | | |
| $Na_2O$ | 0.30 | 0.23 | 0.30 | 0.23 | | | | | | |
| $K_2O$ | 2.49 | 2.69 | 2.50 | 2.90 | | | | | | |
| $P_2O_5$ | 0.13 | 0.38 | 0.12 | 0.65 | | | | | | |
| $TiO_2$ | 0.86 | 0.95 | 0.92 | 0.80 | | | | | | |
| MnO | 0.12 | 0.27 | 0.23 | 0.05 | | | | | | |
| $H_2O+$ | 13.8 † | 10.8 | 6.9 | 7.0 | | | | | | |
| $CO_2$ | 0.16 | 1.73 | 0.16 | 0.13 | | | | | | |
| Loss on Ignition | 30.0 | 12.8 | 15.8 | 8.7 | | | | | | |
| Total** | 83.41 | 95.64 | 92.35 | 97.89 | | | | | | |

Comments:
* FeO could not be determined due to interference by black organic matter.
** Not including loss on ignition.
† Average of five determinations.

RESULTS OF CHEMICAL ANALYSES

Rock Type Diabase Locality Jaguariuna, São Paulo

| Sample Number | 430 | 431 | 431R | 432 | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 47.1 | 49.9 | 49.4 | 37.6 | | | | | | |
| $Al_2O_3$ | 15.9 | 13.8 | 13.7 | 24.4 | | | | | | |
| Total Iron | 17.1 | 14.2 | 15.4 | 20.9 | | | | | | |
| $Fe_2O_3$ | 12.6 | 4.11 | 7.44 | 19.0 | | | | | | |
| FeO | 4.07 | 9.09 | 7.17 | 1.68 | | | | | | |
| MgO | 3.76 | 6.18 | 5.37 | 0.39 | | | | | | |
| CaO | 5.01 | 10.06 | 8.86 | 0.32 | | | | | | |
| $Na_2O$ | 1.36 | 2.29 | 2.18 | 0.04 | | | | | | |
| $K_2O$ | 0.98 | 0.93 | 1.02 | 0.14 | | | | | | |
| $P_2O_5$ | 0.27 | 0.33 | 0.35 | 0.19 | | | | | | |
| $TiO_2$ | 2.84 | 2.35 | 2.53 | 3.19 | | | | | | |
| MnO | 0.25 | 0.20 | 0.18 | 0.10 | | | | | | |
| $H_2O+$ | 5.63 | 0.59 | 1.55 | 11.35 | | | | | | |
| $CO_2$ | 0.09 | 0.04 | 0.05 | 0.06 | | | | | | |
| | | | | | | | | | | |
| Total | 99.93 | 99.94 | 99.87 | 98.51 | | | | | | |

Comments:

RESULTS OF CHEMICAL ANALYSES

Rock Type Cascavel Pegmatite Locality Gov. Valadares, Minas Gerais

| Sample Number | CP-1 | CP-2 | CP-3 | CP-4 | CP-5 | CP-6 | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| $SiO_2$ | 64.8 | 65.4 | 65.3 | 65.3 | 65.3 | 65.3 | | | | |
| $Al_2O_3$ | 18.89 | 19.28 | 19.03 | 19.18 | 19.18 | 21.47 | | | | |
| Total Iron | - | - | 0.1 | 0.1 | 0.61 | 1.47 | | | | |
| $Fe_2O_3$ | - | - | - | - | 0.53 | 1.34 | | | | |
| FeO | - | - | not det'm | not det'm | 0.07 | 0.12 | | | | |
| MgO | 0.01 | 0.01 | 0.01 | - | <0.01 | 0.03 | | | | |
| CaO | 0.10 | 0.01 | 0.05 | - | - | 0.44 | | | | |
| $Na_2O$ | 2.32 | 2.74 | 2.77 | 2.66 | 2.99 | 10.06 | | | | |
| $K_2O$ | 13.10 | 12.32 | 12.33 | 12.38 | 12.02 | 0.88 | | | | |
| $P_2O_5$ | 0.10 | 0.08 | 0.11 | 0.07 | 0.16 | 0.11 | | | | |
| $TiO_2$ | <0.01 | - | 0.01 | - | - | 0.01 | | | | |
| MnO | - | - | - | - | - | - | | | | |
| $H_2O+$ | 0.13 | 0.17 | 0.19 | 0.19 | 0.13 | 0.60 | | | | |
| $CO_2$ | 0.06 | 0.06 | 0.06 | 0.03 | 0.06 | 0.03 | | | | |
| | | | | | | | | | | |
| Total | 99.51 | 100.07 | 99.95 | 99.91 | 100.44 | 100.39 | | | | |

Comments:

# APPENDIX D

## Powder Density, Bulk Density, Cation Exchange Capacity, Surface Area and Abrasion pH

Powder densities were determined using a Beckman Air Comparison Pycnometer on the same crushed, ground and air-dried material used for chemical analysis. If oven-dried samples were used (110°C), results were poor and unreproducible; more consistent results were obtained on unheated, air-dried material. Bulk density of coherent samples were determined using the mercury balance method described in Clemency (1972). Samples that were incoherent powders or soils, of course, could not be run for bulk density. Such incoherent samples are marked with an asterisk (*) in the bulk density column. Both powder and bulk density figures are expressed as grams per cubic centimeter.

Cation exchange capacities were determined by the method of Busenberg and Clemency (1973) using the ammonia specific ion electrode. Results are expressed as milliequivalents per 100 grams of material. In general, only one sample was run (not duplicates).

Surface areas were determined using the single-point BET method at 25°C on a Quantachrome Monosorb Model MS-3 instrument. Results are expressed in square meters per gram.

Abrasion pH was determined by stirring 5 g of ground sample in 5 ml distilled water, allowing to stand for ten minutes, stir and read pH with a standard pH meter and electrode.

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 8-20-1 | 2.58 | 2.48 | | - | - |
| -2 | 2.61 | * | 0.94 | - | - |
| -3 | 2.58 | 1.29 | 2.39 | - | - |
| -4 | 2.58 | 1.46 | 2.30 | - | - |
| -5 | 2.63 | 1.74 | 2.04 | - | - |
| -6 | 2.82 | 1.34 | 9.08 | - | - |
| -7 | 2.79 | 1.16 | 8.15 | - | - |
| -8 | 2.82 | 1.12 | 5.77 | - | - |
| -9 | 2.79 | 1.31 | 3.67 | - | - |
| -10 | 2.77 | 1.52 | 3.43 | - | - |
| -11 | 2.70 | 1.65 | | - | - |
| -12 | 2.63 | 2.54 | | - | - |
| -13 | 2.55 | 1.79 | 0.40 | - | - |
| -14 | 2.61 | 2.55 | | - | - |
| -15 | 2.54 | 1.43 | | - | - |
| -16 | 2.58 | 1.48 | 3.11 | - | - |
| -17 | 2.85 | 0.96 | 10.86 | - | - |
| -18 | 2.62 | 2.62 | 0.65 | - | - |
| -19 | 2.55 | 2.54 | | - | - |
| -20 | 2.62 | 2.60 | | - | - |
| -21 | 2.61 | 1.93 | | - | - |
| 8-22-1 | 2.62 | 2.60 | 0.86 | | |
| 8-22-12 | 2.74 | 2.63 | 6.21 | 8.2 | - |
| -13 | 2.83 | 2.10 | 6.12 | 6.2 | - |
| -14 | 2.95 | 1.68 | 2.86 | 6.2 | - |
| -15 | 2.91 | 2.02 | 5.99 | 5.8 | - |
| -16 | 2.85 | | 6.66 | 5.6 | - |
| -17 | 2.92 | 1.67 | 6.65 | 5.7 | - |
| -18 | 2.88 | 1.65 | 5.56 | 5.6 | - |
| -19 | 2.63 | 2.60 | 9.61 | 7.8 | - |
| -20 | 2.75 | 1.02 | 4.15 | 5.0 | - |
| -21 | 2.85 | * | 6.57 | 5.4 | - |
| 17-6 | 2.76 | 2.70 | 12.1 | 9.6 | - |
| 17-7 | 2.60 | 2.50 | 18.2 | 9.9 | - |
| 8-22-22B | | | | | |
| Fresh | 2.73 | 2.62 | 3.20 | 9.8 | |
| Inner | 2.70 | No sample | 0.30 | 4.5 | |
| Middle | 2.72 | " | 0.54 | 5.6 | |
| Outer | 2.79 | 1.10 | 0.72 | 5.6 | |

* incoherent sample (powder)

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 8-22-23 | 2.50 | 2.48 | 3.97 | | |
| -23A | 2.53 | 2.07 | 0.87 | | |
| -24 | 2.35 | 1.83 | 7.33 | | |
| -24A | 2.46 | * | 7.07 | | |
| -24B | 2.44 | * | 3.13 | | |
| -25 | 2.47 | 1.07 | 1.03 | | |
| -26 | 2.48 | 1.08 | 0.88 | | |
| -27 | 2.51 | 2.47 | 3.01 | | |
| 53 | 2.68 | 2.12 | 7.90 | 5.0 | - |
| 54 | 2.62 | 1.99 | 8.16 | 5.3 | - |
| 55 | 2.67 | 3.19 | 8.15 | 5.8 | - |
| 56 | 2.65 | 1.75 | 16.4 | 5.3 | - |
| 57 | 2.64 | 1.55 | 19.1 | 4.6 | - |
| 58 | 2.64 | 1.38 | 10.2 | 5.0 | - |
| 59 | 2.78 | 2.75 | 1.15 | 9.7 | - |
| 60 | 2.75 | 2.66 | 1.39 | 8.4 | - |
| 61 | 2.70 | 2.23 | 2.11 | 6.7 | - |
| 62 | 2.72 | 2.31 | 2.89 | 6.8 | - |
| 63 | 2.69 | 2.23 | 2.79 | 6.3 | - |
| 64 | 2.77 | 1.47 | 6.1 | 5.4 | - |
| 65 | 2.69 | * | | - | - |
| 66 | 2.67 | 2.44 | | - | - |
| 67 | 2.67 | 2.42 | | - | - |
| 68 | 2.66 | 2.31 | | - | - |
| 69 | 2.63 | 2.27 | | - | - |
| 70 | 2.64 | 2.38 | | - | - |
| 71 | 2.63 | 2.21 | | - | - |
| 72 | 2.60 | 2.28 | | - | - |
| 75 Fresh | 3.02 | 2.97 | 4.63 | 7.0 | - |
| 75 Inner | 2.90 | * | 9.01 | 6.0 | - |
| 75 Outer | 3.03 | * | 5.43 | 6.7 | - |
| 76 | 2.88 | 1.79 | 11.5 | 6.1 | - |
| 77 | 3.03 | 1.42 | 4.12 | 6.5 | - |
| 78 | 3.18 | 1.28 | 2.72 | 7.0 | - |

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 90 | 2.63 | 2.55 | | | - |
| 91 | 2.70 | 2.69 | | | - |
| 92 | 2.71 | 2.48 | | | - |
| 93 | 2.63 | 2.38 | 1.21 | | - |
| 94 | 2.65 | 2.09 | 1.82 | | - |
| 95 | 2.64 | 1.93 | 2.37 | | - |
| 96 | 2.68 | 2.55 | | | - |
| 97 | 2.66 | 1.33 | 3.26 | | - |
| 99A | 2.64 | 2.63 | | | - |
| 99B | 2.62 | 2.57 | | | - |
| 100 | 2.85 | 2.77 | 0.93 | 6.7 | |
| 101 | 2.84 | 2.24 | 0.57 | 6.0 | |
| 103 | 2.86 | 2.78 | 0.96 | 6.9 | |
| 104 | 2.74 | 2.71 | 0.46 | 6.9 | |
| 105 | 2.77 | 1.75 | 1.09 | 5.0 | |
| 106 | 2.76 | 1.41 | 1.64 | 4.5 | |
| 107 | 2.86 | 1.30 | 4.36 | 4.6 | |
| 108 | 2.85 | 1.41 | 4.97 | 4.8 | |
| 109 | 2.62 | 1.50 | 1.71 | 5.4 | |
| 110 | 2.62 | 1.45 | 1.50 | 4.8 | - |
| 110A | 2.68 | 1.52 | 4.65 | 5.3 | - |
| 111 | 2.63 | 1.41 | 2.59 | 5.1 | - |
| 112 | 2.63 | 1.61 | 3.24 | 5.1 | - |
| 113 | 2.66 | 1.49 | 6.40 | 5.0 | - |
| 114 | 2.63 | 2.57 | 0.40 | 6.1 | - |
| 136 | 2.94 | 1.90 | 34.5 | 6.0 | |
| 137A | 3.00 | 2.18 | 19.0 | 6.6 | |
| 137B | 2.91 | 1.92 | 27.3 | 6.5 | |
| 138 | 2.95 | 2.52 | 13.3 | 7.7 | |
| 139 | 2.97 | 2.86 | 10.8 | 8.3 | |
| 140 | 2.98 | 2.87 | 9.1 | 8.5 | |
| 141 | 2.98 | 2.91 | 6.6 | 9.2 | |
| 142 | 2.99 | 2.92 | 6.6 | 7.7 | |
| 151 | 2.77 | 2.08 | 34.6 | - | - |
| 152 | 2.83 | 1.88 | 59.7 | - | - |
| 153 | 2.78 | 1.74 | 8.86 | - | - |
| 154 | 2.99 | 1.69 | 16.3 | - | - |
| 154AR | 3.01 | 1.73 | 17.0 | - | - |
| 154AW | 2.83 | * | 29.7 | - | - |
| 155 | 2.73 | 1.69 | 6.87 | - | - |
| 156 | 2.89 | 1.62 | 10.3 | - | - |
| 157 | 3.05 | 1.61 | 11.3 | - | - |
| 158 | 2.99 | 1.46 | 9.90 | - | - |
| 159 | 2.95 | 1.38 | 8.47 | - | - |

(cont'd.)

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 160 | 2.95 | 1.20 | 3.34 | - | - |
| 161 | - | 1.93 | - | - | - |
| 163 | 2.92 | 1.93 | 23.9 | - | - |
| 164 | 2.87 | 1.99 | 29.7 | - | - |
| 165 | 2.79 | 1.96 | 31.7 | - | - |
| 166 | 2.42 | 1.74 | 58.7 | 6.0 | - |
| 167 | 2.63 | * | 5.8 | 5.4 | - |
| 168 | 2.76 | 1.54 | 5.8 | 5.9 | - |
| 169 Fine | 2.71 | 1.63 | 2.9 | 5.2 | - |
| 169 Coarse | - | 1.75 | - | - | - |
| 170 | 2.43 | 1.73 | 74.8 | 5.8 | - |
| 171 | 2.96 | 2.87 | 0.7 | 6.5 | - |
| 172A | 2.98 | 2.91 | 2.7 | 6.4 | - |
| 172B | 2.74 | 1.93 | 6.6 | 4.9 | - |
| 180 | 2.48 | 1.80 | 24.05 | | |
| 181 | 2.42 | 2.00 | 28.60 | | |
| 182 | 2.56 | 1.68 | 11.02 | | |
| 183 | 2.92 | 1.52 | 20.86 | | |
| 184 | 2.42 | 1.73 | 28.47 | | |
| 185 | 2.41 | 1.76 | 31.77 | | |
| 186 | 2.44 | 2.07 | | | |
| 187 | 2.78 | 2.69 | 0.62 | | |
| 188 | 2.68 | 2.24 | 2.67 | | |
| 189 | 2.65 | * | 1.33 | | |
| 190 | 2.63 | 1.50 | 1.79 | | |
| 192 | 2.61 | 1.52 | 14.44 | | |
| 193 | 2.66 | 1.60 | 3.82 | | |
| 194 | 2.70 | 1.51 | 4.01 | | |
| 195 | 2.63 | 1.48 | 2.46 | | |
| 196 | 2.55 | 2.50 | | | |
| 197 | 2.60 | 2.43 | | | |
| 198 | 2.62 | * | 41.11 | | |
| 199 | 2.75 | 2.73 | | | |
| 200 | 2.72 | 2.68 | - | - | |
| 201 | 2.86 | * | 7.2 | 7.2 | |
| 202 | 2.86 | * | 5.4 | 6.1 | |
| 203 | 2.82 | * | 3.4 | 6.1 | |
| 204 | 2.81 | * | 3.4 | 5.5 | |
| 205 | 2.79 | * | 4.8 | 5.9 | |
| 206 | 2.93 | * | 3.9 | 6.3 | |
| 207 | 2.99 | * | 5.1 | 5.3 | |
| 208 | 3.00 | * | 5.5 | 5.5 | |

(cont'd)

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 209 | 2.69 | 2.68 | - | - | |
| 210 | 2.69 | 2.69 | - | - | |
| 211 | 2.87 | * | 2.3 | 6.0 | |
| 212 | 2.85 | * | 1.4 | 4.8 | |
| 230 | 3.02 | 2.76 | 7.0 | 6.7 | |
| 231 | 2.90 | 1.81 | 17.9 | 6.6 | |
| 232 | 2.44 | 1.47 | 72.0 | 5.8 | |
| 233 | 2.30 | 1.54 | 94.3 | 4.9 | |
| 234 | 2.38 | 1.78 | 83.5 | 5.7 | |
| 235 | 2.60 | 1.88 | 32.0 | 5.1 | |
| 236 | 2.84 | 2.82 | 0.8 | 7.5 | |
| 237 | 2.69 | 2.61 | 10.4 | 6.8 | |
| 238 | 2.63 | 2.24 | 25.6 | 5.8 | |
| 239 | 2.66 | 1.29 | 12.4 | 5.2 | |
| 240 | 2.71 | 1.29 | 6.8 | 4.9 | |
| 241A | 2.64 | 2.61 | 3.03 | 9.0 | 1.95 |
| 241B | 2.64 | 2.60 | 2.80 | 9.0 | 2.62 |
| 241C | 2.63 | 2.52 | 3.20 | 7.6 | 3.64 |
| 241D | 2.64 | 2.13 | 2.93 | 7.1 | 5.33 |
| 241E | 2.63 | 2.07 | 2.76 | 6.8 | 5.76 |
| 241F | 2.66 | 1.95 | 3.93 | 6.6 | 7.19 |
| 241G | 2.65 | 1.90 | 2.70 | 6.3 | 8.01 |
| 241Hg | 2.69 | 1.87 | 2.96 | 5.2 | - |
| 241Hy | 2.69 | - | 3.53 | 5.4 | - |
| 241I | 2.68 | 1.54 | 5.90 | 5.4 | 12.45 |
| 241J | 2.69 | 1.55 | 4.45 | 4.7 | 10.9 |
| 244 | 2.84 | * | 0.52 | - | |
| 244AA | 2.85 | 2.85 | - | - | |
| 244AB | 2.85 | 2.84 | - | - | |
| 244AC | 2.83 | 2.84 | - | - | |
| 244AD | 2.85 | 2.73 | - | - | |
| 245 | 2.83 | 2.52 | 0.65 | - | |
| 246 | 2.74 | * | 5.2 | 5.5 | |
| 247 | 2.73 | * | 4.9 | 5.0 | |
| 248 | 2.73 | * | 1.9 | 6.1 | |
| 249 | - | 2.65 | | | |
| 249A | 2.84 | 2.84 | - | - | |
| 249B | 2.86 | 2.40 | - | - | |
| 250 | 2.79 | * | 0.17 | - | |
| 251 | 2.99 | 2.98 | 3.75 | 7.4 | |
| 252 | 2.94 | 2.86 | 8.71 | 7.0 | - |
| 253 | 2.68 | * | 21.2 | 5.8 | - |
| 254 | 2.58 | * | 22.5 | 5.7 | - |
| 255 | 2.47 | * | 21.4 | 5.6 | - |
| 256 | 2.75 | * | 20.2 | 5.7 | - |

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 260 | 2.79 | 2.75 | 0.7 | 9.2 | - |
| 262 | 2.78 | 2.47 | 1.9 | 5.6 | - |
| 263 | 2.77 | 2.24 | 3.0 | 6.0 | - |
| 264 | 2.77 | 1.98 | 3.0 | 5.8 | - |
| 265 | 2.77 | 1.28 | | | |
| 265A | 2.72 | 1.13 | | | |
| 266 | 2.73 | 2.06 | | | |
| 267G | 2.82 | 2.82 | | | |
| 267W | 2.75 | 2.81 | | | |
| 268 | 2.60 | 1.34 | | | |
| 269F | 3.06 | 3.03 | | | |
| 269W | 2.81 | * | 22.7 | | |
| 23-2 | 2.69 | 2.68 | 2.31 | - | - |
| 23-3 | 2.70 | 2.71 | 2.05 | - | - |
| 291 | - | 2.70 | - | - | - |
| 291WR | 2.64 | 2.70 | 2.62 | - | - |
| 292 | 2.73 | 2.65 | 2.61 | - | - |
| 293 | 2.71 | 2.54 | 2.45 | - | - |
| 294 | 2.64 | 2.09 | 5.22 | - | - |
| 295 | 2.65 | 2.37 | 3.27 | - | - |
| 296 | 2.67 | 2.14 | 7.95 | - | - |
| 297 | 2.73 | 1.47 | 8.34 | - | - |
| 302 | 3.05 | 2.97 | 4.10 | 8.6 | - |
| 303-A | 3.00 | 2.78 | 5.13 | 8.5 | - |
| 303B | 2.99 | 2.64 | 13.99 | 7.5 | - |
| 304 | 2.93 | 2.61 | 23.84 | 7.1 | - |
| 311 | 2.68 | 2.65 | 1.2 | 7.9 | - |
| 312 | 2.67 | 2.62 | 1.5 | 8.3 | - |
| 313 | 2.65 | 2.61 | 1.6 | 6.7 | - |
| 314 | 2.64 | 2.29 | 3.0 | 5.8 | - |
| 315 | 2.64 | 2.42 | 2.5 | 6.3 | - |
| 316 | 2.63 | 2.36 | 3.4 | 5.8 | - |
| 317 | 2.63 | 2.13 | 3.7 | 6.0 | - |
| 318 | 2.61 | 1.79 | 11.7 | 4.6 | - |
| 319 | 2.62 | * | 6.7 | 4.7 | - |
| 320 | 2.68 | 1.62 | 5.5 | 4.5 | - |
| 321 | 3.02 | 2.98 | 4.08 | 8.6 | - |
| 322 | 2.96 | 2.79 | 11.02 | 6.2 | - |
| 323 Inner | 3.00 | 2.80 | 3.58 | 6.1 | - |
| 323 Middle | 2.89 | | 11.13 | 5.6 | - |
| 323 Outer | 2.99 | - | 10.79 | 5.9 | - |
| 324 (cont'd) | 2.83 | 1.16 | 27.41 | 5.0 | - |

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 324A | 2.76 | 1.63 | 16.60 | 5.6 | - |
| 324B | 2.84 | - | 8.82 | 5.3 | - |
| 325 | 3.18 | 1.56 | 6.84 | 5.5 | - |
| 326 | 2.84 | 1.76 | 20.6 | 6.02 | - |
| 327 | 2.79 | 1.44 | 19.5 | 5.01 | - |
| 328 | 2.45 | 1.87 | 8.5 | 3.39 | - |
| 329 | 2.80 | 2.51 | 2.34 | - | - |
| 330 Inner | 2.90 | 2.78 | 11.7 | 7.51 | - |
| 330 Middle | 2.90 | 2.73 | 13.6 | 6.96 | - |
| 330 Outer | 2.88 | 2.59 | 18.9 | 6.04 | - |
| 331A | 2.84 | - | 19.2 | 6.99 | - |
| 331B | 2.84 | - | 16.8 | 6.99 | - |
| 331C | 2.87 | 2.47 | 23.8 | 6.70 | - |
| 332 | 2.85 | 2.16 | 30.3 | 6.74 | - |
| 333 | 2.80 | 1.97 | 48.9 | 6.84 | - |
| 338 | 2.64 | 2.61 | 3.1 | 7.4 | - |
| 338A | 2.61 | 2.93 | 3.7 | 5.9 | - |
| 339A | 2.71 | 2.68 | 3.6 | 8.7 | - |
| 339B | 2.71 | 2.66 | 3.6 | 8.9 | - |
| 340 | 2.66 | 2.41 | 4.2 | 5.8 | - |
| 341 | 2.65 | 2.45 | 2.8 | 5.8 | - |
| 342 | 2.65 | 2.40 | 5.6 | 5.4 | - |
| 343 | 2.65 | 2.30 | 4.8 | 5.5 | - |
| 344 | 2.65 | 2.11 | 3.8 | 5.5 | - |
| 345 | 2.64 | 1.97 | 2.1 | 5.8 | - |
| 346 | 2.72 | * | 4.5 | 5.3 | - |
| 346A | 2.78 | * | 0.8 | 4.6 | - |
| 347 | 2.65 | 2.60 | 1.0 | 7.9 | - |
| 348 | 2.64 | 2.04 | 2.7 | 5.7 | - |
| 349 | 2.64 | 1.86 | 1.7 | 6.1 | - |
| 350 | 2.59 | 1.54 | 1.9 | 5.2 | - |
| 351 | 2.64 | 1.48 | 7.9 | 4.6 | - |
| 352 | 2.67 | 1.40 | 3.6 | 4.5 | - |
| 353 | 2.66 | 1.58 | 3.4 | 4.7 | - |
| 365 | 2.68 | 2.62 | | - | - |
| 366 | 2.66 | 2.47 | | - | - |
| 367 | 2.64 | 2.06 | | - | - |
| 368 | 2.64 | 2.10 | 1.19 | - | - |
| 369 | 2.71 | * | 2.61 | - | - |

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 377 | 2.96 | 2.88 | 7.30 | - | - |
| 378 | 2.82 | 2.58 | 26.51 | - | - |
| 379 | 2.61 | 1.72 | 71.45 | - | - |
| 380 | 2.71 | 1.58 | 53.46 | - | - |
| 381 | 3.32 | 1.54 | 13.06 | - | - |
| 382 | 3.48 | 1.48 | 9.54 | - | - |
| 383 | 2.72 | 1.57 | 51.88 | - | - |
| 384 | 2.65 | 1.72 | 58.82 | - | - |
| 385 | 2.82 | 1.49 | 54.16 | - | - |
| 385A | 2.90 | * | 47.75 | - | - |
| 385B | 2.91 | * | 47.03 | - | - |
| 386 | 2.96 | 1.49 | 35.82 | - | - |
| 387 | 2.85 | 2.24 | 1.16 | - | - |
| 388 | 2.82 | 1.42 | 2.15 | - | - |
| 389 | 2.83 | 1.51 | 1.28 | - | - |
| 390 | 2.66 | 2.18 | 1.48 | - | - |
| 392 | 2.85 | 1.74 | 0.97 | - | - |
| 393 | 2.88 | 1.69 | 0.78 | - | - |
| 394 | 2.81 | 1.25 | 0.88 | - | - |
| 395 | 2.94 | 1.43 | 3.94 | - | - |
| 396 | 2.73 | 1.15 | 0.81 | | |
| 397 | 2.71 | 1.85 | 0.77 | | |
| 398 | 2.95 | 1.47 | 2.63 | | |
| 399 | 3.05 | 3.04 | | | |
| 400 | 3.01 | 3.14 | | | |
| 401 | 3.07 | 3.04 | 0.94 | 7.85 | 0.87 |
| 402 | 2.74 | 1.31 | 3.02 | 5.09 | - |
| 403 | 2.69 | 1.65 | 5.10 | 5.10 | 21.9 |
| 404 | 2.86 | 1.16 | 1.29 | 5.19 | - |
| 405 | 2.38 | 1.35 | 3.56 | 4.85 | 40.9 |
| 406 | 2.56 | 1.35 | 5.85 | 4.62 | - |
| 407 | 2.36 | 1.46 | 7.36 | 4.40 | 47.8 |
| 408 | 2.90 | 1.44 | 4.41 | 4.60 | - |
| 409 | 2.55 | 2.17 | 1.28 | 4.80 | 12.7 |
| 418 | 1.98 | 1.57 | 39.9 | | |
| 419 | 2.48 | 1.77 | 32.5 | | |
| 420 | 2.47 | * | 31.2 | | |
| 421 | 2.51 | 1.56 | 31.8 | | |

| Sample Number | Powder Density | Bulk Density | Cation Exchange Capacity | Abrasion pH | Surface Area |
|---|---|---|---|---|---|
| 430 | 2.77 | 2.94 | 20.6 | | |
| 431 | 3.00 | 2.97 | 3.13 | | |
| 431R | 2.96 | 2.69 | 7.61 | | |
| 432 | 2.89 | 1.65 | 10.6 | | |
| CP-1 | 2.56 | 2.49 | 0.17 | | |
| CP-2 | 2.57 | 2.50 | 0.23 | | |
| CP-3 | 2.56 | 2.49 | 0.27 | | |
| CP-4 | 2.57 | 2.45 | 0.22 | | |
| CP-5 | 2.57 | 2.51 | 0.23 | | |
| CP-6 | 2.64 | 2.37 | 0.37 | | |

# APPENDIX E

## Index of Rock Types by Name

For various reasons it was not always possible to establish the exact rock type (name) with certainty. For example, no fresh rock may have been found, weathering may have obscured the original texture or rock type, or it may not have been clear in the field, on the basis of one small outcrop, to determine whether a rock was intrusive or extrusive. Brazilian geologists distinguish basalt from diabase not so much on the basis of textural differences as on whether the rock is intrusive (diabase) or extrusive (basalt). The names applied to basalts, diabases or gabbros, therefore, should not be taken too seriously, and indeed, it might be better to lump them all under one category such as "Rocks of basaltic composition". This has been done. In cases of uncertain identity, a question mark (?) has been placed after the rock name, and in cases where the rock may be one of two kinds, it has been entered under both rock types. Rocks marked with an asterisk (*) are those which are also listed under the category called "Rocks of basaltic composition".


| Rock name | Series number |
|---|---|
| Amphibolite | 166-172; 230-240; 260-264; 401-410 (?) |
| Andesite | 233-235 (?) |
| Basalt * | 136-142; 302-304 (?); 431 (?) |
| Basaltic composition, rocks of | 75-78; 136-142; 251-256; 302-304; 321-325; 377-386; 396-400; 430-432. |

| | |
|---|---|
| Biotite schist | (see schist) |
| "Bloating" shale | (see shale) |
| Bituminous shale | (see shale) |
| Charnockite | 291-297 (?) |
| Chibinite | 8-22-19 to 8-22-21 |
| Dacite | 233-235 (?) |
| Diabase* | 75-78; 251-256 (?); 302-304 (?); 321-325; 396-400 (?); 430-432 (?) |
| Diorite | (see metagabbro) |
| Dolomite | 244-250; 265-267; 326-329 |
| Eudialyte-bearing syenite | (see chibinite and lujavrite) |
| Fenite | 59-64 |
| Foyaite | 8-22-23 to 8-22-27; 8-22-19 to 8-22-21; 8-22-12 to 8-22-18 |
| Gabbro* | 251-256 (?); 396-400 (?) |
| Gabbro*, olivine | 396-400 (?) |
| Gabbro, meta- | (see metagabbro) |
| Gneiss | 8-20-1 to 8-20-21; 166-172; 187-199; 311-320; 338-346; 365-369; 109-114 (?) |
| Granite | 90-99; 291-297; 338-346; 347-353; 375-376 (also see under gneiss) |
| Granitic gneiss | (see under gneiss and granite) |
| "Green granite" (Ubatuba) | (see charnockite) |
| Leucite phonolite | (see phonolite) |
| Limestone | (see marble) |
| Lujavrite | 8-22-12 to 8-22-18 |
| Marble | 200-212 |
| Metadiorite | (see metagabbro) |

| | |
|---|---|
| Meta gabbro | 401-410 (?). Series 401-410 is called "metagabbro" in this paper. It has been called "metadiorite", diorite (Knecht), and may be the rock called "amphibolite" in the papers of Gomes (1956) and Felicissimo and Franco (1956). |
| Mica schist | (see schist) |
| Nepheline Syenite | (see foyaite, chibinite and lujavrite) |
| Pegmatite | 187-199; 305-309; 387-395; CP-1 to CP-6 |
| Phonolite, leucite | 55-58 (?) |
| Phonolite, variety "tinguaite" | 8-22-1; 8-22-22 |
| Phyllite | 100-114 (?) |
| Rhyolite | 241A through 241J |
| Schist | 167-169; 371-374; 387-395 |
| Shale, bituminous | 180-186; 418-421; 151-165 (?) |
| Shale, black | 326-326 |
| Shale, bloating | 151-165 |
| Shale, oil | (see shale, bituminous) |
| Shonkinite | 81-89 |
| Slate | 100-114 (?) |
| Syenite, eudialyte | (see chibinite and lujavrite) |
| Syenite, nepheline | (see foyaite) |
| Tillite | 65-72 |
| Tinguaite | (see phonolite, variety "tinguaite") |

# APPENDIX F

## INDEX OF ROCK TYPE WITH LOCALITY BY NUMBER

| | |
|---|---|
| 8-20-1 through -20. | Granite or granitic gneiss, Perus. |
| 8-22-1. | Tinguaite, Poços de Caldas. |
| 8-22-12 through -18. | Lujavrite, Poços de Caldas. |
| 8-22-19 through -21. | Chibinite, Poços de Caldas. |
| 8-22-22 (A and B). | Tinguaite, Poços de Caldas. |
| 8-22-23 through -27. | Foyaite, Poços de Caldas. |
| 55-58 | Lava (Leucite phonolite ?), Poços de Caldas. |
| 59-64 | Fenite, Pocinios, Poços de Caldas. |
| 65-72 | Tillite, Mogi Guaçu. |
| 75-78 | Diabase (?), Campinas. |
| 81-89 | Shonkinite, Tatuí. |
| 90-99 | Granite, Sorocaba. |
| 100-114 | Phyllite (?) or slate (?), Soracaba. |
| 136-142 | Basalt, Jupiá. |
| 151-165 | Bloating shale, Jundiai. |
| 166-172 | Amphibolite and gneiss, Jundiai. |
| 180-186 | Bituminous (oil) shale, Taubaté. |
| 187-189 | Gneiss, Linhares. |
| 200-212 | Marble, Barroso. |
| 230-240 | Amphibolite, Curitiba. |
| 241A through -J | Rhyolite, Curitiba. |
| 244-250 | Dolomite, Tranqueira. |
| 251-256 | Diabase or gabbro, Rio Branco do Sul. |
| 260-264 | Amphibolite (?), Ponta Grossa. |
| 291-297 | Charnockite ("green granite"), Ubatuba. |
| 302-304 | Olivine diabase, São Sebastião |

| | |
|---|---|
| 311-320 | Gneiss (?), Tatuí. |
| 321-325 | Diabase (?), Tatuí. |
| 326-329 | Black shale and black dolomite, Tatuí. |
| 338-346 | Gneiss (?), São Roque. |
| 347-353 | Granite, Itapevi. |
| 365-369 | Gneiss (?), Mongonguá. |
| 377-386 | Basalt or diabase (?), Ribeirão Preto. |
| 387-396 | Pegmatite and mica schist, Billings Reservoir. |
| 396-400 | Olivine gabbro (or coarse diabase), Curucutu. |
| 401-410 | Meta gabbro (?) or amphibolite (?), Evangelista de Souza. |
| 418-421 | Bituminous (oil) shale, Pindamonhagaba. |
| 430-432 | Fine diabase or coarse basalt, Jaguariuna. |
| CP-1 through CP-6 | Pegmatite (Potash Feldspar), Governador Valadares. |