ART. XXXVII.—*On the Magnetite Ore Districts of Jacupiranga and Ipanema, São Paulo, Brazil;*† by ORVILLE A. DERBY.

Two ore districts that have lately been investigated by the São Paulo Geological Survey afford instances of what appears to be a hitherto unnoticed mode of occurrence and association of magnetic iron ores. The districts in question, which agree so closely that they serve to mutually explain each other, are situated about 150 kilometers apart on opposite sides of the Serra do Mar. That of Jacupiranga is in a region of comparatively low hills at the extremity of a high ridge of the Serra do Mar system, rising from the low plains of the coast and of the lower course of the Ribeira (or Iguape) river. The Ipanema ore deposits are in the center of an isolated mountain block, bounded by fault planes that rise some 300 meters above a plain that is essentially horizontal with a mean elevation of about 700^{m}. The basement rocks in both districts are

* An examination, not yet concluded, kindly made by Dr. G. H. Williams, seems to prove that this cannot be monazite. Whatever it may prove to be, it illustrates the value of the batea in petrographical study, as by its use an abundance of a rare and interesting accessory was obtained with about ten minutes' work.

† This paper is an English abstract of two reports prepared in the Portuguese language for publication in the Boletina da Commissão Geographica e Geologica de São Paulo, by the present writer, with the coöperation, in the case of the Ipanema district of Dr. Luiz Gonzaga de Campos. The petrographical work has been carefully revised by Dr. Eugen Hussak while Mr. Henry E. Bauer, an able amateur geologist and volunteer assistant, has furnished much valuable material and information regarding the Jacupiranga district.

the same and identical with the characteristic formation of the intervening position of the Serra do Mar, which in this region is made up principally of a series of more or less completely metamorphosed schists cut by numerous and extensive eruptions of granite. These schists are mainly clay-slates, but more highly metamorphosed argillaceous strata appear and more rarely quartzites. One or more beds of limestone, generally black and amorphous but frequently altered to marble, form a very characteristic and presistent member of the series. As no fossils have yet appeared the age of this series cannot be made out, but it is certainly pre-Devonian and presumably Cambrian. The plain surrounding the Ipanema mass, as well as a portion of the block itself, is of late Carboniferous or Permian age. The eruptive rocks described below while in the main confined to the Cambrian (?) area have been found at a few points cutting the Carboniferous strata. At Jacupiranga on the contrary nothing with the exception of eruptive rocks has been recognized between the ancient formation and the modern alluvial deposits, so that there is no criterion for determining the age of the eruptions.

For purposes of study the Jacupiranga district far excels that of Ipanema not only in the variety of its rocks, but also in their state of preservation.* The one district proper includes an area of 30–40 square kilometers of nearly rectangular form lying to the west of the small river Jacupiranga, and extending well over towards the great parallel stream, the Ribeira, which below its great bend, receives the Jacupiranga. The divide between the two streams consists of gneiss and granite flanked on each side by Cambrian (?) schists cut by a great variety of eruptive rocks. These last include various types of orthoclase-pyroxene, orthoclase-nepheline, and plagioclase-nepheline rocks, nephelinites, teschinites, vosgesites, basalts, etc. In the study of the field relations of these various groups, made in great part by Mr. Bauer, in part by the writer with the assistance of Drs. Campos and Hussak, an intimate connection between the most of them and with the iron ore, has been directly proven in many cases and is strongly suspected in others.

The ore district proper is for the most part heavily wooded and covered with a rich dark soil containing everywhere a greater or less amount of magnetite in grains or blocks ranging in size from the finest sand up to masses of the size of a man's head. The predominant rock, as seen in the deeper parts of the cuttings, is a dark-brown or black schist in inclined layers with an abundance of mica flakes along the division

* Unusual facilities for examination were afforded by the operations (since suspended), for the erection of iron works. These included several large excavations for foundations and the grading of six kilometers of tramway affording a nearly continuous section across a large portion of the district.

planes, which give it the aspect of a mica schist. Sections from the inner portion of one of these mica-covered slabs (the outer micaceous portion is too friable for section cutting), show the rock to be composed almost exclusively of irregular grains of violet-colored titaniferous pyroxene with, as accessories, an abundance of iron minerals (magnetite and titaniferous iron), rare grains of perofskite and milky white grains, in part apatite, in part a zeolitized silicate. No mica can be seen in these sections. Higher up in the cuttings where the rock is so friable as to readily crumble in the fingers, the mica becomes more abundant, lining not only the original planes of schistosity but all secondary divisional planes including those between the partially disaggregated grains of pyroxene. The origin of the mica from the weathering of the pyroxene is perfectly clear, and higher up in the cuttings the rock is seen to lose entirely its lithoid character, and to pass to a yellow clay composed exclusively of decomposed mica flakes.* This in turn passes to a dark-red soil which, like the yellow micaceous clay affords, on washing, the characteristic residue of the sound pyroxene rock, viz: iron minerals, apatite and perofskite.

At many points throughout the district, the iron minerals in the rock above described rise from the rôle of an accessory to that of an essential element giving layers composed of various proportions of pyroxene and magnetite which, by the disappearance of the pyroxene, pass to a pure iron ore. This enrichment in iron is accompanied by the total disappearance of the white silicate, and a diminution in the quantity of perofskite. In specimens of nearly pure ore, the magnetite forms a continuous network enclosing detached grains of pyroxene in the same manner as the metallic portion of a meteorite of the mesosiderite type encloses the silicate portions. The annexed figure from a microphotograph of a section of Jacupiranga ore represents this structure. In one place a layer about 15 centimeters thick of pure magnetite containing pyroxene (in part altered to mica) only in a thickness of a few millimeters at the upper and lower surfaces, was seen *in*

* This wholesale passage of pyroxene to mica through weathering is a capital feature in the geology of the two districts and has been very carefully verified. It is not confined to any particular kind of pyroxene as it has been noted also in acmite-bearing rocks and in the pyroxene rocks associated with marble beds.

situ intercalated in schist in which the pyroxene predominates over the magnetite.

At other points flaggy layers were found in which a white element is equally abundant with the pyroxene. This in well preserved specimens proves to be nepheline and the rock standing alone might be called a schistose nephelinite. In this type the iron minerals are rare, while perofskite, apatite, and primary biotite are constant, olivine a frequent accessory.

The peculiar rock above described might very properly be called a pyroxenite if it were not for the objection that this would add still another to the very heterogeneous (as regards geological relations) reunion of types to which that name has been applied.* In view of the evident necessity of subdividing according to geological origin, the so-called pyroxenites, it seems necessary to distinguish this by a distinct name, and it will here be called *jacupirangite*. The rocks included under this title are allied to the nepheline-bearing series and present the various types of pure magnetite, magnetite with accessory pyroxene, pyroxene with accessory magnetite, and pyroxene and nepheline with biotite and olivine as accessory or (in the case of the former at least) essential elements. All these types are most intimately associated as parts of the same mass and the gradual passage from one to the other has been most satisfactorily proven. The most constant and characteristic element is a violet titaniferous pyroxene. Another type of pyroxene-nepheline rock (nephelinite) characterized by green pyroxene and abundant biotite occurs in the district, but has only been seen rarely in loose masses and is presumed to come from dykes and to have an intimate relation to the jacupirangite. At Ipanema a rock of similar mineralogical composition cuts the Carboniferous strata.

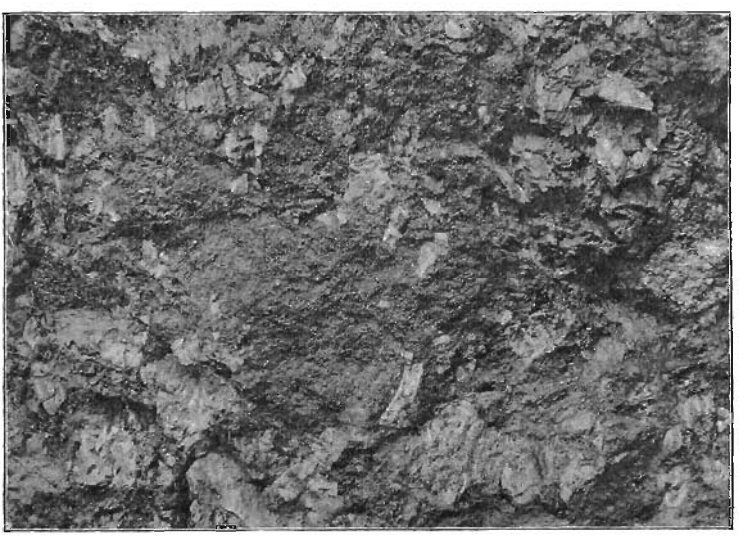
The relations of the jacupirangite to the other rocks of the district are not clear. The nepheline-bearing varieties are suggestive of an eruptive origin and the phenomena observed about a long narrow ridge of limestone of presumed Cambrian age, that rises near the center of the jacupirangite area, appear to confirm this suggestion, although no actual contact could be observed. The limestone is a white, coarsely crystalline marble, heavily charged in places with crystals of magnetite and

The mica shows the optical properties of biotite but chemically (at least in the decomposed state in which it could be obtained for analysis), it is essentially a hydrated silicate of iron and alumina.

* In Brazil alone three or four distinct groups of pyroxenite have been recognized. Aside from the one here described, there is one associated with the limestone of the Cambrian (?) series and undoubtedly derived from it through metamorphism. Another is similarly associated with limestones of the gneiss series and still another forms dykes in gneiss. The calcareous groups are rich in scapolite and apparently correspond with a part of the pyroxenites of Barrois and Lacroix, but none agree with the original type as established by Dana for rocks on the Hudson, whose genetic relations seem to be with the peridotites or norites.

apatite. In an opening close to the supposed contact the jacupirangite (profoundly decomposed) is of much coarser texture than is ordinarily the case, with large perfect crystals and crystalline groups of magnetite, an unusual amount of apatite, and large flakes of hydrated biotite with perfect crystalline outlines that appear to form a primary constituent of the rock. The limestone in the neighborhood of the contact contains orthite, which is found abundantly in beautiful microscopic crystals in the sands of the streams flowing from the limestone ridge, but has not been met with elsewhere. At the margin of the area a small isolated hill of Cambrian (?) schists and eruptive rocks of a different type is partially surrounded by jacupirangite, but the contact zone is occupied by swamps. In the saw-mill pit small dykes of foyaite (nepheline-syenite) are seen cutting the jacupirangite which, near the contact, shows large mica flakes as at the supposed limestone contact.

At Ipanema an ore pit in what is presumed to be decomposed jacupirangite shows clearly the eruptive origin of the iron-bearing rock at this place, since it presents a well characterized dyke margin against decomposed schist and, for a distance of a few meters from this margin, a well defined breccia



character due to the inclusion of irregular angular fragments of the schist, as shown in the annexed reproduction of a photograph, in which the lighter colored schist fragments are seen scattered helter-skelter in the dark iron-bearing rock. The

latter is, for the most part, a granular mixture of small irregular grains (often perfect crystals in the leaner ores) of magnetite and decomposed mica, that passes abruptly to a micaceous clay almost free from iron. In this, as in general appearance, abundant residue of apatite and other particulars, it agrees with the decomposed rock of Jacupiranga, the only noticeable differences being in the less apparent schistosity and absence of perofskite.* Unfortunately no sound rock of this type could be found at Ipanema, but in view of the similarity in the decomposition products, the close correspondence in the eruptive rocks of other types in the two districts and the lack of any primary mica-magnetite type to which the Ipanema rock can be referred, it seems quite safe to consider the latter as decomposed jacupirangite and to conclude for the eruptive origin at both localities.

The above described mode of occurrence is the only one that has been observed in the Jacupiranga district. At Ipanema on the contrary only a small portion of the ore in sight can be referred to the Jacupirangite type of rock. The greater part occurs as a superficial drift-like deposit resting (where the underlying rock has been seen, in the extension of about 100 meters) on micaceous clay which according to all the indications results from the decomposition *in situ* jacupirangite free from iron. The ore masses are rounded as if water-worn and vary in size from shot-like grains to blocks of half a cubic meter or more. These for the most part differ in aspect from the jacupirangite ores and, when impure, contain, instead of decomposed mica, nests of granular apatite and masses of secondary silica (chalcedony, quartz and rarely tridymite). Large rounded bowlders of secondary silica with or without inclusions of ore are abundant. In these the only recognizable minerals, aside from the magnetite, are decomposed mica, rare prisms of green pyroxene (acmite) and exceedingly fresh enstatite in large grains much invaded by chalcedony. It is evident from the inspection of the blocks of this superficial deposit that, with the exception of a small part that can be referred satisfactorily to the jacupirangite type, the magnetite occurs as segregations in a rock extremely subject to alteration with separation of secondary silica. This rock contained magnetite, apatite and acmite as primary constituents without original free silica. Whether the mica and enstatite are primary constituents or not could not be determined, but it is strongly suspected that they are not. In this case it may be surmised that they point to original pyroxene and a magnesium silicate probably olivine.

* This is in accord with the general character of the ores, that of Ipanema being a pure magnetite, while that of jacupiranga is highly titaniferous.

An abandoned working badly obscured by forest shows the ore masses *in situ* as rounded aggregates in soft decomposed material which higher up the hill in the natural exposures is charged with secondary silica giving the siliceous masses above described. The whole evidently forms a dyke some ten meters or more in width cutting the Cambrian (?) schists. In the soft material only decomposed mica (perhaps original biotite) could be recognized. A washing gave an extraordinary abundance of apatite and rare prisms of acmite. A loose block with schistose structure consisting of a finely granular mixture of apatite and acmite (the latter showing micaceous decomposition) serves to connect this cutting with another in the vicinity.

A small dyke about 20 centimeters wide and about 100 meters distant from the one above described has afforded specimens in which the original rock-type can be recognized. It consists almost exclusively of orthoclase with some large crystals porphyritically developed in a fine grained holocrystalline ground-mass with rare prisms of acmite and is thus a typical augite-syenite.* Lower down the hill and apparently coming from the same or a similar dyke are some large partially decomposed, partially reconstructed (with secondary silica) blocks of extreme interest. The soft material and the totally reconstructed (with quartz, chalcedony and tridymite) portions closely resemble those of the old mine above described and the latter also contain enstatite. In other portions in which the orthoclase is partially preserved in a kaolinized state the introduction of secondary quartz gives the aspect of an ordinary granite. The acmite is in great part transformed to amphibole and finally to mica. It varies greatly in abundance becoming in places the predominant element and with its increase, apatite substitutes in great part, or wholly, the feldspathic element giving a rock composed entirely of pyroxene and apatite. There is thus at this place an intimate association of three apparently distinct types, viz: an orthoclase-pyroxene rock with predominant feldspar, an orthoclase-apatite-pyroxene and an apatite-pyroxene rock. These last two give on decomposition an apatite-mica rock.

A large road cutting on the opposite side of the ravine and nearly in front of the locality last described is in totally decomposed schistose material in highly inclined layers. The predominant rock is a pyroxene-apatite schist in which the pyroxene (acmite) has, except in a few points, been wholly altered to mica. Through this run narrow dyke-like streaks (particularizations?) relatively poor in apatite in which the

* The daily increasing importance, wide range of variation and peculiar character of the orthoclase-pyroxene combination seems to demand a simple non-committal term as a generic title for so-called augite-syenite group and Brögger's name *Laurvikite* is here employed in that sense.

white element appears to have been feldspar. This resembles the decomposed schist fragments contained in the ore breccia and like them is characterized by an abundance of zircons of peculiar type. In the midst of these schists appear irregular bands and patches (dykes?) of purely micaceous material exactly resembling the iron-free portions of the eruptive rock of the breccia and like it enclosing fragments of schist. The mica-apatite schists also contain several streaks of a much whiter more compact material that look exceedingly like dykes but may perhaps be particularizations. In these mica and apatite are the only recognizable constituents, but it is tolerably certain that a large part of their mass was originally feldspar. One of these streaks about 5^{cm} wide has a central line of rounded aggregates, the size of a walnut, of magnetite and apatite exactly resembling, on a small scale, the bowlders of the superficial ore deposit and the aggregates of the large dyke (p. 12). Large blocks of magnetite scattered about the neighborhood of the cutting indicate that larger aggregates occur though none were seen *in situ*. This little dyke or streak shows that considerable aggregates of magnetite do actually occur in a rock which is presumably a phase of laurvikite and thus permit the reference to that type of the large decomposed dyke with its workable ore bodies.

The decomposed schist of the ore breccia gives on washing an abundant slime of mica flakes and kaolin with a residue of microscopic zircons* of peculiar type and rare grains of undecomposed orthoclase and aconite thus indicating an original orthoclase-pyroxene rock. Just such a rock, characterized by the same peculiar type of zircons, is found in a sound state in the schist hill (Morro de Area Preta)† at Jacupiranga mentioned on p. 800. It here cuts across and is insinuated between the layers of an ordinary metamorphosed Cambrian (?) schist containing quartz, mica, tourmaline and staurolite, in such a manner as to form an extremely curious complex of regular alternating layers, often only a few millimeters thick, of eruptive and rudimentary material. This schistose phase of laurvikite occurs again in a low ridge at a place called Modesto a kilometer or so above the Morro de Area Preta, but here it is itself included in a breccia of which the matrix is the pyroxene-apatite (with subordinate orthoclase) phase of the same rock similar to that already described from Ipanema.

Indications of the genetic relations and geological age of this last phase are afforded by a cutting on the tramway at Ipanema

* These are complicated crystals of the Miask type in strong contrast with the simple prismatic forms found in many scores of washings from the ordinary feldspathic rocks such as gneiss, mica schist, granite, syenite, foyaite, phonolite, diorite, etc.

† Black Sand Hill from the abundance of magnetite in the stream at its base.

where a decomposed intrusive sheet of a highly micaceous rock is intercalated in the Carboniferous sandstone and shale. This includes lenticular nodules that have escaped decomposition varying in size from that of an egg to that of a bushel measure. These consist of the orthoclase-pyroxene (with subordinate apatite) and pyroxene-apatite (with subordinate orthoclase) combinations identical in aspect, both macro- and microscopically, with the rocks from the ore locality at the same place and from the Modesto locality at Jacupiranga. At this place, owing to the decomposition of the enclosing rock, no idea can be found of the origin of the nodules which appear like transported blocks. At another point where the rock is better preserved small aggregates of the same nature seen in microscopic slides are evident segregations. The enclosing rock has a porphyritic structure with large phenocrysts of nepheline, apatite, green pyroxene (acmite) and biotite (extremely abundant) in a fine grained ground-mass too much altered for determination. It had thus the structure and aspect of a phonolite although no feldspar could be detected in it* and the biotite is much more abundant than is usual in the ordinary phonolites. In composition it recalls a coarse holocrystalline nephelinite found in loose blocks at Jacupiranga. A comparison is also suggested with some of the rocks from the Azores and Masai Land called acmite-trachyte by Mügge. A rock of this last type with phenocrysts of sanidine brown pyroxene and haüyne in a felt like ground-mass of orthoclase, acmite and possibly nepheline (since the former gelatinizes freely) occurs in considerable masses at Jacupiranga somewhat to the westward of the ore district.

The above observations indicate in the phases of laurvikite here described a genetic relation with nepheline-bearing rocks and a tendency to a schistose structure, and to abrupt changes in mineral composition, especially in the direction of phosphatic and basic segregations, that is found to a greater or less extent in other phases of the same type at various localities in Brazil. Thus, at two points in the Jacupiranga district and at Cabo Frio, a coarse granitoid laurvikite with rare grains of nepheline and abundant biotite is associated with foyaite masses. A fine grained phase of the same type found in considerable bodies in various outlying hills about the Jacupiranga ore district and in a few loose blocks within it, show a tendency to a linear arrangement of the bisilicate elements (pyroxene, hornblende and biotite) that gives a gneissoid aspect to the rock. The same tendency is seen in an angular fragment

* This may be due to decomposition though as the nepheline is still recognizable it seems singular that orthoclase should have been less persistent. In the segregations nepheline is totally excluded and primary biotite is rare.

enclosed in the foyaite of Tingua (the only specimen of laurvikite found at this locality) in which pyroxene and magnetite are linearly arranged.* A small loose block found associated with foyaite at Jacupiranga has large idiomorphic phenocrysts of dark violet pyroxene, full of inclusions and with beautiful zonal structure, embedded in a holocrystalline ground-mass of orthoclase with abundant bisilicates (green pyroxene and biotite) and occasional grains of plagioclase. This rock, which illustrates beautifully the tendency towards a basic type, presents some features that suggest a comparison with certain phases of jacupirangite. The frequent occurrence of olivine as an accessory in rocks of the laurvikite type also points in the same direction and suggests a possible hypothesis to account for the presence of enstatite in some of the Ipanema rocks.†

In this connection it is interesting to note the same tendency to a basic phase in the granitoid, or foyaite, type of nepheline-bearing rocks. At several points in the Jacupiranga district, considerable masses (dykes ?) appear of a plagioclase-pyroxene-biotite rock that has been referred to diabase or gabbro by several eminent petrographers to whom they have been submitted. At two points the blocks of this type are mingled with those of foyaite in a manner to suggest a geological connection, while occasionally, as at Cabo Frio, also particularizations of the same type have been observed in the latter rock. Moreover, a diligent search made by Dr. Hussak reveals an occasional grain of nepheline in the plagioclase rock. A rock of similar character with idiomorphic violet pyroxene and an abundance of olivine also contains rare nepheline grains and is referred to the same type‡ as is also a plagioclase-analcime-pyroxene rock identical in all essential particulars with the teschenite of Elgoth, Silesia, that occurs near the river Ribeira at Jaguary. These plagioclase rocks, which may be compared with the theralithes of Montana and the teschenites of various localities, simulate closely the diabases and gabbros, but differ in their genetic relations, from the ordinary types of that family. Various other peculiar types of eruptive rocks abound in the Jacupiranga district, but so far as known they have no

* The quantity of magnetite in this rock would be large for a rock of purely basic type and is extraordinary for one in which orthoclase is the predominant element. It shows the tendency to basic segregations that culminates in the Ipanema on bodies.

† If the enstatite is primary it is extraordinary that a mineral so subject to alteration should be perfectly fresh while all the other elements, except magnetite and apatite, are altered beyond recognition. If secondary it might have been formed from original olivine as suggested above, or possibly from the magnesia of the decomposed pyroxene.

‡ This, with more abundant nepheline, would correspond very closely with the theralithe of Crazy Mts., Montana.

bearing on the magnetic question. For the most part they are of a basaltic character* corresponding to the rocks referred to augitite, limburgite and tephrite (?) that abound in small dykes in every Brazilian locality of foyaite with which they appear to have some genetic connection. One contains leucite, the third occurrence of that mineral noted in Brazil. Small basic dykes, totally decomposed, but apparently of the same character, cut the Carboniferous strata at Ipanema.

Specimens of magnetite ore from various other points in Brazil in the states of São Paulo, Minas Geraes, Sergipe, Parahyba, etc., show inclusions of decomposed mica and apatite that suggest a comparison with the Ipanema and Jacupiranga ores, and perhaps indicate that the mode of occurrence above described may be quite general. In view of the tendency to a schistose structure and transformation into siliceous masses, it may be suggested that possibly some of the jaspery hematites may have had a similar origin.† The only Brazilian magnetite thus far seen that can be definitely determined as having a different origin is from Palmeiras dos Indios in the state of Alagoas. This, which is similar in appearance to the Cumberlandite of Wadsworth, contains plagioclase and augite and is an enrichment of a gabbro.