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1. GEOLOGICAL SECTIONS *through the* ANDES *of* PERU *and* BOLIVIA: II—*From the* PORT *of* MOLLENDO *to the* INAMBARI RIVER. By JAMES ARCHIBALD DOUGLAS, M.A., B.Sc., F.G.S. (Read February 4th, 1920.)

[PLATES I–VI.]

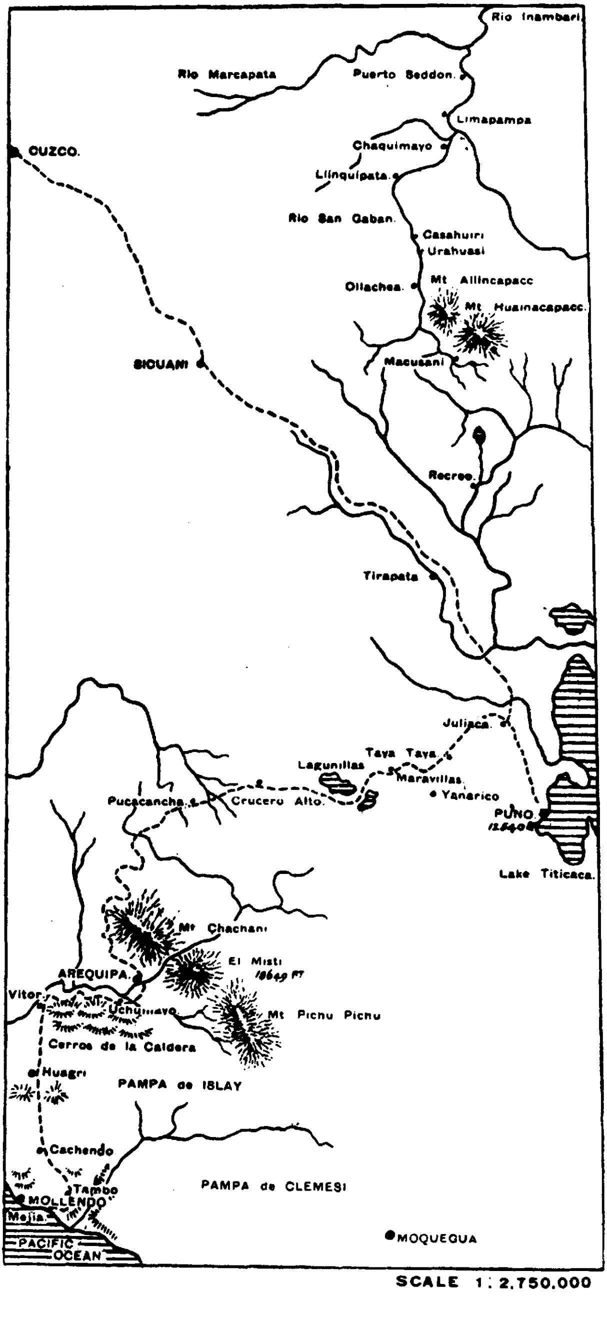
CONTENTS.

I. INTRODUCTION.

IN a former communication to this Society, published in April 1914, I described a geological section through the South American Andes, from Arica on the Pacific coast of Northern Chile to the Bolivian Yungas.

The present paper, the publication of which has been long delayed owing to the War, is a further contribution to the same series, the

Fig. 1.—*Sketch-map of the district between Mollendo and the Inambari River.*



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result of work undertaken on the Balston Expedition to Peru. It deals with a second and parallel section drawn through the south of Peru from the port of Mollendo to the River Inambari, a tributary of the Madre de Dios, one of the head-waters of the Amazon. That part of the country illustrated in the western half of the section, which includes the important town of Arequipa and the port of Puno on Lake Titicaca, is accessible by the Southern Railway of Peru, of which we were enabled to make full use during the course of our work from Arequipa to the coast, through the kindness of Mr. McCulloch, manager for the Peruvian Corporation. I have also to thank Mr. F. A. Corry, chief engineer of the line, for the original from which the sketch-map (fig. 1) was taken.

For the continuation of the section beyond Puno through the Eastern Cordillera, it was found necessary to proceed northwards as far as Tirapata, a station on the Puno-Cuzco railway, whence access could be gained, by the trail of the Inambari Rubber Company, to the forested region of the Montaña.

The railway between Puno and Tirapata, however, runs more or less parallel to the strike of the chain; and, although the eastern part of the section from Tirapata to the Inambari River has a more northerly trend, and is described under a separate heading, it may be regarded as being practically continuous with that part which lies between Mollendo and Puno.

The journey northwards was done by road, in order that we might examine the intervening country.

After completion of the Arica–La Paz section we travelled northwards from Tacna to Arequipa, a distance of about 150 miles, over the coastal deserts here known as the Pampa de Clemesi and the Pampa de Islay, hoping thereby to obtain an occasional glimpse of the underlying rocks which might prove of assistance to us in an attempt to correlate the two sections. With the same object in view, we made a further journey southwards from Puno round the western shores of Lake Titicaca to the peninsula of Copacabana and the Island of the Sun.

Although the district described in the following pages is one of the best-known areas in Peru, little attention seems to have been paid to its geological features, unless account is taken of the explorations made by those interested solely in its mineral wealth.

In 1886, Dr. F. H. Hatch gave a petrographical description of the volcanic rocks of the Western Cordillera in the neighbourhood of Arequipa; but it is not until comparatively recent years that our knowledge of the district has been increased by the publications of the following authors:—Dr. George I. Adams (1908), Mr. V. F. Marsters (1909), Prof. R. Hauthal (1911), and Prof. Isaiah Bowman (1909), all of whom have confined themselves mainly to an account of the coastal regions.

I must repeat my thanks to Mr. W. E. Balston for enabling me to undertake the work of investigating the country, and to Mr. J. R. Thomas for his assistance and companionship in the field.

II. Main Topographical Features of the Country included in the Second Section (Mollendo to the Inambari River).

From the port of Mollendo, the southern railway of Peru follows the coast towards the south-east as far as the hamlet of Mejia (kilometre 15). Thence turning inland it ascends to the station of Tambo (kil. 30, alt. 1000 feet), situated on a flat plain at a considerable height above the village of that name which lies in a fertile valley on the south.

This coastal region, as it may be termed, is particularly well defined when viewed from a passing steamer. It has been described by Prof. Isaiah Bowman as being composed of gently sloping rock-benches of huge size, formed by the sea, and subsequently uplifted to a height of at least 1500 feet. Along the inner margin of these terraces coves are to be found, like those now seen at many places on the present strand-line, or but little above it.

The same author further cites the discovery, at an elevation of 800 feet, of a clay-bank containing recent shells of the same sort as those now found on the beach, and from this concludes that

'after the formation of the terrace at this level and its partial dissection as the result of elevation, it was again submerged long enough and deep enough for the formation of the clay and deposition of the shells; a second uplift then brought the whole above water, and it is this movement that is continuing to-day.'

That a comparatively recent uplift has taken place is manifest from the abundant remains of raised beach preserved along the foot of this shelving plateau, consisting chiefly of angular fragments of gneiss and granite derived *in situ* from the rocks cropping out along the shore. These remains, however, so far as my own observations go, do not extend more than about 50 feet above present high-water mark, and the assumption that the uplift has amounted to as much as 800 feet in recent times and is still continuing at the present day, as held by Prof. Bowman, is, I think, hard to reconcile with facts recorded from other parts of the coast.

I have already shown that the presence of pre-Spanish burial tumuli only a few feet above high-water mark at Arica precludes the possibility of any considerable rise in the last 400 years; a change of level of 4 feet, in fact, might with reason be taken to be the absolute maximum, or such loosely-consolidated mounds must inevitably have been destroyed by wave-action. A rise of 800 feet, if the elevation be considered as having taken place at a uniform rate, would therefore necessitate a period of some 80,000 years.

I have previously suggested that a considerable post-Pleistocene elevation must be assumed, in order to account for the fossil mammalian fauna of the inter-Andean region; and some authors have gone so far as to claim a rise of over 1000 feet in the last 11,000 years, in order to explain the position of the ruined city of Tiahuanacu in its present barren site. Effects due to climatal changes, however, have probably been underestimated, and I can find no conclusive evidence to show that the elevation has been any more rapid here than on the coast.

The occurrence of marine shells at a considerable height above the sea cannot always be taken as conclusive proof of recent uplift, for they are often carried far inland by sea-fowl, and their remains are sometimes so numerous that they appear to be *in situ*. Another case, one in which human agency is involved, is the accumulation on the high-level pampa of shells thrown from the windows of a passing train; one species in particular, a delicacy much esteemed by the native population, is consumed daily in large quantities on the journey to Arequipa. The shells become incorporated in the drifting sand, and are often carried some considerable distance from the line, when their discovery is at first very misleading.

From Tambo the line rises in a series of curves somewhat steeply to Cachendo (kil. 55, alt. 3250 feet). Beyond this point the aspect of the country undergoes a remarkable change, for the rocky hills bounding the coastal region become buried beneath a vast desert known as the Pampa de Islay, which, although broken through by isolated rounded hills of granite in the neighbourhood of Huagri (kil. 70), stretches as far as Vitor (kil. 122, alt. 5350 feet). Scattered widely over its surface are magnificent examples of crescentic sand-dunes, the white sand of which contrasts strongly with the general reddish colour of the pampa. These are particularly well developed in the neighbourhood of La Joya, where they are frequently 20 feet or more in height. The prevailing winds, during the first half of the year at least, come from the south-east, and the horns of the crescents point in consequence uniformly towards the north-west, in which direction the dunes are said to advance at the rate of 100 feet in the course of a year.

After leaving Vitor a steep winding ascent is made, through the hills known as the Cerros de la Caldera, to the town of Arequipa (kil. 172, alt. 7550 feet), picturesquely situated in the centre of a well-irrigated and fertile plain.

Throughout this ascent the railway is bounded on its northern side by the deep gorge of the Uchumayo River, which may be regarded as forming the dividing-line between the foot-hills and the main volcanic peaks of the Western Cordillera.

The panorama of these giant snow-capped mountains, apparently towering above the city, although in reality some 10 miles distant, is one of extraordinary beauty. On the north-west lies the jagged ridge of Mount Chachani (19,300 feet), on the south-east the flat-topped Pichu Pichu, while in the centre rises the symmetrical cone of El Misti (18,649 feet).

From Arequipa the railway takes a bold sweep to the north-west, so as to circumvent the foot of Mount Chachani. We chose the more direct route, however, between this mountain and El Misti, following the old Inca trail up the right or northern bank of the River Chili, which here cuts a deep gorge between the two mountains.

Fording the River Sumbay, we rejoined the line at Pucacancha [1] (kil. 130), and, continuing to ascend, reached its summit at Crucero Alto (kil. 187, alt. 14,667 feet).

The descent on the eastern side is at first gradual, then more abrupt to Santa Lucia (kil. 238, alt. 13,250 feet), passing on the way over the narrow neck of land between the twin lakes of Lagunillas and Saracocha.

From Santa Lucia to the copper-mines of Maravillas the river-valley, along which the line is built, is comparatively broad, its floor being covered by a thick deposit of alluvial gravel. Beyond this point, however, it narrows considerably, and is flanked on both sides by hills of steeply-dipping stratified Palæozoic rocks, on the upturned edges of which rests a younger Mesozoic series. This striking unconformity is a conspicuous feature of the landscape, and can be clearly seen from the passing train.

The country north of Puno furnishes little of geological or topographical interest, comprising as it does the broad alluvial swamps left by the receding waters of Lake Titicaca; we, therefore, left the line after reaching Taya Taya in favour of the more direct route south-eastwards by the hacienda of Yanarico and Vilque, where the trail is flanked by isolated flat-topped hills which owe their form to a capping of lava.

The final descent into Puno (alt. 12,540 feet) affords a magnificent view of the lake, backed by the snow-clad peaks of the Bolivian Cordillera in the far distance.

For the continuation of our traverse we proceeded along the line to Cuzco as far as the village of Tirapata, and thence journeyed north-eastwards into the region drained by the head-waters of the Amazon, along the trail of the Inambari gold and rubber companies.

I have previously shown that the Eastern Cordillera of Bolivia constitutes a well-defined range of high peaks, formed of granite and Palæozoic sediments—Mount Illimani, Huaina Potosi, etc. In the district under discussion, however, such is no longer the case; individual peaks, recognizable on a map, are of rare occurrence and scattered over a wide area, and the Cordillera here consists of a number of intersecting ridges which unite farther north in the so-called 'Vilcanota knot.' On the route mentioned above, the divide is crossed at about 15,500 feet, between a little river known as Viscachani and the village of Macusani.

Some 20 miles or more north-east of this point, two much higher snow-capped peaks are visible, the altitudes of which have apparently never been determined. They are known to the natives as Mount Allincapacc and Mount Huainacapacc, and if we judge from the amount of snow on their summits, they must at least rival some of the better-known peaks of Bolivia.

After leaving Macusani, a rapid descent is made down the valley of the San Gaban River, famous as the source of much Spanish gold. This valley shows a very immature stage of development.

[1] Distances are henceforward reckoned from Arequipa.

Its sides are steep, often precipitous, and the river descends in a series of falls and boiling rapids to join the Inambari a few miles below the rubber camp of Chaquimayo.

Numerous small tributary streams enter the main river in the form of hanging valleys, at the mouths of which are fine examples of 'cônes de déjection.' These are remarkably well developed, and control the mighty rush of water in the most striking manner, forcing it repeatedly from one side of the valley to the other.

The trail enters the dense tropical vegetation of the 'Montaña' or forest-region at Ollachea (alt. 8860 feet), and, after several times crossing the river by frail swinging bridges, reaches its termination on the Inambari River at Puerto Seddon (alt. 1575 feet).

III. Geological Description of the Section from Mollendo to the Inambari River. (See Pl. VI.)

For the purposes of geological description, it has been found convenient to divide this section into three parts:—

(1) Mollendo to Arequipa: comprising the ancient metamorphic and intrusive rocks of the coastal Cordillera, the plutonic complex of the Cerros de la Caldera, and the fragmentary remains of a Mesozoic cover.

(2) Arequipa to Puno: comprising the volcanic rocks ejected from the giant cones which fringe the Western Cordillera; the Mesozoic and Palæozoic sediments of the inter-Andean region corresponding to the Altaplanicie of Bolivia; the dioritic intrusions of the Maravillas district; the lava-flows of post-Cretaceous age in the neighbourhood of Puno, and the alluvial flats of Lake Titicaca.

(3) Tirapata to the Inambari River: comprising the Palæozoic sediments and plutonic rocks of the Eastern Cordillera and the Amazon slopes.

(1) The Geological Structure of the Country between Mollendo and Arequipa.

In a former paper dealing with the geology of a section from Arica to the Bolivian Yungas, I described the coast of Northern Chile as being composed of stratified Mesozoic deposits associated with igneous rocks of contemporaneous origin; this series, with its intruded core of granodiorite, was shown to form the basement on which are situated the volcanic cones of the Western Cordillera.

If the coast be followed southwards, however, this Mesozoic zone is soon found to be cut off from the ocean by an intervening zone of ancient crystalline rocks, comprising chiefly granites, gneisses, and mica-schists. Rocks of this nature are well exposed at Mejillones, Coquimbo, Valparaiso, and other intermediate ports; they constitute the coastal Cordillera of Chile.

North of Arica, the Peruvian coast-line bends sharply towards the north-west. This change of direction, though accompanied by a corresponding deflection in the strike, is sufficiently great once more to bring to light rocks that may be regarded as forming the continuation of the coastal Cordillera of the south. Such rocks fringe the coast from Ilo to Mollendo, and thence are continued northwards.

The fossiliferous coal-bearing beds of Upper Carboniferous age which are found on the peninsula of Paracas, a few miles south of Pisco, must also be included in this coastal zone, as distinguished from the typically Mesozoic zone of the Western Cordillera. This is the only known occurrence of fossiliferous Palæozoic sediments on the whole coast of Peru, and must not be confounded with the statement made by A. d'Orbigny, that the beds of the Morro de Arica are of Carboniferous age, since the latter have now been proved to contain Jurassic ammonites.

The section described in the following pages commences at the port of Mollendo, which is situated on the crystalline rocks of the coastal Cordillera.

The earliest rock of this series is a medium-grained pink gneiss (A 71), composed of irregular alternating bands of quartz, felspar, and dark minerals, of which biotite is alone recognizable in a hand-specimen. The rock is much contorted and fractured, and is traversed by a complicated system of faults. Although there is no direct evidence for its antiquity, it has the typical appearance of an Archæan rock. Forming reefs and low-lying cliffs along the shore as far as Mejia, it is everywhere seen to be pierced by numerous acid veins of pegmatite (A 103) and greisen (A 101), the former consisting chiefly of quartz and microcline, the latter of quartz and muscovite.

Less abundant are basic intrusions in the form of dark microcrystalline dolerite-dykes (A 97), good examples of which crop out on the beach at kilometre 2 and kil. 11. The relationship of the rocks is clearly defined at the first locality, where a 2-foot basic dyke is seen to cut both the gneiss and the minor pegmatite-veins, the latter having been injected parallel to the planes of foliation. The gneiss has further been penetrated by larger masses of plutonic rock, both acid and basic, representing the parent bodies from which the minor intrusions have been derived.

The connexion of the basic dykes with the parent rock is, for the most part, a matter of inference, suggested by their constant association in several localities, and they appear to represent somewhat earlier differentiation-products; in the case of the acid veins, however, the connexion is clearly visible.

The basic rock is a fine-grained holocrystalline diorite (A 70), which forms large reef-like masses on the shore in the immediate neighbourhood of Mollendo, where it crops out from beneath the sands of the coastal pampa. Although of dark colour and basic appearance, with a high percentage of ferromagnesian minerals (chiefly biotite and hornblende), it contains abundant quartz. This, however, in many cases appears to be of secondary origin, occurring in the form of minute veins associated with crystals of pyrites.

(The grey granite used during the construction of the mole, and frequently found washed up in blocks on the beach, does not occur here *in situ*, being quarried farther inland near Tingo.)

The junction of diorite and gneiss is well seen in one of the railway cuttings at kilometre 2, where the former rock along the chilled margin assumes the aspect of a fine-grained amphibolite, while the gneiss has undergone little change. A similar occurrence is to be noted at kil. 13, where the latter rock is again penetrated by a second and smaller mass of diorite with associated basic dykes.

The acid magma has consolidated as a coarse-grained pink granite (A 91), containing clear smoke-coloured quartz, pink felspar, and a small percentage of biotite and chlorite.

The rock is much fractured and weathered. Its junction with the gneiss is plainly seen at Mejia, the latter rock being penetrated in every direction by numerous veins of pegmatite. The presence on the Pacific coast of this typically 'alkaline' type of rock, containing, as it does, abundant microcline and few ferromagnesian minerals, in a district essentially characterized by rocks of a 'calcic' facies, is of considerable interest. It would appear to support the theory of a remote, possibly Archæan, age for the gneiss and granite, by the suggestion that their formation preceded the development of the forces which gave rise to the uplift of the Andes, with the accompanying intrusion of plutonic rocks of 'Pacific' type.

That a generalization of distribution of so-called Atlantic and Pacific provinces cannot be applied to the older rocks, has already been proved by Dr. G. T. Prior[1] in the case of the Great Rift Valley of British East Africa, where a younger foyaitic-theralitic series overlies older crystalline rocks of Pacific kindred. In the present instance the reverse is the case, rocks of an alkaline facies being succeeded by a younger calcic group.

Petrographical Description of the Rocks of the Coastal Cordillera.

(A 71) Gneiss. Mollendo (kil. 2).

Microscopic characters:—This rock consists essentially of a granular mosaic of clear quartz, felspar, and certain coloured minerals, showing marked parallel structure in their arrangement; the effects of dynamic metamorphism have further resulted in the crushing or bending of many of the constituents.

Quartz is abundant, and exhibits pronounced strain-shadows.

The felspars are slightly turbid owing to alteration, which has resulted in a confused mass of sericite-flakes; they comprise microcline, orthoclase, and plagioclase (near andesine), the last-named frequently showing bending and fracture of the twin-lamellæ. The microcline structure, although possibly in some cases original, often appears to be a phenomenon due to strain-pressure acting on the orthoclase.

The micas are not abundant; muscovite and biotite are present in about equal proportions, the latter showing alteration into chlorite and epidote.

A colourless or faintly pink garnet is abundant; the crystals are

[1] 'Contributions to the Petrology of British East Africa' Min. Mag. vol. xiii (1901–1903) pp. 228–63.

intensely crushed and broken, the cracks being filled with a greenish alteration-product which appears to be a variety of serpentine.

Numerous colourless crystals of kyanite are also present, showing the characteristic cleavage and high index of refraction.

Magnetite occurs in somewhat large irregular grains.

(A 91) Granite. Mejia (kil. 15). (Pl. II, fig. 2.)

Microscopic characters:—A coarse-grained holocrystalline rock with typical granitoid structure. It consists chiefly of quartz and felspar, to which the coloured minerals are quite subordinate.

The felspars comprise microcline in large crystals with characteristic cross-hatching, orthoclase, and plagioclase; monoclinic and triclinic forms frequently showing perthitic intergrowths. The plagioclase exhibits very narrow twin-lamellæ, and has a refractive index considerably lower than that of balsam, being nearer albite. Its decomposition has resulted in the production of flaky aggregates of sericite; while, in some instances, the entire centre of a crystal is replaced by a clear patch of brilliantly-polarizing muscovite.

A little biotite is present, but it has been almost completely converted into green chlorite.

The minor accessories include apatite, magnetite, hæmatite, and small crystals of zircon, the last-named occurring as inclusions in the biotite with strongly pleochroic halos.

In addition, there are frequent pseudomorphs of calcite crowded with small yellow crystals, which from their outlines and extremely high refractive index appear to be anatase. These pseudomorphs probably represent original sphene.

(A 103) Pegmatite. Mollendo (kil. 2).

Microscopic characters:—This rock consists essentially of quartz and microcline in coarse pegmatitic intergrowth.

Coloured minerals are almost entirely absent, but muscovite occurs in some abundance, largely in the form of sericite from the decomposition of the felspar.

(A 101) Greisen. Mollendo (kil. 2).

Microscopic characters:—The bulk of this vein consists of an irregular mosaic of clear quartz and brilliantly-polarizing muscovite, although there is also a certain amount of much-decomposed felspar. This appears to have been chiefly orthoclase, but traces of albite-twinning are occasionally visible.

A little biotite, showing conversion into chlorite, is also present.

(A 70) Hornblende-mica-diorite. Mollendo (kil. 1).

Microscopic characters:—A holocrystalline rock of medium grain, consisting chiefly of felspar and ferromagnesian minerals (hornblende and biotite) in roughly equal proportions.

Quartz occurs in some abundance, but appears to be more or less restricted to definite veins, and is therefore probably in great part of secondary origin; analysis of the rock would undoubtedly give a somewhat high percentage of silica.

The felspar is chiefly plagioclase, showing twinning on the albite law; the extinction-angles of sections, cut perpendicular to the lamellæ, do not usually range above 15° (oligoclase-andesine), and the refractive index is about equal to that of quartz.

The ferromagnesian minerals, which are very abundant, and appear to have crystallized simultaneously, consist of green hornblende (with occasional idiomorphic contours) and brown biotite much altered into chlorite and epidote.

Sphene is also plentiful in somewhat large irregular crystals; a few small needles of apatite occur, but iron-ores are very sparingly developed.

(A 99) Near its junction with the gneiss the rock becomes converted into a fine-grained, confused, fibrous aggregate of hornblende, biotite, and chlorite, with abundant grains of magnetite and a little felspar.

Numerous small light-coloured areas of circular outline are also visible in a hand-specimen. These, when viewed microscopically, are found to be composed of a patchwork of clear tremolite-crystals with an occasional large grain of magnetite. Their outline is sharply defined, and they appear to be xenoliths that have undergone metamorphism.

(A 97) Dolerite. Mollendo (kil. 2). (Pl. II, fig. 1.)

Microscopic characters:--This rock, which occurs in the form of dark, compact, fine-grained dykes penetrating the gneiss, is composed of small porphyritic crystals of plagioclase and augite embedded in a micro-crystalline ground-mass.

The plagioclase-phenocrysts are idiomorphic to the augite: they have an elongate lath-shaped habit, and are of a peculiar brownish hue which is due to 'schillerization,' for under a high magnification they are seen to be crowded with ultramicroscopic dust-like inclusions. They exhibit Carlsbad twinning in conjunction with that on the albite and pericline laws, and are comparatively fresh, although after their separation they have undergone a certain amount of corrosion by the residual magma, with the production of a clear selvage of irregular outline and free from schiller inclusions. Extinction-angles indicate a range from oligo-clase to andesine.

The augite is a colourless or very pale-green variety, showing numerous interpenetrating twin-growths. It tends to wrap round the felspar-crystals in a subophitic manner, but never completely encloses them. In many instances it has been entirely replaced by scaly aggregates of serpentinous and chloritic material, though some unaltered phenocrysts still remain to indicate the original nature of these peculiar pseudomorphs.

The ground-mass approaches in structure the 'intersertal' of Rosen-busch, consisting of a network of small felspar-laths (chiefly oligoclase) enclosing granules of augite and magnetite, and a small amount of residual glass.

The foot-hills bounding the coastal region between Tambo and Cachendo are composed mainly of holocrystalline plutonic rocks of granitic texture, which are well exposed in the numerous cuttings on the railway. These rocks are usually pink or grey, and consist essentially of quartz, felspar, hornblende, and subsidiary biotite. They have the composition of typical granodiorites; plagioclase is, as a rule, in considerable excess of orthoclase, the percentage of ferromagnesian minerals is not high, and quartz is frequently present in some abundance.

A parallel arrangement of the hornblende-crystals is noticeable in some localities, which suggests slight movement during consoli-dation. An incipient development of gneissic structure due to earth-stresses, however, must also be regarded as a possible explanation, for similar rocks, probably of the same age, were discovered farther inland, showing every stage of dynamic metamorphism from a coarse-grained plutonic rock to a finely-banded gneiss.

In places, overlying beds of white and reddish quartzite are ob-served, the age of which, in the complete absence of palæontological evidence, cannot at present be determined. On comparison with similar rocks from the Arica section, however, it is logical to suppose that they are altered Mesozoic sediments, forming a continuation of the Jurassic zone of the south.

The contact of igneous with sedimentary rock, on which the gold mines of Posco are situated, appears to be an irregular one irrespective of the dip of the strata: a mode of intrusion similar to that described in the case of the batholitic mass of the Llutah and Palca Valleys.

On our journey from the south we met with plutonic rocks of like character in the valley of Moquegua and in the Quebrada de Huaneros, and it is therefore natural to conclude that we are here dealing with the northward prolongation of the same batholite. A definite connexion between the two areas, however, cannot be established, owing to the enormous intervening stretch of desert, the Pampa de Clemesi.

If this granodiorite of Cachendo were the only plutonic rock in the district, the evidence for such a connexion might reasonably be deemed sufficient. But, between the foot-hills of the coast and the high volcanic peaks of the Western Cordillera, occurs a vast plutonic complex comprising rocks of very varied composition; and, as many of these crop out, in isolated positions, from beneath the sand of the desert, it is frequently impossible to determine the relationship that they bear one to the other. In the Cerros de la Caldera, however, where the evidence is more easily interpreted, a clearer sequence can be established, in which at least three distinct phases of plutonic intrusion are represented, separated by definite (though not necessarily long) intervals of time.

The problem, then, consists in proving which of these intrusions corresponds to, or is continuous with, the batholite of Northern Chile.

(A 95) Granodiorite. Posco (kil. 40).

Microscopic characters:—A holocrystalline rock of granitic structure, containing a certain amount of quartz and a little orthoclase.

The bulk of the felspar, however, is a plagioclase showing albite and pericline twinning and occasional zonary banding. The extinction-angles indicate an acid labradorite. Green hornblende is abundant in large idiomorphic crystals which are frequently twinned.

The biotite has been almost completely converted into chlorite, with numerous lenticular masses of yellow epidote lying between the cleavage-planes.

Minor accessories include a little sphene, magnetite, apatite, and a few small crystals of zircon.

(A 72) Granodiorite. Cachendo (kil. 51).

This rock is essentially similar to the last, but of somewhat finer grain, and with a more pronounced pink coloration. The phenocrysts of hornblende tend to have a parallel arrangement.

Microscopic characters:—Compared with A 95, it is seen to contain more abundant quartz and orthoclase, though the latter is still quite subordinate to the plagioclase, which shows marked zonary banding with frequent alteration of the internal zones.

The idiomorphic hornblende is twinned parallel to 100.

The biotite is fairly fresh, and retains much of its original brown colour, though there is a considerable amount of chlorite and epidote.

Magnetite is abundant, but apatite and sphene are not well represented.

In comparing the above-described rocks with the granodiorites of the Arica section, the main points of difference to be noticed are the relatively-greater proportion (in the present case) of plagioclase to orthoclase, the greater abundance of idiomorphic green hornblende, and the frequent occurrence of sphene; moreover, the acid pegmatite-veins with tourmaline, so characteristically developed farther south, here seem to be absent or at least extremely rare.

Beyond Cachendo (kil. 55) we reach the Pampa de Islay, a flat expanse of desert unbroken in monotony, save for the countless sand-dunes and an occasional outcrop of the underlying rock. This stretches as far as Vitor, where it ends against the foot of the rocky Cerros de la Caldera.

In the neighbourhood of Huagri occurs a series of isolated rounded hills of reddish hue, formed of granite, which when unweathered, as in the shallow cutting at kilometre 66, is seen to be a coarsely-crystalline grey rock. It is composed of quartz, felspar (both orthoclase and plagioclase), biotite, and hornblende. This granite is a highly-acid rock, and, as the two felspars are present in roughly equal proportions, it may be described as a typical adamellite. Patches occur, however, composed entirely of quartz and pink orthoclase, with occasional pegmatitic intergrowth, and large plates of biotite often measuring an inch or more in diameter. These patches are occasionally so abundant that the rock presents the appearance of a normal pink granite.

Smaller basic secretions are also met with.

(A 73) Adamellite. Huagri (kil. 65). A specimen characteristic of the main bulk of the rock.

Microscopic characters:—A holocrystalline plutonic rock, with hypidiomorphic granitic structure; consisting essentially of quartz, felspar, hornblende, and biotite.

Clear allotriomorphic quartz is abundant.

The amount of orthoclase present is equal to, or in slight excess of, the plagioclase; it occurs in the form of large plates, without definite crystal boundaries, surrounding and enclosing idiomorphic crystals of the latter (near andesine). This structure is typical of the adamellites, as distinct from the true granodiorites.

Green hornblende and brown biotite are present in about equal proportions, the two minerals being often intergrown. Minor accessories include magnetite, sphene, and a little apatite.

After passing La Joya, one notes occasional exposures of quartzites and sandstones, forming low-lying hills between Ramal and Vitor. These beds doubtless belong to the same series as the quartzites of Posco and Cachendo, but failed to yield any palæontological evidence to prove the connexion.

In the neighbourhood of Vitor, about a mile east of the station, occurs a further isolated outcrop of plutonic rock which has a very distinct individuality; but, as it is completely surrounded by desert sand, it was found impossible to determine its relation with the rest of the series. Its surface is deeply etched by the natural sandblast to which it is exposed, and presents a marked difference in appearance from the smooth highly-polished surfaces of the fine-grained blocks of basic lava that are found scattered in the vicinity. In a hand-specimen the rock bears a strong resemblance to the well-known syenite of the Plauens'cher Grund, near Dresden, being composed almost entirely of a dull pink felspar and greenish-black hornblende; in microscopic section, however, it appears to be more closely related to the acid end of the monzonite series.

(A 75) Quartz-monzonite. Vitor.

Microscopic characters:—This rock is composed mainly of felspar and uralitic hornblende, with subsidiary quartz, biotite, and minor accessories.

It has a coarse-grained holocrystalline structure, and, with the exception of containing a less amount of biotite, agrees in all essential features with the typical monzonite of the Tyrol.

The plagioclase (oligoclase-andesine) is remarkably free from alteration, although traversed by numerous irregular cracks; it is present in slight excess of the orthoclase, to which it tends to be idiomorphic: the latter is grey and somewhat turbid.

The hornblende occurs in the form of yellowish-green fibrous paramorphs of uralite after augite, which was probably a variety rich in iron, for the uralite is crowded with disseminated grains of magnetite and hæmatite. Indications of dual and multiple orthopinacoidal twinning in the original crystals are still visible.

Quartz is fairly abundant; it appears somewhat dusty, owing to the presence of numerous liquid inclusions which frequently show mobile bubbles.

There is a small amount of reddish-brown biotite showing alteration into chlorite, and the felspar includes numerous minute needles of apatite.

After leaving Vitor (kil. 123) we commence the ascent of the Cerros de la Caldera, and at once meet with a complex suite of igneous rocks, representing, as mentioned above, at least three distinct phases of deep-seated plutonic intrusion. Many of these rocks have been subjected to powerful earth-movements with resultant dynamic metamorphism, and the development of banded or gneissic structure. The gradual passage of a coarsely-crystalline granitoid plutonic rock into a fine-grained gneiss can be clearly followed at more than one locality.

Recrystallization of many of the component minerals is a further well-marked feature; but it is not easy to determine how much of this is due to dynamic agency, and how much to thermal metamorphism of one member of the series by another.

Before I attempt to describe the minute structure of the rocks forming this complex, it will be as well to run briefly over the section, stating the various types met with and the evidence on which a determination of their sequence has been arrived at. The majority of the specimens in my collection were obtained from the actual railway-cuttings, where the exposures were comparatively fresh, and as the line ascends with the most sinuous curves, it is possible that intrusions of the same rock, regarded as separate, might in some cases prove to be in reality connected. This, however, is a point of minor importance in reading the general history of the complex, and the detailed mapping, which alone could have made this clear, would not have repaid the time necessary for the purpose: for example, the plural description of a single dyke, met with in more than one cutting, would not affect the determination of the relative ages of intrusion and country-rock, provided that the separate exposures were noted as being of the same type.

The earliest rock of the sequence is first seen at kilometre 124, in the form of a granodiorite (A 76) almost-identical in character and appearance with that previously described from the foot-hills of Cachendo (A 95), and in all probability belonging to the same phase of intrusion. When this rock is traced up the line, however, it is found to undergo a remarkable change, which on microscopic examination is seen to be due to acidification and entire recrystallization of its constituent minerals.

Quartz, of a faintly pink colour, becomes increasingly abundant, the felspars assume a distinctly green tint, and biotite is extensively developed in little well-defined clusters, replacing to a large extent the hornblende as the dominant ferromagnesian element. The relative proportion of the two minerals, however, is a very inconstant character, varying in the most pronounced manner often in the space of a few inches.

Large basic patches composed almost entirely of hornblende are of frequent occurrence. These appear to represent xenoliths of cognate origin, such as occur elsewhere in the unaltered rock, and their somewhat obscure outline is probably due to a certain amount of admixture during the recrystallization which they have undergone in common with the surrounding mass.

Epidote is everywhere abundant, both disseminated throughout the rock and associated with quartz in the form of epidosite-veins; as a rule these seem to have been formed in pre-existing fissures by a process of leaching from the country-rock, though in some cases they have the appearance of original igneous injections.

No definite line of demarcation between this abnormal rock and the normal granodiorite could be determined, and it is thought to be a hybrid rock or a mixture of two distinct types, in which the effects of dynamic metamorphism are superimposed on those of contact-metamorphism. Its origin is discussed later.

With the further ascent of the line to Quishuarani, the change in the granodiorite is still more remarkable.

The rock assumes a banded character, at first somewhat indistinct with further development of biotite, then becoming increasingly pronounced, until at kilometre 145 it is seen to be completely crushed into a true gneiss of extremely fine grain (A 81), in which the clusters of biotite have been drawn out into thread-like lines, only distinguishable by their dark colour.

The forces which produced so marked a structural change in this rock must have been considerable, and as they seem to have had no effect on the other rocks of the complex, we might safely regard the latter, even in the absence of further evidence, as being of subsequent origin, for there is no reason to suppose that they were of a more resistant nature than the granodiorite. When the stresses reached a maximum, relief appears to have been afforded by fracture, accompanied by the intrusion of a second type of igneous magma, for at the points where the gneissic structure is most completely developed (kilometres 145 & 149, west of Uchumayo) the rock is seen to be broken through by large basic intrusions in the form of a medium-grained green augite-diorite (A 84).

The constant occurrence of the latter rock in localities where the granodiorite has assumed a gneissic structure, can, I think, only be explained in this way, for the contact of the two rocks is distinct, and there does not appear to be any admixture of the two types, nor can the gneissic structure developed in the granodiorite be explained as having been formed by a process of injection.

The diorite consists chiefly of felspar, augite almost completely converted into a fibrous green actinolite, and a deep-brown biotite. Between kilometres 131 and 132 the granodiorite is again penetrated by a rock of somewhat similar character (A 77), paler in colour and with a considerable amount of unaltered pyroxene present.

The diorite forms the sides of the railway-cuttings and the river gorge between Uchumayo and Huaico (kils. 149–160). Like the granodiorite, it is frequently traversed by small veins of quartz and epidote, and near kilometre 153 it is associated with rocks resembling phyllites, which have the appearance of highly-metamorphosed sediments.

Near the station of Tiabaya, between kilometres 160 and 164 and again at kilometre 167, it is itself penetrated by a medium-grained grey granite or adamellite (A 85), representing the third and last phase of plutonic intrusion. This rock is composed of clear quartz, white felspar, hornblende, biotite, and small yellowish-brown crystals of sphene. Epidote, so abundant in the other members of the series, is typically absent. In general appearance it is not unlike the granite described above as cropping out in the desert near Huagri; but, owing to the isolated position of the latter, the correlation of the two is only a matter of conjecture.

Near the zone of contact the granite contains numerous basic inclusions of diorite, and it is obvious that these are fragments plucked off and partly absorbed, in the nature of accidental xenoliths ('enclaves énallogènes' of Prof. A. Lacroix).

The diorite shows clear signs of contact-metamorphism, chief of which is the formation of green hornblende in crystals of large size; it has also been considerably acidified by admixture with the granitic magma.

Locally, near the margin of contact, it assumes a finely-banded appearance, with the development of abundant minute flakes of biotite. This character, owing to its limited extent, is more probably the result of fluxion of the diorite, rendered viscous by the intrusive granite, than the effect of dynamic pressure; the microscopic features of the rock, in fact, are such that it appears to have been completely melted and recrystallized.

In discussing the general history of the complex, the three phases of intrusion, which may conveniently be termed the granodioritic, the dioritic, and the granitic, must be studied independently, although it will be seen that they are, in all probability, intimately connected; the magmas from which they were derived, moreover, may at one time have been coexistent in the same deep-seated reservoir.

In order that many of the observed phenomena may be more readily explained, it is necessary to assume that a certain degree of magmatic differentiation had been arrived at prior to the first intrusion. The granodiorite may then be regarded as representing more or less the normal composition of the original magma, from which the granite and diorite were derived as differentiation-products; the former richer in silica and alkalis, and the latter richer in ferromagnesian elements and lime.

In describing the granodiorite as the first phase of intrusion, it is important to note that this rock contains numerous basic patches, which in some places become so abundant that they completely alter its appearance. These are regarded as portions of dioritic magma, already in part consolidated, which have been incorporated in the residual magma and have undergone complete recrystallization, either in the process of digestion, or by the subsequent metamorphism to which the entire series has been subjected. The deep-seated origin of these xenoliths is assumed from the fact that no outcrop of basic rock earlier than the granodiorite was anywhere discovered.

The normal granodiorite, with its xenoliths of diorite, appears, next, to have been invaded locally by a highly-acid magma representing the other extreme end of the differentiation series. The result has been an admixture of the two types with the production of a hybrid rock of peculiar character. For the sake of distinction, I have termed this the abnormal granodiorite.

Beyond the limit to which actual assimilation of the earlier rock took place, there appears to be a considerable zone of contact-metamorphism, but the effects due to the one cause or the other are not readily distinguishable; they are, naturally, intimately connected, and therefore differ only in degree. Where the basic xenoliths of the original rock, however, are seen to retain their individuality, it may be assumed that the limit has been passed.

(At one time I thought that the acidification of the granodiorite might be due to assimilation of an original quartzite cover, but the appearance of the quartz-mosaic under the microscope makes it quite improbable that such was the case.)

Before discussing the origin of the xenoliths, some mention must be made of the metamorphism which they have undergone since their incorporation in the granodiorite. Three factors have to be taken into consideration. First, the effects produced by their initial capture and partial digestion; secondly, the effects due to the approach of the acid magma; and last, the effects of dynamic metamorphism. It is by no means easy to discriminate between them.

The most important change that can, I think, be referred to the first of these stages, is the complete recrystallization of many of the component minerals. This has resulted in the development of a deep-green strongly-pleochroic hornblende, in idiomorphic crystals remarkably fresh in character, and quite distinct from the pale yellowish-green variety found in the normal granodiorite.

The felspar, too, has been entirely recrystallized, and occurs in large clear crystals, in which are scattered abundant inclusions of magnetite in quadrate grains, and minute granules and prisms of hornblende. This new felspar appears to have the optical characters of andesine, and we may therefore infer that there has not been much change from the acid labradorite of the original rock.

In this connexion it should be noted that there is not very much epidote present here, whereas in the bulk of the granodiorite which has been acidified by admixture this mineral is abundant. Biotite in fresh unaltered crystals occurs in association with the hornblende; the latter, however, is usually idiomorphic to it. It is doubtful whether its origin should be attributed to the first stage of metamorphism, although it has the appearance of having been entirely recrystallized in common with the felspar and hornblende: for, in the hybrid rock produced by admixture of the normal granodiorite with the residual acid magma, it is seen to become, more and more, the dominant ferromagnesian mineral at the expense of the hornblende, from which, indeed, it appears in great part to have been formed. Moreover, where the latter rock has been crushed, hornblende entirely disappears, whereas biotite is persistent, a fact which suggests that its development may have taken place *pari passu* with the structural change.

Saussuritization of the outer zones of some of the felspars, together with fracture and dislocation of many of the hornblende-crystals, is a proof that they were formed prior to the development of the earth-stresses, and affords an indication that these were already beginning to make themselves felt.

From this stage, where no marked structural changes are visible in a hand-specimen, a complete transition can be traced into a fine-grained, intensely-crushed and banded gneiss, in which the effects of dynamic metamorphism have almost completely obliterated the original characters of the rock.

Before describing this change, however, attention must be directed to the contact-metamorphism of the normal granodiorite by the invading residual magma of highly-acid character. As has been mentioned above, it is not easy to distinguish the effects of contact from those of admixture.

The hybrid rock is characterized by an abundance of free silica, in the form of a coarse quartz-mosaic, of dusty appearance (owing to numerous inclusions), and by the presence of biotite in the form of aggregates of fresh unaltered crystals.

The felspars vary according to the proportion of the invading magma present in the rock. In acid types they are chiefly alkaline, and show sericitization; but, where the granodiorite is in excess, andesine is the dominant form. A few crystals show the original inclusions of magnetite and hornblende; but more usually they are seen to be in the process of recrystallization, with the production of a mosaic of secondary felspar of similar or slightly more basic composition.

Occasional deep-green crystals of hornblende are taken to represent xenocrysts derived from the basic patches, suggesting that the recrystallization of these had already taken place prior to the invasion of the acid magma.

The origin of the biotite clusters is of especial interest. Two possible sources suggest themselves:—

(1) That they are primary derivatives from the acid magma, of the nature of small glomeroporphyritic aggregates, formed in the normal order of crystallization. (2) That they are secondary products of metamorphism, built up at the expense of other minerals.

An examination of the altered granodiorite in the immediate neighbourhood of the acid rock supports the latter view. The characteristic green hornblende is here seen in process of conversion into a yellowish-green chloritoid substance, with which are associated abundant grains of magnetite and crystals of epidote. A segregation of these coloured minerals into patches is already noticeable, which it is not easy to reconcile with a simple process of contact-metamorphism alone, unless the rock has been rendered sufficiently viscous for diffusion to have taken place. By reabsorption of the magnetite the green chlorite becomes deep brown, and is gradually transformed into biotite.

Where the biotite clusters are fully developed the chlorite is typically absent, the magnetite has decreased considerably in quantity, and the green hornblende has almost entirely disappeared.

The granodioritic phase was brought to a close by the development of powerful orogenic movements, which produced intense crushing in these earlier-formed rocks of the complex. The dynamic action, however, was chiefly marginal in effect, and hence the most pronounced metamorphic phenomena attributable to this cause are not of wide extent.

The resultant changes which the rocks have undergone are both structural and mineralogical in character. Although the former are, of course, the more obvious, the latter make their appearance first, and indeed are observed before any actual deformation of the rock is noticeable. It is only by tracing such changes laterally from the seemingly unaltered rock into the crushed and banded gneiss that the true nature of their origin becomes apparent.

The characteristic green hornblende, for example, is then seen to have been formed prior to the crushing, for obvious effects of mechanical action are displayed in the breaking-up of well-defined crystals along cleavage-cracks and subsequent shearing into innumerable small rhombs and prisms, groups of which, more often than not, retain their optical continuity.

Moreover, except in the case of the gneiss formed by the crushing of the granodiorite where it was rich in basic xenoliths, in which hornblende was originally present in great abundance, this mineral is not characteristic of the banded rocks, and in specimens showing the most advanced stage of deformation it has almost completely disappeared.

In any process of orogenic movement the rocks involved must necessarily be subjected to tension as well as to compression, but in many descriptions of dynamic metamorphism it is not unusual to find that too much importance is attached to the latter factor.

It is conceivable, however, that the banding of a gneiss might in some cases be due to stretching alone, and indeed a study of the various stages of the dynamic action exhibited in the present suite of rocks suggests that tension has played a very prominent part in the production of the gneissic structure. For example, the drawing-out of more or less circular patches of biotite-flakes, first into lenticles and finally into long thread-like lines, is more readily explained by such a process than by one of squeezing or rolling-out due to compression: for, in a flexible mineral of this nature, the effects of the latter would be rendered obvious (as is not the case here) by bending and distortion of the lamellæ.

That the biotite may have been in part formed *pari passu* with the movement has already been suggested, but that its origin dates from a comparatively early stage in the metamorphism is clear from the evidence cited above.

The effects of dynamic action are indicated in the quartz at an earlier stage than in the felspar. First, optical disturbances make their appearance in the form of strain-shadows; a coarse mosaic is then developed by granulation; and finally by increased pressure, together with solution and concomitant crystallization, this becomes broken up and converted into a mosaic of extremely fine texture, composed of minute interlocking grains. Comparatively-large patches of clear recrystallized quartz are often seen to have been formed under the lee of a felspar-crystal which has protected them from further granulation.

Mechanical action is clearly shown in the case of the felspars by the bending and fracture of the twin-lamellæ, by the production of secondary lamellæ in the plagioclase, and microcline structure in the orthoclase. The final product is a felspar-mosaic produced by granulation.

That the force has been in many cases one of tension is indicated by the separation of fragments produced by fracture, the intervening spaces becoming filled with secondary quartz and felspar. In the case of compression, overthrusting of the fracture is frequently noticeable.

Apart from purely mechanical effects, the dynamic stresses have lent increased power to the agency of solution, and in this way have probably been largely instrumental in causing the recrystallization of the plagioclase in the form of albite, by the removal of lime as calcite or epidote: for, where the change appeared to be due to contact-metamorphism alone, the secondary felspar was found to differ but slightly from the original andesine, being in fact slightly more basic. The change is accompanied by removal of the inclusions, and by a gradual obliteration of the twin-lamellation.

One of the last stages of metamorphism before the final granulation takes place, is marked by a pronounced sericitization of the alkaline felspars, and thus it seems that this must also be attributed to dynamic agency.

The following descriptions give a more detailed account of some of the leading types :—

(A 76 *a*) Xenolith in granodiorite. (Kilometre 129.) (Pl. II, fig. 4.) A specimen selected from one of the basic patches which appear to be included xenoliths of an earlier-formed rock. A coarse-grained, holocrystalline, melanocratic rock composed largely of ferromagnesian minerals (hornblende and biotite).

Microscopic characters:—The rock has the appearance of having been entirely recrystallized: the three chief constituents—plagioclase, hornblende, and biotite—being remarkably fresh and free from alteration-products. No effects that can be attributed to dynamic metamorphism are noticeable, and it is probable that the recrystallization was the direct result of incorporation by the granodiorite magma.

The felspar, near andesine, occurs in the form of relatively-large clear crystals, characterized by abundant inclusions of quadrate grains of magnetite and minute prisms and rounded grains of hornblende. Twin-lamellation is often ill-defined.

A strongly-pleochroic deep-green hornblende is abundant; it tends to show idiomorphic contours to the biotite, which is also present in considerable quantity. Both minerals seem to have recrystallized in common with the felspar.

Stout prisms and needles of apatite are fairly numerous, and epidote, sphene, and calcite occur sparingly.

Magnetite is chiefly confined to inclusions in the felspar.

(A 76) Metamorphosed granodiorite. (Kilometre 129.) A specimen showing the result of invasion and metamorphism by an acid magma.

In a hand-specimen this rock is almost identical with the granodiorite of Posco (A 95).

Microscopic characters :—The rock consists essentially of quartz, felspar, and hornblende, with secondary biotite and epidote, and accessory sphene, apatite, and magnetite.

The ragged outlines of the felspar and hornblende show clearly the effects of corrosion by the invading magma, which has consolidated in the form of a coarse quartz-mosaic.

Hornblende is abundant, and has the appearance of having been recrystallized. It is intensely pleochroic, with colours ranging from yellow to a deep bottle-green. The crystals are often fractured, the spaces between the separate fragments being filled with secondary quartz and felspar.

Biotite is not abundant; it is here seen in process of formation from large patches of green chlorite crowded with magnetite and epidote, which are being produced at the expense of the hornblende.

Clear andesine-crystals with inclusions of magnetite and hornblende, as in A 76 *a*, are occasionally noticeable; but for the greater part the felspar appears to be in process of recrystallization. The secondary felspar forms a fine granular mosaic similar in appearance to micropegmatite—in fact, except for an occasional indication of twinning, it is not easy to distinguish it from the quartz with which it is associated. Its refractive index is higher than that of the original andesine, and it would therefore appear to be a more basic variety, the addition of lime being possibly explained by the disappearance of the numerous inclusions of hornblende. The change is accompanied by a gradual loss of twin-lamellation.

(A 83) Metamorphosed granodiorite. (Kil. 149.) A specimen intermediate in character between the abnormal acid granodiorite and the true banded gneiss into which it passes. The effects of dynamic action have now become well marked.

The rock has a peculiar and characteristic appearance in a hand-specimen, due to the development of clusters of biotite. Much of the felspar is of a dull greenish colour, suggestive of saussuritization.

Microscopic characters:—Hornblende has now entirely disappeared, and the chloritoid patches have been converted into aggregates of clear biotite-flakes, most of the magnetite having been absorbed in the process. Occasional clusters of magnetite-grains associated with epidote, however, are also visible.

Although a certain amount of andesine is still present, the bulk of the triclinic felspar appears to be albite, having a refractive index distinctly lower than that of quartz and balsam. That this change may be regarded as one of saussuritization is shown by the numerous aggregates of zoisite-grains scattered throughout the felspar substance. With these are associated larger grains of epidote and a green mineral, showing pleochroism and a moderately-high double refraction, which appears to be hornblende. In addition to these inclusions, the alkaline felspars are crowded with flakes of colourless mica, a type of alteration which seems to belong to a comparatively late stage in the dynamic metamorphism.

Peripheral granulation of the felspar-crystals, which ultimately leads to the formation of an albite-mosaic, is also visible, and the orthoclase shows indications of microcline structure.

(A 81) Gneiss. (Kil. 145.) This specimen represents the most advanced stage in the dynamic metamorphism of the granodiorite, being the final product in the transition from A 83.

It is a uniform pink banded rock of splintery fracture and extremely fine grain. The ferromagnesian minerals are no longer recognizable, each individual crystal or group of crystals having been drawn out into microscopic thread-like lines.

Microscopic characters:—The rock exhibits pronounced cataclastic structure. The coarse quartz-mosaic has become crushed or drawn out in the direction of movement, individual grains having been fractured, ground down, and rewelded into a finer mosaic, together with a mass of clear recrystallized felspar.

A few of the larger crystals of felspar having partly escaped this grinding process, except for marginal granulation, remain embedded in the granular matrix (mortar-structure), and show distortion and fracture of the twin-lamellæ.

Hornblende is entirely absent, and the scaly aggregates of biotite have become elongated into flattened lenticles or long drawn-out lines.

A few crystals of apatite still persist; but epidote and magnetite are not abundant.

(A 79) Basic gneiss. (Kil. 139.) (Pl. II, fig. 3.) This specimen shows the effect of intense dynamic action on the more basic type of granodiorite rich in xenoliths.

Microscopic characters:—The constituent minerals have a strongly-marked parallel arrangement. Biotite and hornblende are present in about equal quantity, and tend to occur in alternating bands—due to the breaking-up and drawing-out of individual crystals.

The original crystals of hornblende have broken along their cleavage, and have been sheared into innumerable small prisms and rhombs, groups of which still show optical continuity.

Distortion and fracture of the plagioclase is very well marked. A feature of the rock is the extensive development of magnetite, in the form of minute grains scattered throughout the hornblende and biotite.

The second or dioritic phase was marked by the intrusion of melanocratic rocks of basic character.

Although for the greater part these have undergone profound modification, their original composition can be determined from some of the less altered examples which may be classed with the augite-diorites. In many cases, however, the pyroxene has been almost completely converted into fibrous hornblende. The almost constant association of these unbanded rocks with the gneissic modification of the granodiorite has already been noted. They are unaffected by the forces which produced such intense deformation in the latter rock, and are therefore regarded as constituting a distinct phase of intrusion, their localization having been determined by lines of weakness which were evidently developed in areas of maximum deformation. Although the dynamic stresses never again attained such a degree of magnitude, the abundant quartz-epidote veins which mark lines of fracture in both the diorite and the older rocks show that the district was still subjected to considerable earth-movements. The mineralogical changes which have affected the diorite over wide areas, as exemplified by the uralitization of the pyroxenes and the saussuritization of the felspars, cannot be ascribed to any mere process of weathering, or even to contact-metamorphism: for the distinctive effects of the latter, to be described later, are clearly exhibited where the rock is penetrated by the acid magma of the third or granitic phase.

It would appear, therefore, that their origin must be attributed to some other cause, and the most plausible suggestion is that they are the effects of waning dynamic action which was no longer sufficiently great to produce macroscopic structural change. This theory is supported by microscopic investigation.

The most distinctive feature of the altered rock is the fact that, when viewed with ordinary light, each individual crystal, almost without exception, is clearly defined by an opaque dust-like margin. Under a high magnification this is seen to be composed of minute granules, which appear to be chiefly epidote. The rock, then, has been rendered completely permeable to solution from the large epidote-lined fissures with which it abounds, down to the finest capillary cracks: the bulk of the epidote being evidently derived from the pyroxene during its conversion into hornblende.

This pronounced permeability, which is not possessed to the same extent by the coarser granodiorite (although the latter contains much disseminated epidote), appears to be due to incipient granulation of an even-textured rock of relatively fine grain, as a result of the action of dynamic stresses.

Further evidence of internal movement is also afforded by the biotite, which occurs in the form of somewhat large plates that have been fractured and sheared into irregular fragments, still preserving their optical continuity, though separated by patches of clear plagioclase and quartz. This feature, in fact, is even visible in a hand-specimen, the plates of biotite giving a distinctive lustre-mottling to the rock.

(A 77) Augite-diorite. (Kil. 132.) This rock consists essentially of plagioclase, a colourless augite and biotite, with a little quartz and orthoclase and accessory magnetite, apatite, epidote, and chlorite.

The plagioclase (medium labradorite) is clear and fresh, showing twinning on the albite and pericline laws. It is in considerable excess of the orthoclase, to which it is idiomorphic.

Chestnut-brown biotite and a pale-green or colourless augite are present in roughly equal proportions, the former showing alteration into chlorite and epidote. The augite occurs in the form of irregularly-bounded crystals, showing multiple twinning and incipient alteration into a fibrous uralitic hornblende.

A small amount of interstitial quartz, magnetite in some abundance, and a little apatite are also present.

(A 84) Saussuritized diorite. Huaico (kilometre 156). This rock is a modification of the foregoing, in which the pyroxene has been almost completely converted into a bluish-green fibrous actinolite, frequently showing a fringe of secondary biotite.

A deep-brown biotite also occurs, in the form of large irregular plates usually surrounding magnetite.

Although a considerable amount of plagioclase is clear and unaltered, most of the larger crystals are opaque with decomposition-products: these consist chiefly of minute highly-refracting prisms and granules, which between crossed nicols show the bright interference-colours of epidote and the deep blue of zoisite, the change therefore appearing to be one of saussuritization. It is difficult to determine the nature of the original felspar, but the extinction-angles when visible suggest that it was less basic than the unaltered crystals, which are acid labradorite.

The general appearance of the section, however, makes it not improbable that we are dealing here with a mixed rock, and the fresh felspar and most of the quartz, which occurs in some abundance, may have been derived from an extraneous source.

The third and final phase in the sequence was marked by the intrusion of a granitic magma of acid character, probably derived from the same deep-seated reservoir as that which furnished the acid magma which invaded the granodiorite. Its intrusion, however, is obviously of much later date, for it has nowhere been affected by the dynamic stresses which produced so marked a structural change in the latter rock. It is seen, moreover, to be posterior to the dioritic rocks of the second phase, for these show clearly the effects of contact-metamorphism at the points of junction.

The typical rock of this granitic phase is a coarse-grained grey adamellite, very similar in appearance to the rock previously mentioned as cropping out in the desert near Huagri. It is extensively quarried, for building-purposes, in the neighbourhood of Tingo, and has been used in the construction of the mole at Mollendo. Near its junction with the diorite it contains numerous small basic patches, which are obviously fragments of the latter rock plucked off and partly absorbed. These xenoliths have been almost entirely recrystallized, with the development of relatively-large phenocrysts of a strongly-pleochroic deep-green hornblende; traces of original augite with multiple twinning, however, are still visible.

The diorite along the margin of contact appears to have been completely fused, and has assumed a finely-banded structure due to fluxion.

The subsequent recrystallization of the component minerals throws considerable light on the origin of the xenoliths in the granodiorite of the first phase, the marked similarity of the resultant products of metamorphism in the two cases being a strong argument in favour of the theory that the latter were derived from a deep-seated dioritic magma, although this does not appear to have been drawn upon extensively until a later period in the history of the complex, as exemplified by the rocks of the second phase

In the case of the earlier xenoliths, owing no doubt to a higher degree of viscosity, there seems to have been but little fluxional movement, and as a result, the growth of individual crystals was unrestricted. In the present case, however, the diorite was rendered completely molten by the invading granite, and movement taking place during consolidation, the crystals were broken up as they formed, and in consequence never attained large dimensions.

There is direct and unmistakable evidence that the secondary green hornblende has here been derived from pyroxene, even though the latter had in some cases been uralitized previous to recrystallization. It is not unreasonable, then, to conclude that the xenoliths in the granodiorite also had their origin in a pyroxene-bearing diorite: for, notwithstanding the difference in texture of the two rocks, their mineralogical characters are almost identical; the resemblance being especially well shown in the case of the glassy-clear recrystallized andesine, with its abundant minute inclusions of hornblende, biotite, and magnetite (see Pl. II, fig. 4).

(A 85) Adamellite. Tiabaya (kilometre 161). This rock consists essentially of quartz, orthoclase, plagioclase, hornblende, and biotite, with accessory sphene, magnetite, apatite, and zircon.

Clear quartz is abundant.

Orthoclase occurs in large plates surrounding idiomorphic crystals of plagioclase (andesine–acid labradorite), showing albite-twinning and zonary structure. The two forms are present in about equal proportions, and are remarkably clear and fresh.

The ferromagnesian minerals, which are quite subordinate to the felspars, comprise idiomorphic green hornblende, twinned parallel to 100, and brown biotite showing alteration into chlorite.

Magnetite and sphene are of fairly-common occurrence, the latter in well-developed crystals.

Apatite and zircon occur sparingly.

Associated with the adamellite, and veining both this rock and the older diorites, are a few fine-grained acid dykes. These consist of quartz and turbid orthoclase, often in micropegmatitic intergrowth, subsidiary plagioclase, a little biotite mostly altered to green chlorite and epidote, some magnetite and apatite, and a small amount of tourmaline with characteristic blue and brown pleochroism.

The last-named mineral, however, is never abundant in this area, in which respect the rocks of the complex differ in a marked degree from those of the plutonic batholite of the Arica–La Paz section, where tourmaline-pegmatites are of common occurrence; moreover, it is found here in the form of small isolated crystals, and not in the coarse radial aggregates so typical of that district.

The several stages in the general history of the complex may be summarized as follows:—

(1) The intrusion, probably into Mesozoic strata, of the Quishuarani granodiorite, comparable with that of the Cachendo foot-hills.
(2) Its invasion by a residual acid magma.
(3) Its subjection to powerful earth-stresses, which produced intense dynamic metamorphism, with the local development of gneissic structure, and culminated in:
(4) Fracture, with the intrusion of the augite-diorite of Huaico.
(5) Formation of numerous quartz-epidote veins.
(6) Intrusion of the Tiabaya granite (adamellite) comparable with that of Huagri, producing contact-metamorphism of the diorite.
(7) Final intrusion of minor acid veins containing tourmaline.

(2) The Geological Structure of the Country between Arequipa and Puno.

The Uchumayo Valley, as has already been mentioned, forms a natural line of division between the Cerros de la Caldera and the lofty peaks of the Western Cordillera. On its south-west side lies the plutonic complex just described, while on the north-east is found a thick accumulation of bedded volcanic tuffs, ejected from Mount Chachani and El Misti.

Prior to the cutting of the valley, these tuffs must have extended far towards the coast, for their scattered remains are frequently visible lying as a denuded mantle on the older rocks. Isolated blocks of lava are even met with as far as Vitor; but, as a rule, the eruptions seem to have been chiefly of an explosive nature, resulting in the formation of well-bedded compact tuffs, pure white or of a pink colour, containing abundant fragments of pumice. These tuffs are extensively quarried in the neighbourhood of Arequipa for building-purposes.

True lavas are more or less confined to the vicinity of the mountains. They have already been fully described by Dr. F. H. Hatch, and it is therefore hardly necessary to make more than a passing reference to them here. That author has shown that most of the lavas of the Arequipa district belong to the andesite group, and he has further subdivided them, according to their dominant ferromagnesian mineral, into hornblende-andesites, augite-andesites, hornblende-augite-andesites, and andesites with hypersthene in addition to the former minerals.

Many of the hornblende-andesites bear a striking resemblance to the trachy-andesites described by me from Mount Taapaca in Northern Chile, while the augite-andesites are very similar to those from Mount Tacora.

The volcanic peaks, with the exception of Ubinas a little farther south, which was smoking at the time of our visit, are no longer active, though El Misti still preserves a remarkably fine crater, and signs of latent activity are not wanting in the district.

The effects of a small volcanic earthquake which occurred on April 28th, 1911, were described to me by Mr. Vogel, of Arequipa. While looking down from the astronomical observatory he noticed a thick cloud of dust passing like a sudden wave through the city, and at the same time felt a distinct earthquake shock. He afterwards found that the dust was due to the collapse of buildings constructed of 'adobe' and light volcanic tuff. The wave had left a well-defined track in its wake, on either side of which the houses remained unaffected. Such an extremely-localized shock suggests the formation of a subterranean fissure or dyke.

Some distance north-east of El Misti, in a little tributary valley of the River Sumbay, we also encountered numerous hot springs highly charged with sulphuretted hydrogen and alkaline salts.

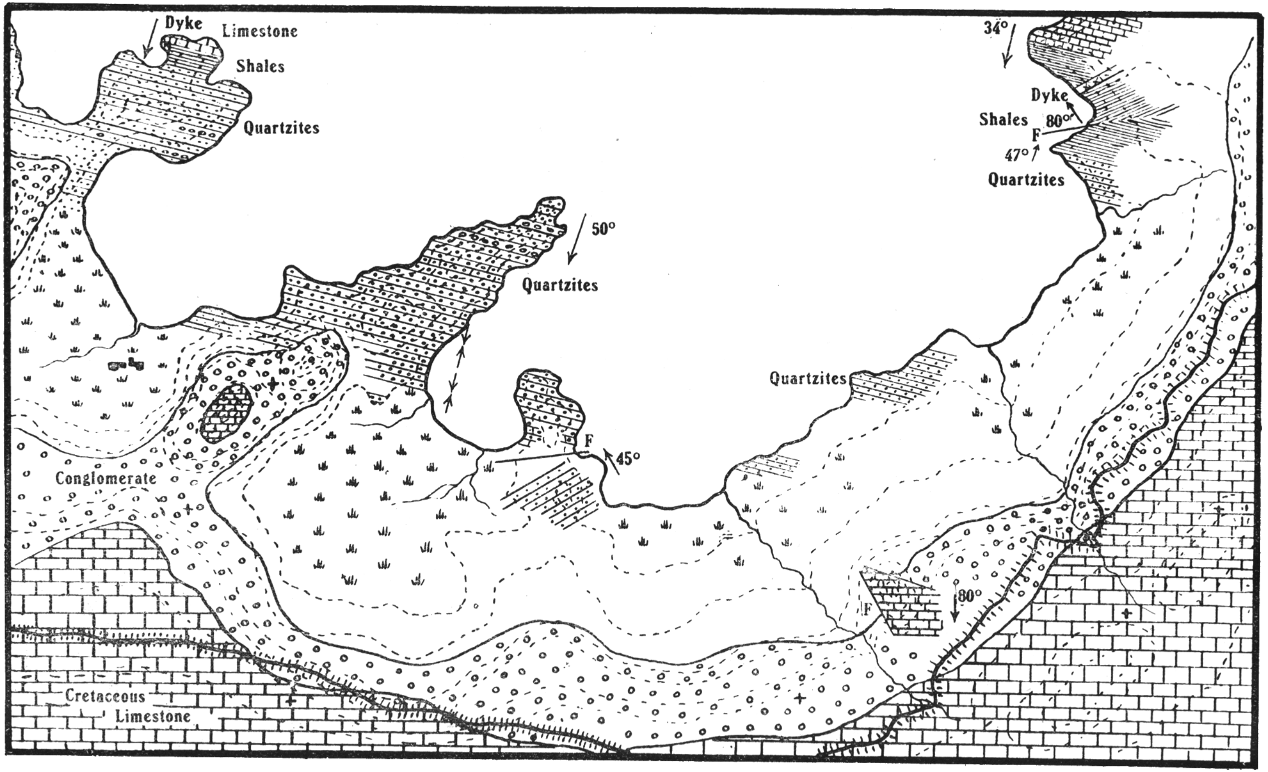
The general sequence of the volcanic deposits is well exposed in the valley of the River Chili, the railway-cuttings round the foot of Mount Chachani, and in the gorge of Uyupampa beyond Yura. Here, too, they consist chiefly of false-bedded, white, yellow, and grey tuffs, with occasional darker bands of coarse ash.

When the line is followed towards the east, the country is found to be very like that of the Mauri-River district in Bolivia, for it is buried beneath a thick mantle of pumiceous tuffs which give the same peculiarly monotonous aspect to the landscape. In many localities, however, the surface is relieved by fine examples of 'Zeugen' or rock-tables, formed of hard blocks of lava capping pillars of less resistant tuff which have been undercut by the erosive action of wind and rain. In places these are so numerous that they are termed by the natives 'rock-forests.' The tuffs frequently exhibit polygonal jointing on a very minute scale.

In addition to this volcanic covering, the structure of the underlying country is further obscured by extensive swamps and thick alluvial gravels, composed chiefly of pebbles of quartzite and rocks of igneous origin; these sometimes cover wide tracts, such as that between Vincocaya and Crucero Alto, and have the appearance of being old lake-deposits. The quartzite-pebbles have evidently been derived from a series of beds which only occasionally crop out at the surface.

Rocks of this nature were first met with on the banks of a small tributary of the River Sumbay, where they were found to consist of unfossiliferous white quartzites, dipping 10° south-westwards. They are broken through by a small volcanic neck filled with a coarse agglomerate. Similar beds of quartzite also crop out on the road to Pucacancha, and occasionally form low hills bounding the alluvial flats between this point and the summit of the line.

Fig. 2.—*Sketch-map showing the Cretaceous unconformity at Lagunillas. Approximate scale, 1 : 15,000.*



In the complete absence of palæontological evidence, they are here provisionally regarded as forming the continuation of the Mesozoic (probably Jurassic) zone of the foot-hills.[1]

After crossing the divide at Crucero Alto, and continuing in the direction of Lagunillas, we meet with a further series of igneous rocks (at kilometre 204), which appear to be totally distinct from those described above as lying within the volcanic zone of the Western Cordillera. They consist, for the greater part, of dark amygdaloidal basalts, weathering brown or red, and containing abundant traces of copper in the form of carbonates.

The amygdules are usually filled with calcite or chalcedony, and small porphyritic crystals of augite are also visible in the groundmass. These lavas are associated with beds of coarse volcanic breccia, which contain blocks of lava, sometimes more than a foot in diameter, set in a matrix of white tuff. Such beds appear to have been formed by a brecciation of the lava *in situ*.

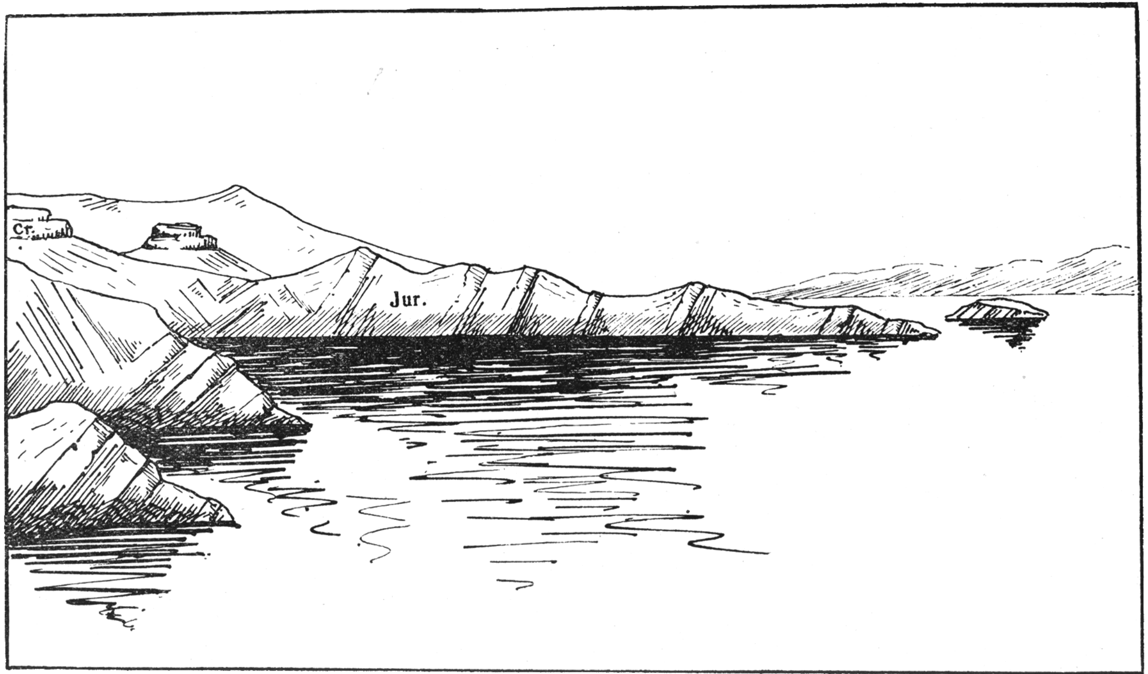
Beyond Lagunillas Station a further change takes place in the nature of the landscape: the volcanic covering has entirely disappeared, and the structure of the underlying country again becomes visible. The railway-cuttings between this point and Saracocha reveal a thick series of grey cherty limestones. These beds cap the hills on the south of the lake, and have, in some cases, the appearance of reef-knolls, occurring in more or less isolated masses which pass laterally into red marls. They are frequently much dolomitized, and included fossils are extremely rare; a few weathered fragments of echinoderms and lamellibranchs were obtained, however, and these leave little doubt that the limestones are of Cretaceous age, having been formed during the period of wide transgression which is represented in the north by a limestone series of similar appearance, but of extremely fossiliferous character.

At the base of the Saracocha limestone occurs a thick purple conglomerate, which rests with marked unconformity on an underlying series of quartzites and shales, with occasional dark-grey limestones (see sketch-map, fig. 2). This conglomerate is well stratified, and frequently contains bands of red marl, devoid of pebbles. Its lowest beds are composed almost entirely of quartzite-pebbles derived from the underlying rocks, while those above contain abundant well-rounded pebbles of igneous origin (chiefly porphyrites and hornblende-diorites), together with scattered subangular and rounded blocks and pebbles of cherty limestone, evidently derived *in situ*.

The source of the igneous pebbles is a matter for some speculation. They are composed, for the most part, of rocks entirely dissimilar to any found in the district, and it is only possible to conclude that they were derived from an older series of plutonic rocks with their

[1] Dr. Erich Jaworski mentions the occurrence of Bajocian-Bathonian beds at Lumbay (Sumbay ?) on the railway from Arequipa to Puno, from the discovery of cherty limestone with *Nerinea bathonica* Rig. & Sauv., Neues Jahrb. Beilageband xxxvii (1913) p. 305.

Fig. 3.—*Horizontal Cretaceous beds lying unconformably on folded Jurassic, Lagunillas.*



J.A.D. del.

associated dykes, which formerly cropped out farther west, but are now completely concealed by the Tertiary volcanic covering.

The diorite of Maravillas, described below, to which they bear some resemblance, breaks through the limestones, and is obviously an intrusion of post-Cretaceous age.

The red marls with which the limestones are associated are very similar in appearance to the Cretaceous marls of the Coro Coro district of Bolivia, and the thinning-out of the limestones when followed in this direction shows that, while the country in the north gradually became depressed beneath the waters of the Cretaceous sea, shallow-water conditions continued to prevail in the south.

The conglomerates and overlying limestones undulate but slightly in the neighbourhood of Lagunillas. Between the two lakes, however, they show indications of being much faulted, and dip steeply until they reach the valley-floor, the conglomerate attaining its greatest development in the rugged cliffs bounding the eastern basin.

The physiography of the district is also of considerable interest, and it is a matter of some difficulty to account for the origin of these twin lakes, separated by a steep though narrow neck of land. The most probable solution is that they owe their position to faulting on a large scale.

Numerous instances of minor faults, affecting both the Cretaceous and the underlying rocks, are, indeed, visible along the shores of Lagunillas, where they are occasionally associated with igneous intrusions in the form of small basaltic dykes. Although these seem to bear little relation to the present contour of the lakes, they at least show that the district was subject to dislocation and subsidence, and in this way relief may have been obtained from the earth-stresses which a few miles away to the east have caused pronounced folding in the Cretaceous limestones.

Beneath the basal conglomerates of this series lies an older system of rocks, which are well exposed on the promontories of the lake-shore, where they consist of false-bedded white and yellow quartzites, frequently containing bands of small white quartz-pebbles. They are strongly folded, but have a general dip of about 45° south-south-westwards (see fig. 3). Most of these beds appear to be unfossiliferous; but near the base occur black shales and a thickly-bedded, dark-grey, cherty limestone which yielded a scanty and badly-preserved fauna, comprising one or more species of brachiopods (*Terebratula*), gasteropods (*Nerinea*), and a lamellibranch (*Perna*). These remains were much silicified and difficult to extract, and they seemed to afford little clue as to their age. Mr. S. S. Buckman, however, has kindly examined some of the specimens for me, and reports that the Terebratulas almost certainly belong to the *perovalis* group, and as such, indicate beds of Inferior Oolite age, *discites* zone.[1] The fragmentary

[1] Cf. *T. perovalis* Gottsche *non* Sowerby, pl. iv, fig. 9, 'Beiträge zur Geologie & Paläontologie der Argentinischen Republik' Palæontographica (1878), Naturgesch. der Vorwelt, Suppl. iii, Lief. ii, Heft 2.

remains of *Perna* he compares with specimens from the '*Witchellia*' Beds of Cold Comfort, near Cheltenham (*P. mytiloides* Bronn).[1]

In a palæontological map of Peru, recently published by Prof. Carlos Lisson, of Lima, a considerable area lying on the north-west of Puno is coloured as Lower and Middle Jurassic, from the reported occurrence, at a locality known as Compuesta, of an ammonite which he calls '*Reineckia anceps*.' This solitary piece of evidence, however, can hardly be deemed sufficient to warrant the mapping of so extensive an outcrop as that depicted. Most of this area is covered by transgressive Cretaceous deposits, and the specimen mentioned was probably obtained from the underlying Jurassic beds, which appear to be of somewhat limited extent.

Petrographical Notes.

(A 111) Basalt. Lagunillas.

Microscopic characters :—This rock contains idiomorphic phenocrysts and aggregates of smaller crystals of a colourless augite, showing twinning on the orthopinacoid, also zonary and hour-glass structure, with less abundant greenish-brown hornblende and brown biotite, both possessing well-marked resorption-borders.

The felspars do not occur as phenocrysts, and in this respect the rock has a certain resemblance to a basic lamprophyre.

The ferromagnesian phenocrysts are set in a fine-grained hyalopilitic ground-mass, composed of felspar-microlites (labradorite) with a more or less parallel arrangement in lines of flow, granules of augite, magnetite, and corroded flakes of biotite.

An olivine rich in iron (hyalosiderite), of a deep golden-brown colour, also occurs in sporadic crystals.

(A 112) Olivine-basalt. Saracocha. This rock occurs in the form of dark microcrystalline dykes cutting the limestone series on the shores of Lagunillas. It contains small phenocrysts of augite and brown pseudomorphs after olivine.

Microscopic characters :—Augite occurs in the form of relatively-large, pale-green, idiomorphic crystals, showing well-marked twinning and occasional zonary structure.

Large pseudomorphs with the characteristic outlines of olivine are also abundant. These consist of a network of fibrous serpentine, crowded with minute rhombs of calcite, and patches of a clear, colourless, isotropic mineral.

The felspar-crystals (basic labradorite) are confined to the ground-mass, which is holocrystalline and shows little or no trace of flow-structure.

It consists of minute, elongated, idiomorphic prisms of augite, larger lath-shaped crystals of labradorite, showing lamellar twinning and zonary structure, and frequent grains of magnetite; there is also much limonite in the more weathered portions, and an abundance of carbonates (calcite or magnesite).

From the Saracocha Lake to Santa Lucia, the structure of the country is somewhat obscured by a covering of volcanic tuff; but, as we approach Maravillas, an extensive development of pale-grey cherty limestone is again met with, being the continuation of the Cretaceous limestone-series of Lagunillas. In this district, however, the rocks have been strongly folded, and are penetrated by

[1] In R. I. Murchison, 'Geology of Cheltenham' 2nd ed. (1845) p. 76.

large intrusive masses of diorite. The diorite of Maravillas, both in petrographical characters and in mode of occurrence, is essentially similar to the rock previously described by me from Comanche in the Arica–La Paz section; moreover, though the country-rock is of an entirely different nature in the two areas (in the former case being a red sandstone, the 'Puca' sandstone of Steinmann), the intrusions are associated in both instances with productive copper-ores. We may reasonably conclude, then, that we are here dealing with the northward prolongation of that post-Cretaceous line of dioritic intrusion, which runs through Comanche and the Cerro de las Esmeraldas farther south in Bolivia; a line which is probably continued still farther northwards into the district drained by the Apurimac River.

It is interesting to note that the rocks in the immediate neighbourhood of the diorite do not appear to be cupriferous, and the mines are usually situated at some little distance from the actual contact. This fact has led some observers to regard the occurrence of the ore as being in no way connected with the igneous intrusion. After visiting both districts, however, I find it impossible to uphold such a theory.

The association of these rich copper deposits with the diorite is too striking to admit of any other explanation than that they were produced as a direct result of the intrusion; and, in view of the known distribution of the ore at some distance from the outcrop of plutonic rock, the absence of the latter from the mines of Coro Coro is an argument in favour of, rather than against, this theory: for, if we judge from the outcrops at Comanche and the Cerro de las Esmeraldas, we may reasonably infer that the diorite here lies at no great depth below the surface.

Although many of the mines have been worked ever since the time of the Spanish conquest, and in some cases previous to that date, the recent discovery of another rich ore-bearing district during the construction of the Arica–La Paz railway shows that the intervening country has not yet been thoroughly prospected with a proper appreciation of the facts.

(A 118) Diorite. Maravillas.

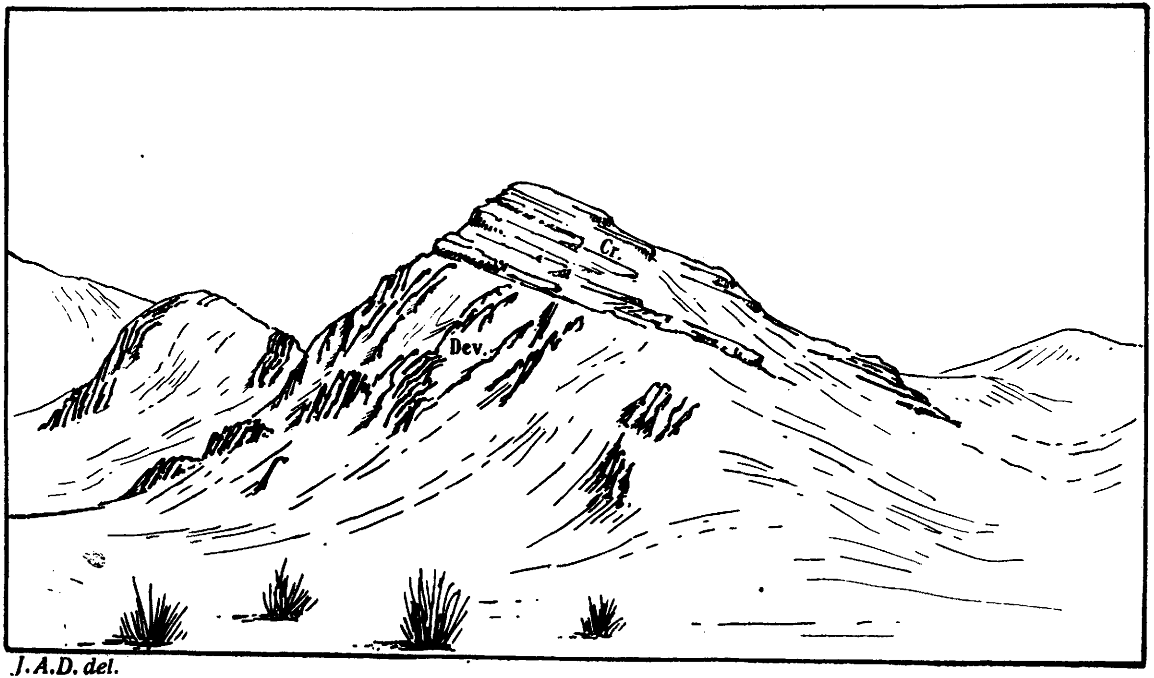
A grey holocrystalline rock of medium texture, almost identical in appearance with the Comanche diorite of Bolivia.[1] It consists essentially of white plagioclase and dark-green hornblende with, in the present case, a few flakes of biotite in addition to the latter. Small rounded patches of more basic composition, having the appearance of cognate xenoliths, are of common occurrence.

Microscopic characters:—A thin section of the rock, when viewed between crossed nicols, has a very peculiar appearance. This is due to the presence in great abundance of minute rounded and irregular grains of quartz, which seem to have been derived from the sedimentary rocks (chiefly Devonian quartzites), through which the dioritic magma has made its way towards the surface.

The plagioclase (an acid labradorite) shows little signs of alteration,

[1] See Q. J. G. S. vol. lxx (1914) p. 29 & pl. v.

Fig. 4.—*Cretaceous beds lying unconformably on steeply-inclined Devonian quartzites, Taya Taya.*



J.A.D. del.

and is remarkable for its pronounced zonary structure: a characteristic feature of the Comanche rock (see *op. cit.* pl. vii, fig. 5). It tends to be porphyritic in habit, having crystallized in general before the hornblende; numerous small crystals are also frequently enclosed in pœcilitic fashion by plates of the latter.

A yellowish-brown biotite is present, in addition to the green hornblende; they both show ragged outlines, and are but seldom idiomorphic. This, however, is a feature apparently due to subsequent partial solution in the magma, after they had assumed the crystalline form.

Magnetite is fairly abundant, and there is also a considerable amount of calcite.

Apatite occurs sparingly in small prisms.

Although the rock has undergone so profound a modification, all the essential underlying features of the Comanche diorite can at once be recognized.

The absorption of so large an amount of extraneous material would appear to suggest a batholitic mode of intrusion, rather than, as appears to be the case where it penetrates the Cretaceous limestones, one involving actual displacement of the strata. The latter rocks, however, are intensely folded, while the underlying Devonian quartzites, although dipping steeply, approach the diorite without any sign of such disturbance.

It is conceivable, then, that the magma gradually stoped its way by batholitic replacement through these ancient and resisting rocks, becoming much acidified in the process, and on reaching the overlying Cretaceous deposits, which, if we judge from the neighbouring districts, were at that time little folded, it encountered a less resistant mass capable of being removed from its path by the more drastic and rapid method of bodily displacement.

Much of the silica, derived according to this theory from the Devonian quartzites, must have become dissolved in the igneous magma, thereby rendering it increasingly acid, and causing a partial resorption of those minerals which had already begun to crystallize: of these the hornblende and biotite were most readily attacked, and their idiomorphic contours have been almost entirely destroyed.

Finally, the residue of the acidified magma consolidated as an intergrowth of quartz and plagioclase, the latter of a more acid variety than the phenocrysts. The rounded outlines of many of the quartz-grains, however, make it probable that they represent original sedimentary material that has been derived and corroded, but not fully dissolved.

The alluvial pampa of Maravillas ends in a somewhat narrow river-gorge, flanked on each side by cliffs of limestone and crimson marl; a short distance farther on, however, the valley once more expands to form the pampa of Taya Taya, and from this point to Lake Titicaca the fall of the river is very slight (about 1 in 1250).

On entering the pampa we meet for the first time with Palæozoic rocks. These are of Devonian age, and form an unbroken series on the north of the valley as far as Cabanillas, with an almost constant dip of 45° east-north-eastwards (see Pl. V).

On the south, however, the Cretaceous limestone continues as far as Taya Taya, where, capping the prominent escarpment behind the station, it rests with striking unconformity on the older series (see fig. 4, p. 34). The chocolate-coloured conglomerate of the Saracocha district is no longer represented: the basement-beds here consist of a white and pinkish quartzite-breccia, derived *in situ* from the underlying rocks.

In places, small isolated hills, with conspicuously rugged outline, mark the outcrop of the diorite.

The Devonian beds, which are almost bare of vegetation, are readily accessible by fording the river at Taya Taya, where they are found to consist of olive-green grits and sandstones and black ferruginous shales. Although for the greater part of their extent they appeared to be unfossiliferous, the shales opposite Las Huertas yielded a fairly prolific fauna.

The lowest beds are here crowded with crinoid-stems and the hollow casts of a bryozoan; these are succeeded by shales containing abundant brachiopods:—*Leptocœlia*, *Tropidoleptus*, *Spirifer*, *Chonetes*, etc., usually preserved in the form of casts. The highest beds of the series consist of black shales, with rounded concretionary nodules, which are highly fossiliferous, yielding several species of *Conularia*, and an occasional trilobite. Although many of the specimens recorded in the accompanying list, owing to their poor state of preservation, are of little value for the purposes of correlation or description, an analysis of the collective fauna clearly shows that these Devonian beds of Taya Taya correspond to the upper part of Steinmann's 'Icla Schiefer' of Bolivia, characterized by *Leptocœlia flabellites*; and, from the abundance of the genus *Conularia*, they may be considered as the equivalent of his '*Conularia*-Shales.'

Liorhynchus bodenbenderi, *Leptocœlia acutiplicata*, and *Scaphiocœlia boliviensis*, the forms characteristic of the Devonian beds of Coniri regarded by me as of Lower Devonian age, appear to be unrepresented in the district now described, and the continuation of these beds must be sought still farther west, where they are buried beneath the transgressive Cretaceous rocks. The Taya Taya beds, then, probably represent a somewhat higher horizon, and may be correlated with the *Marcellus* Shales, or lower division of the Middle Devonian Hamilton Group of North America.

FAUNAL LIST.

Orthoceras sp.
Bucaniella aff. *dereimsi* Knod.
Platyceras sp.
Nuculites sp.
Conularia africana Sharpe.
Conularia baini Ulrich.
Conularia quichua Ulrich.
Conularia acuta A. Rœmer.
Hyolithes sp.
Rhynchonella sp.
Tropidoleptus carinatus Conrad.
Spirifer aff. *mucronatus* Conrad.
Spirifer cf. *antarcticus* Morris & Sharpe.
Spirifer planoconvexus Knod.
Chonetes arcei Ulrich.
Chonetes aff. *coronata* Conrad.
Orthotetes cf. *chemungensis* Conrad.
Leptocœlia flabellites Conrad.
Dalmanites sp.
Phacops cf. *rana* Green.
Phacops aff. *schlotheimi* Kayser.
Proëtus sp.
Bryozoa and crinoids.

PALÆONTOLOGICAL NOTES.

CONULARIA AFRICANA Sharpe. (Pl. I, fig. 1.)

This species, which was originally described by Sharpe from the Bokkeveld Beds of South Africa,[1] is characterized by the fact that the interspaces between the transverse ribs, in all states of preservation, are entirely devoid of any longitudinal striation. The smooth and somewhat pronounced transverse ribs are bent sharply towards the mouth, meeting along the median line on each side of the pyramid at an angle of about 120°. One specimen was obtained which showed that the ribbing is continued over the inner surface of the incurved lobes of the aperture.

This form has also been described from Bolivia by Ulrich.[2]

CONULARIA BAINI Ulrich. (Pl. I. fig. 2.)

Numerous examples of this species were obtained from the ferruginous nodules in the upper shales of Taya Taya, the reticulate appearance of its ornamentation readily distinguishing it from *C. africana*, with which form it has been confused by Knod.[3]

The transverse ribs, which curve towards the mouth and do not bear tubercles, are extremely fine in the young shell, but become coarser with increased growth; the somewhat sudden change is marked by the incoming of longitudinal ornamentation in the form of subordinate, flattened or gently-rounded ribs crossing the interspaces between the transverse ribs. The latter, however, are uninterrupted, except along the median line of each pyramid face, where a definite midrib occurs.

The longitudinal ribs are most marked towards the angles of the shell, and do not alternate in successive interspaces as in the North American form *C. huntiana* Hall,[4] being arranged as a linear sequence, resembling in this respect the type of ornament figured by Barrande as occurring in *C. proteica*.[5] *C. baini* was first described by Ulrich from Bolivia,[6] and was compared by him with *C. continens* var. *rudis* of Hall.

The Peruvian shells, however, show no signs of interlocking of the transverse ribs along the median line, a feature which appears to be characteristic of Hall's species.[7]

CONULARIA QUICHUA Ulrich. (Pl. I, fig. 3.)

This typical South American species is characterized by its distinctive outline, and by the extremely fine nature of its ornament. The transverse ribs, which curve gently towards the mouth and are cut by a shallow median groove on each face, bear numerous small tubercles, due apparently to their intersection with the faint longitudinal striation. By abrasion of these tubercles each rib appears to be pierced by a single row of closely-set minute perforations.

A cross-section of the shell has the form of an elongate oval, and though this appears to be a constant feature, occurring both in our specimens and in those obtained by Ulrich from Bolivia,[8] it may possibly be due to deformation, consequent on the possession of an extremely thin shell which may have been sufficiently flexible to resist the fracture that has affected many of the more

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[1] Trans. Geol. Soc. ser. 2, vol. vii (1856) pl. xxvii, fig. 13.

[2] 'Paläozoische Versteinerungen aus Bolivien' Neues Jahrb. Beilageband viii (1892) p. 29 & pl. iii, fig. 4.

[3] 'Devonische Faunen Boliviens' Neues Jahrb. Beilageband xxv (1908) p. 516 & pl. xxiii, fig. 8.

[4] 'Natural History of New York: pt. vi, Palæontology' vol. iii (1861) pl. lxxii *a*, figs. 2 *a* & 2 *b*.

[5] 'Système Silurien de la Bohème' vol. iii (1867), Ptéropodes, pl. v, fig. 18.

[6] *Op. supra cit.* p. 36 & pl. iii, fig. 8.

[7] 'Nat. Hist. N.Y.—Pal.' vol. v, pt. ii (1879) pl. xxxiv *a*, figs. 7 & 8.

[8] *Op. supra cit.* p. 34 & pl. iii, figs. 7 *a* & 7 *b*.

stoutly-built forms. This species has also been described from the Argentine by Prof. E. Kayser,[1] and by Ivor Thomas.[2]

TROPIDOLEPTUS CARINATUS Conrad.

This species has now been shown by Henry S. Williams[3] to recur in three distinct horizons in the Portage and Chemung formations of New York; it can, therefore, no longer be regarded as a distinctive fossil of the Hamilton Shales.[4]

Beyond Cabanillas the Devonian strata dip steadily beneath the broad alluvial plains of Juliaca, which have been left by the gradual recession of the waters of Lake Titicaca, to reappear in the district north of the lake.

With the view, therefore, of obtaining further insight into the structure of the surrounding country, we decided to take the more direct route to Puno, and proceeded in a south-easterly direction from Las Huertas. Between this point and the hacienda of Yanarico, the transgressive Cretaceous beds are again seen resting on steeply-dipping Devonian quartzites. The country then becomes covered by large areas of swamp and tracts of alluvium, in such wise that its geological structure is almost entirely obscured.

Beyond Vilque, however, a new feature appears in the landscape, in the form of prominent flat-topped hills or 'buttes.' These were found to be due to the dissection of a thick horizontal sheet of lava, an olivine-basalt, which was traced nearly as far as Puno. Such an occurrence is of considerable interest, as being almost the only sign of volcanic activity in this inter-Andean region, comparable with the great outbursts which have built up the lofty peaks of the Western Cordillera.

The vesicular nature of the lava and its wide lateral extent suggest that it was extruded in the form of a fissure-eruption, which spread far over the surface of the surrounding country. Its undisturbed horizontality, when we consider the post-Cretaceous folding that has affected the district, shows that its formation must be of comparatively recent date.

No trace of feeders was detected in the immediate neighbourhood; but this is not surprising, as the slopes of the hills are everywhere covered by talus and vegetation.

(A 120) Olivine-basalt. Tiquillaca.

A highly-vesicular greyish-brown lava showing occasional flakes of biotite.

Microscopic characters:—In mineral composition it exhibits a marked similarity to the basaltic dykes which have been described above as cutting the Jurassic rocks of Lagunillas, and the microscopic structural differences are only such as can be explained by the different conditions

[1] Zeitschr. Deutsch. Geol. Gesellsch. vol. xlix (1897) p. 288 & pl. xi, figs. 1 & 2.

[2] *Ibid.* vol. lvii (1905) p. 254 & pl. xii, fig. 19.

[3] 'Recurrent *Tropidoleptus* Zones of the Upper Devonian in New York' U.S. Geol. Surv. Prof. Paper 79 (1913).

[4] For a comparison with *Tropidoleptus fascifer* Kayser, see 'El Devoniano de la Argentina Occidental' by Dr. J. M. Clarke, pp. 6–7: Anales del Ministerio de Agricultura, Republica Argentina, Seccion Geologia, etc. vol. viii (1912) No. 2.

under which the rocks have consolidated. The greater freedom of movement in the present case has hindered the ready growth of porphyritic crystals.

The phenocrysts of augite, seen in A 112, are here represented by granular aggregates, which in some instances show that they originated by the breaking-up of a larger crystal.

Porphyritic flakes of biotite are not uncommon, the presence of this mineral possibly being dependent on the relatively low temperature of consolidation.

An iron-rich olivine, altering to a yellowish-brown iron-oxide, is also present in some abundance, with an occasional trace of the original mineral still apparent.

The ground-mass consists of granules and prisms of a faintly-coloured augite, irregular grains of magnetite, and minute laths of felspar with pronounced flow-structure.

(3) The Geological Structure of the Country between Tirapata and the Inambari River.

After completing the first half of our section at Puno, we proceeded northwards, along the strike, to the village of Tirapata, in order to gain access to the interior or 'Montaña' region. The geological structure of the intervening country is for the greater part concealed beneath the wide alluvial flats, formerly covered by the waters of Lake Titicaca. In places, however, outcrops of the underlying rocks are met with, and a connexion between the two halves of the section can thus be established.

About a mile south of Puno, in a small quarry on the shores of the lake, is seen an unfossiliferous grey limestone with a dip of 45° south-south-westwards; this was found to overlie a thick series of red sandstones and conglomerates, which were traced along the south-western shore of the lake as far as the village of Pomata.

On proceeding northwards from Puno along the trail to Juliaca, we again meet with grey dolomitic limestones, red shales, sandstones, and conglomerates, cropping out from beneath the sheet of vesicular olivine-basalt of Tiquillaca, while beds of white quartzite are exposed in a small ravine leading down to the railway-line. Limestone again appears at the little village of Caracoto, and red sandstone at the station of Juliaca.

Thus far we have been dealing solely with lithological characters, for no palæontological evidence was obtained from this area.

In general appearance, however, these rocks are totally unlike those in the neighbouring districts known to contain Devonian fossils, and as they bear a marked resemblance to the Upper Carboniferous or Permo-Carboniferous series, previously described from the Copacabana peninsula and the district east of Comanche in Bolivia, which lie along the same line of strike, they are provisionally regarded as being of the same age as the latter.

(Prof. Lisson, in a summary of the distribution of the fossiliferous deposits of Peru, describes a small collection of Devonian fossils, preserved in the museum of the School of Mines at Lima, said to come from the neighbourhood of Puno; no exact locality is recorded, however, and it is more than likely that they were obtained from the Devonian beds between Puno and Taya Taya. The following forms are mentioned:—*Cryphæus convexus* Ulrich, *Platyceras* sp., *Spirifer planoconvexus* Knod, *Lyopora gigantea* Knod, and crinoid-remains.)

Continuing northwards, we meet with a further series of beds between Juliaca and Laro, apparently distinct from those above enumerated, comprising olive-green quartzites, shales, and sandstones, which have a more or less constant dip in a south-westerly direction. These are very similar in appearance to the Devonian beds of Taya Taya; and, in fact, a short distance farther east, between Pusi and Taraco, the following fossils have been recorded by Señores Dueñas & Romaña:—*Phacops* cf. *dagincourti* Ulrich, *Orthoceras* sp., *Conularia* sp., *Tentaculites* sp., and *Tropidoleptus carinatus* Conrad.

An identical fauna has also been obtained from the neighbourhood of Sicuani, a village still farther north on the line to Cuzco; and, as Tirapata lies directly between these two points, the barren shales and shaly sandstones which are found at this locality are regarded on both stratigraphical and lithological grounds as being of the same age.

If we proceed, moreover, along the same line of strike far towards the south-east, we eventually reach the Devonian area of Tiahuanaco and Coniri in Bolivia.

It will thus be seen that, although I rely in great part on the lithological characters of the rocks in the determination of their age, the conclusions arrived at are in no way contradicted by the meagre palæontological evidence obtained at one or two isolated localities.

As we continue our journey north-eastwards from Tirapata, the Devonian shales and impure sandstones are no longer inclined towards the south-west, but are seen to dip in an easterly direction beneath a strongly-folded series of grey limestones, dolomites, red marls, and white quartzites. These rocks are well exposed along the road to Progreso, and on the southern shore of the lake beyond Asillo.

At the hamlet of Recreo the trail turns northwards, following the strike of the folds up a small river-valley cut along one of the anticlinal axes. The beds here consist chiefly of conglomerates and sandstones, with an occasional prominent band of grey limestone.

The river has its origin in a small lake (Lago Cerera), at the far end of which we traverse the actual core of the anticline, here seen to be formed of limestone overlain on the east by conglomerate dipping 30° north-eastwards.

This whole series of rocks, although well exposed and freely accessible, failed to reveal any trace of fossils; but there can be little doubt that it represents the northward continuation of the Carboniferous series of the isthmus of Copacabana and the Island of the Sun in Lake Titicaca.

Both the geological structure of the country and the lithological character of the beds are almost sufficient to warrant this conclusion; but more convincing proof was fortunately obtained, in the form of palæontological evidence, a few miles farther north in a little valley known as Viscachani.

A short distance beyond the lake lies the disused Indian chapel of Santa Isabel, and in the bed of the stream at this point appear beds of red shaly sandstone showing beautiful ripple-marking; these have a steep dip of about 80° south-south-westwards, and, although their junction with the overlying beds is not visible, they appear to belong to an older series (probably of Devonian age, being very similar to the red shales of Tirapata).

The valley of Viscachani is flanked on the west by a steep escarpment of grey limestone, the continuation of that seen in the valley above Recreo. This was found to overlie a purple limestone series which yielded fossils in some abundance.

The late Dr. Arthur Vaughan, having looked through the specimens obtained from this locality, gave it as his opinion that they represent a fauna indicative of the very top of the Lower Carboniferous or Avonian sequence, corresponding to the *Cyathaxonia* Beds (D 2–3) immediately below the Pendleside of the Midlands. They may thus be regarded as being from a somewhat lower horizon than the fauna previously described by me from the Copacabana peninsula, which was shown to be of Upper Carboniferous or of Permo-Carboniferous age.

The more important index-fossils were starred by Dr. Vaughan, and on these his determination was based; but it must be noted that he had no opportunity of examining the sections of corals, which were not cut until the present year. Although these, for the greater part, belong to new or little-known types, it is interesting to find that they in no way negative his conclusions, which are further supported by stratigraphical considerations, for the limestones of the Titicaca district overlie the beds here described.

FAUNAL LIST.

Productus aff. *semireticulatus* Martin.
Productus aff. *cora* D'Orbigny.
**Productus* aff. *longispinus* Sowerby.
Rhipidomella aff. *michelini* (L'Éveillé).
**Spirifer bisulcatus* Sowerby.
Spiriferina aff. *cristata* Schlotheim.
**Reticularia lineata* (Martin).
**Ambocœlia urii* (Fleming).
Seminula aff. *ambigua* (Sowerby).
**Retzia radialis* Phillips.

Euomphalus sp.
Pleurotomaria sp.

Edmondia sp.

Fenestella sp.
Fistulipora aff. *incrustans* (Phillips).

**Cyathaxonia* aff. *rushiana* Vaughan.
Cyathaxonid (cf. *Cyathaxonia* aff. *costata* M'Coy, Vaughan: figured in Q. J. G. S. vol. lxii, 1906, pl. xxix, fig. 5).
Zaphrentis aff. *enniskilleni* Milne Edwards & Haime.
Lophophylloid *Zaphrentis*.
Lophophylloid *Caninia* (cf. *Caninia cornucopiæ* Michelin, Carruthers).
Zaphrentis aff. *eruca* (M'Coy).

A study of the faunal assemblage enumerated in the above list shows that many of the leading coral groups, characteristic of the

Viséan of Europe (as, for example, *Lithostrotion* and the Clisiophyllids), are entirely unrepresented. Its most remarkable feature is the abundance of small Zaphrentid corals showing a certain degree of resemblance to *Lophophyllum* and *Cyathaxonia*.

Since some confusion still appears to exist as to the exact limitations of these genera, I have added a short discussion on their relationship with the forms here described.

Palæontological Notes.

Of the specimens which I have termed Lophophylloid Zaphrentids many appear to be closely related to the corals figured and described as *Lophophyllum* by Thomson & Nicholson in 1876,[1] agreeing with them in general size and form, in the absence of any external zone of vesicular tissue, and in the possession of a longitudinally-ribbed epitheca and a clavate columella joined at one extremity with a single septum. The latter, however, was described as lying within the septal fossula, whereas in the present case it is invariably the counter-septum that is elongated.

Although classed as Lophophylla, their relationship with *Zaphrentis* is admitted: the only essential point of difference being the presence of a 'central columellar eminence.'

Of late years, Mr. R. G. Carruthers has shown, from an examination of Belgian topotypes, that the genotype of *Lophophyllum* (*L. konincki* Edwards & Haime) had a smooth epitheca, and is synonymous with *Cyathaxonia tortuosa* of Michelin. In the absence of the original holotypes, *Lophophyllum tortuosum*, as redefined by Mr. Carruthers, must, therefore, be taken as the type, and the forms described by Thomson & Nicholson can no longer be referred to this genus, which differs from them in possessing a smooth epitheca, well-developed minor septa, and a zone of dissepiments.

If Vaughan was correct in assigning the fauna here described to the extreme summit of the Avonian sequence, these corals cannot be considered as phylogenetically intermediate between *Zaphrentis* and *Lophophyllum*: for, according to Mr. Carruthers, the latter genus is already typically developed in the Tournaisian, whereas *Zaphrentis* does not approach extinction until the close of Avonian time. It is equally impossible to regard these Zaphrentid corals as derived from a Lophophylloid ancestor. Any tendency in one or other of the two forms towards the development of a similarity of structure must, therefore, be ascribed to convergence or coeval assimilation.

Mr. Carruthers has recently given an instructive description of the evolution of *Zaphrentis delanouei*; and some of the later members of that gens, predominant in the Upper Limestone Group and Millstone Grit of Scotland, show in their ephebic stages a marked resemblance to the forms described here. A comparison,

[1] Ann. & Mag. Nat. Hist. ser. 4, vol. xvii (1876) pp. 126–28 & pl. viii, figs. 3–7.

for example, of the specimen shown in Pl. I, fig. 8, with *Zaphrentis disjuncta* as figured by Mr. Carruthers,[1] shows that the two possess the following features in common:—Longitudinal ribbing of the epitheca; cardinal fossula on the concave side of the corallum; 22 major septa; septa Amplexoid, thickened at their inner ends, and convex to the cardinal fossula; no minor septa; simple tabulæ.

The development of Amplexoid septa in a late stage of the phylogenetic history of the gens must necessarily have seriously lessened the structural strength of the corallum, and the lengthening of one of the septa, in this case the counter-septum (which, from its position, is naturally most fitted for the purpose), to form a central plate thickened at its end into a rod-like columella, would materially aid in counteracting any such weakness. It is possible, then, that the extinction of the *delanouei* gens, foreshadowed by this catagenesis or simplification of structure, may have been delayed by the acquisition of a Lophophylloid columella.

The causes of variation are too little known to admit of an adequate proof of such a theory; but the phenomenon of parallel development in many Avonian corals suggests that these forms of life were readily adaptable to external conditions.

Perspecialization in any gens is characteristic of the stage immediately prior to extinction, when its capacity for survival is limited by its power to change; and this doubtless is largely influenced by environment, migration to new surroundings tending to give a new lease of life.

It might reasonably be argued, however, that the extension of the counter-septum more than half-way across the corallum may be taken to imply the retention of a primitive character rather than the acquisition of a new one, for in the protoseptal stage of the Rugosa the cardinal and counter-septa are continuous one with the other, and the point of separation need not necessarily be central, a feature often seen in such forms as *Caninia cornucopiæ* and *Zaphrentis omaliusi*. It is the secondary thickening of the counter-septum, however, rather than its length, that is the chief factor in forming the columella, and a study of the ontogenetic development of the coral, made by grinding down a number of individual specimens, shows that its special modification for this purpose does not take place until a comparatively late stage of growth, when the septal plan is already well established. The central rod-like columella, moreover, often almost circular in cross-section, appears in some cases to be added to the extreme tip of the counter-septum, while in others it is formed by lateral thickening.

In discussing the question of convergence or coeval assimilation, it is not without significance that several of the corals here described, which possess in common this feature of an extended and swollen counter-septum, differ one from the other in other points of structure, and appear to have been derived, if not from different genera, at least from different species-groups. If, then, I have

[1] Q. J. G. S. vol. lxvi (1910) pl. xxxvii, fig. 7*a*.

not attached undue importance to this modification of structure, it may be said that the dominant 'tone' of the age was Lophophylloid.

In the absence of any known Lower Avonian corals from South America, a direct descent from a true Zaphrentid ancestor along any known gens-line cannot at present be definitely proved. It has not been thought advisable, however, to institute distinctive generic names for these new forms until such a possibility is denied. I have, therefore, restricted myself to the use of such terms as 'Lophophylloid *Zaphrentis*,' thereby implying a coral having the typical structure of a *Zaphrentis* combined with an essentially Lophophylloid columella, which, unlike that of a *Cyathaxonia*, is a direct continuation of the counter-septum. The relationship of any of these forms with *Cyathaxonia* is more superficial than real, although an occasional individual section may reveal a disposition of septa suggestive of a Cyathaxonid type of structure.

In one example (Pl. I, figs. 9*a*–9*e*) the inner ends of the septa are fused with a thick stereoplasmic lining, the continuity of which is broken by the cardinal and alar fossulæ.

In earlier stages of growth, however, increased thickening often results in the formation of a confused central mass, the nature of which is not apparent until further sections are cut from the same specimen. The columellar thickening of the counter-septum and the club-shaped extremities of the other major septa are then seen to have their origin in this stereoplasmic lining, and, where the latter wraps round the ends of the septa without forming complete contact, a series of hollow terminal tubes is produced.

It thus becomes apparent that, although the final result attained (an increase of strength in the corallum) is the same in many cases, homogenesis of structure must by no means be taken for granted.

LOPHOPHYLLOID ZAPHRENTIS. (Pl. I, figs. 8*a*–8*f*, 9*a*–9*e*.)

Description.—Corallum simple, conical and cornute. Epitheca strongly costate: alternate sulci corresponding to internal septa. Floor of calyx radiated by a single series of 22 well-spaced major septa. Cardinal septum short, situated on the concave side of the corallum. Fossular depression ill-defined.

Counter-septum long, extending to the centre of the corallum, and thickened at its inner end to form a laterally-compressed plate-like columella.

Horizontal sections.—In the earlier stages of growth the septa are distinctly Zaphrentid in character, the cardinal and alar breaks being well-defined. The septa are considerably thickened, and show a curvature convex to the cardinal fossula. The latter is at first wide, narrowing inwardly, but in the adolescent stage, owing to the growth of new septa in the cardinal quadrants, becomes somewhat constricted at its centre (fig. 8*d*). In the mature stage, the septa, with the exception of the counter-septum, are thin and Amplexoid in character, having become entirely separated at the centre of the corallum. The cardinal fossula is inconspicuous, being indicated merely by a shortened septum.

Minor septa are absent or undeveloped. Tabular intersections are rare.

Vertical section.—Tabulæ are seen to be few in number and widely spaced (fig. 8*f*). They are gently arched towards the calyx, and dip somewhat steeply into the cardinal fossula, which extends to the centre of the corallum, and is penetrated by the counter-septum.

Affinities.—This form appears to be closely related to *Zaphrentis disjuncta* Carruthers,[1] the points of resemblance having been noted above.

LOPHOPHYLLOID CANINIA. (Pl. I, figs. 7 *a*–7 *c*.)

Description.—Corallum cylindro-conical; variable in shape; often showing marked irregularities of growth. Epitheca thin and smooth, but occasionally bearing traces of longitudinal ribbing.

Horizontal sections.—Major septa irregular, with radial disposition; slightly thickened at their inner ends; Amplexoid in character from an early stage, leaving a central tabulate area penetrated only by the counter-septum, which is elongated and thickened to form a central columellar plate. Cardinal septum short. Fossula indistinct, usually bounded by the intersection of a tabula with the plane of section.

Minor septa absent or undeveloped. Tabulæ few in number, somewhat irregular and widely spaced. No marginal dissepimental zone.

Affinities.—This form in its general septal development and irregularity of growth appears to be more nearly related to *Caninia* than to the Zaphrentids. It differs from *Caninia cornucopiæ* Michelin emend. Carruthers (Geol. Mag. 1908, p. 158) chiefly in the less numerous major septa, and by the absence in all stages of growth of minor septa and an external zone of dissepiments. In these respects it bears considerable resemblance to *Zaphrentis amplexoides* Wilmore.[2]

ZAPHRENTIS aff. ERUCA (M'Coy). (Pl. I, fig. 5.)

Description.—Corallum simple, conical, slightly cornute. Epitheca strongly costate. Major septa, 22 in number, straight and slightly swollen at their inner extremities; radial in disposition and becoming Amplexoid at an early stage of growth.

Counter-septum long, extending more than half-way across the corallum; laterally thickened at its end to form a clavate columella. Cardinal fossula inconspicuous, the break being indicated by a shortened septum. Tabular intersections very regular and evenly spaced. Outer wall thick, but showing no trace of minor septa. No marginal zone of dissepiments.

Affinities.—This form agrees closely with *Cyathopsis eruca* of M'Coy.[3] The genus '*Cyathopsis*,' founded by A. d'Orbigny for corals resembling *Amplexus* but possessing a septal fossula, is, however, an unsatisfactory one, and the species was redescribed and figured as a *Lophophyllum* by Thomson & Nicholson.[4] Mr. R. G. Carruthers has shown that it can no longer be referred to that genus; and, until more light can be thrown on the phylogeny of this and kindred species, it may be regarded as an Amplexoid *Zaphrentis* possessing a Lophophylloid type of columella.

In the possession of a strongly-costate epitheca, in the radiate arrangement of the septa, and in the regularity of the tabular intersections, it shows a close affinity with *Cyathaxonia costata* M'Coy, as figured by Vaughan[5]; the latter species, however, has now been assigned to the genus *Lophophyllum* by Dr. A. Wilmore,[6] although it appears to be doubtful whether that author is justified in regarding the forms discovered by him in the Craven district as identical with that figured by Vaughan, for the latter species is described as having a strongly-costate epitheca, and is apparently devoid of minor septa.

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[1] Q. J. G. S. vol. lxvi (1910) p. 534 & pl. xxxvii, figs. 6 *a*–8 *d*.
[2] *Ibid.* pl. xxxviii, figs. 1–9.
[3] Ann. & Mag. Nat. Hist. ser. 2, vol. vii (1851) p. 167.
[4] *Ibid.* ser. 4, vol. xvii (1876) pl. viii, fig. 7*a*.
[5] Q. J. G. S. vol. lxii (1906) pl. xxix, fig. 5.
[6] *Ibid.* vol. lxvi (1910) p. 573.

CYATHAXONIA sp. (Pl. I, figs. 4 *a* & 4 *b*.)

Description.—Corallum simple, conical, slightly cornute. Epitheca strongly costate. Eighteen major septa, radially disposed, and of more or less equal length; slightly swollen at their inner extremities. These alternate with a series of minor septa, two of which (the fourth from the cardinal septum on each side) are more pronounced than the others.

The centre of the corallum is occupied by a rod-like columella, oval in cross-section, which appears to be a structure independent of the septa. In the earlier stages of growth the ends of the major septa are fused to it, and at first sight seem to take part in its construction. In some cases, however, the central core has been dissolved away, leaving a hollow tube, and thereby disclosing its true character. In the mature stages the counter-septum alone remains attached, its continuation through the solid axis being disproved by the absence of any trace of a mesial line.

The structure of the columella, therefore, is distinctly Cyathaxonid in character, for it has clearly not been formed, as in the Lophophylla, by the upward growth and thickening of the counter-septum. A fossular break is merely indicated by a shortened cardinal septum. No trace of tabular intersections were observed.

Affinities.—The Cyathaxonid type of columella, the presence of minor septa, and the apparent lack of tabulæ, readily distinguish this form from any of the preceding. The solidity of the central axis, and the strongly-costate epitheca, suggest that it is closely related to *Cyathaxonia costata* M'Coy, the relationship of which with the Densiphylloid Zaphrentes has already been noted by Vaughan.[1] In the earlier stages of its growth it shows a certain resemblance to *Carcinophyllum simplex* Garwood,[2] but differs from that form in its small size, less number of major septa, and the absence of any peripheral dissepimental zone.

ZAPHRENTIS aff. ENNISKILLENI Edwards & Haime. (Pl. I, figs. 6 *a* & 6 *b*.)

Description.—Corallum conical, cornute. Epitheca smooth, with annular striations. Cardinal fossula deep, extending to the centre of the corallum; situated on the concave side; narrow, and with almost parallel sides; widening slightly towards the wall, the expansion becoming more pronounced in sections near the calyx. Position of alar fossulæ clearly defined by a septal break and discontinuity of tabular intersections. Major septa, 35 in adult, strongly thickened, especially in the anti-fossular group; their inner ends are coalescent in the younger stages of growth. Cardinal septum very short. Curvature of the septa convex to the cardinal fossula, ill-defined in youth but becoming pronounced in the adult. Minor septa absent or undeveloped. Tabulæ few in number and evenly spaced.

Affinities.—This form appears to be a typical representative of the '*Enniskilleni*' gens, differing from the type chiefly in the absence of minor septa. In the character of the fossula, the number and disposition of the septa, and the thickening of the counter-septum, it most nearly approaches the form figured by Vaughan from the *Posidonomya* Beds of Loughshinny.[3]

The limestone of the Viscachani district, as has been mentioned above, is divisible into an upper grey cherty limestone and a lower purple limestone, the latter being largely composed of fragmentary crinoid-remains. With the exception of *Zaphrentis* aff. *enniskilleni* and *Productus* aff. *cora*, all the forms mentioned in the faunal list on p. 41 appear to be restricted to the lower beds; and, since the lithological change is also accompanied by a slight discordance in the dip, it is possible that a gap in the sequence

[1] Q. J. G. S. vol. lxii (1906) p. 318.

[2] *Ibid.* vol. lxviii (1912) p. 556 & pl. xlviii, figs. 3*a*–3*c*.

[3] *Ibid.* vol. lxiv (1908) pl. xlix, fig. 13.

is indicated. A comparison of the faunal list given here with that of the limestone of the Titicaca district[1] further bears out this suggestion, for only one or two species are common to both.

The basement-beds are seen to rest with a well-marked unconformity on an older series of rocks, comprising olive-green sandstones, quartzites, and black shales with concretionary limestone-bands. These beds are strongly folded, the dip in places being nearly vertical, and, if we judge from the frequent discordance in their strike, they appear to have been much faulted, as shown in the accompanying sketch-map (fig. 5, p. 48). With the exception of countless worm-tracks and a single obscure specimen of a lamellibranch shell, they proved to be unfossiliferous. Their lithological character suggests that they are of Devonian age, but it was not considered advisable to separate them definitely from the older Palæozoic rocks with which they are continuous.

The latter, comprising hard grits, greywackes, and dark slates, when first met with have a more or less constant dip westwards, but at the summit of the Quellosani Pass they are inclined in a north-easterly direction, and between this point and Macusani they are much folded. In general appearance these beds closely resemble the ancient rocks of the Pongo Valley, on the eastern slopes of the Bolivian Cordillera, which are regarded as being of Silurian or even earlier age; and they are grouped together here, tentatively, as Lower Palæozoic, for fossiliferous beds of similar character were met with farther east.

A short distance beyond Macusani commences the descent of the San Gaban river-gorge, and one immediately encounters a remarkable suite of igneous rocks which differ totally in character from those described above as forming the plutonic core of the Western Cordillera. With these are associated wide tracts of schistose rocks presenting the appearance of highly-altered sediments, while the igneous rocks themselves locally show signs of intense crushing with the production of gneissic structure. The district is one that has evidently undergone profound dynamic metamorphism; but, as the Cordillera has been subjected to more than one period of orogenic movement, it is difficult to say to which of these such a result should be attributed. I can see no valid reason for supposing these rocks to be of earlier date than the fossiliferous Lower Palæozoic rocks found still farther east, and I am tempted to regard them as constituting an ancient resistant horst formed during the period represented by the gap between Middle Devonian and Upper Avonian deposits, and thus as having played an important part in determining the structural features produced during subsequent folding of the Cordillera.

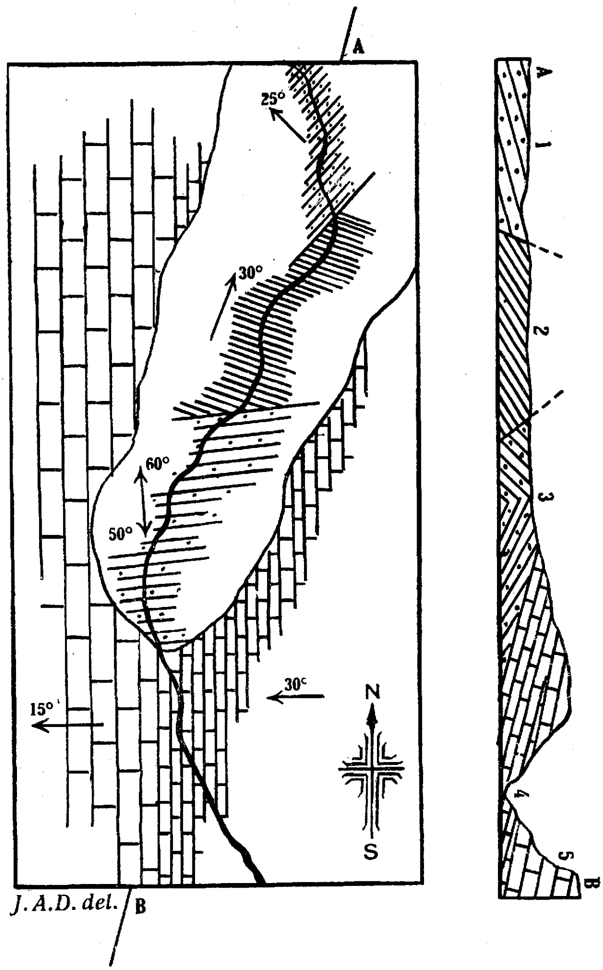
The evidence on which this assumption is based, however, is too slight to be in any way conclusive, and it is given here merely in the light of a suggestion for future work.

At the head of the San Gaban gorge, a short distance beyond

[1] Q. J. G. S. vol. lxx (1914) p. 31.

Quencha, beds of white quartzite, dipping 20° north-north-eastwards, are seen cropping out on the right of the valley. They

Fig. 5.—*Geological sketch-map of the Viscachani Valley, showing unconformity of Carboniferous Limestone on older Palæozoic rocks.*



[Approximate scale, 1 : 4000.]

1 & 3 = Olive-green quartzites. 2 = Black shales. 4 = Purple limestone with Zaphrentids. 5 = Grey limestone.

show no signs of the intense crushing exhibited by the underlying rocks; and, although the actual junction of the two is not visible, it is obvious that they are of later date than these. The only other rock of like character that I have come across in the whole district is a white quartzite from the Carboniferous Series in the neighbourhood of Puno, and I know of no record of beds of later age than this occurring on the eastern slopes of the Cordillera in this latitude.

The sides of the river-valley almost as far as Ollachea are formed of a coarse elæolite-syenite porphyry of very distinctive character. It is a handsome rock, composed of large, grey, porphyritic crystals of anorthoclase and elæolite, set in a black or dark-grey micro-crystalline ground-mass. Locally it has been subjected to intense dynamic metamorphism, and has been transformed into a banded gneiss. The conspicuous phenocrysts normally show no definite arrangement; but, where pressure has affected the rock, they assume a roughly-parallel direction, individual crystals being crushed and sheared in the process, first into elongate lenticles, and finally into long drawn-out lines.

The change, as seen macroscopically, is almost identical with that described by Prof. H. J. Seymour[1] in the progressive dynamo-metamorphism of a porphyritic andesite from County Wicklow, the result in each case being a banded rock in which original ground-mass and phenocrysts have given rise respectively to alternating dark and light bands.

Owing to the inaccessible nature of the gorge, the tectonic relations of this rock are not clear; but it appears to be intrusive into the slates and metamorphic schists which succeed it lower down the valley.

A short distance above Ollachea hot springs issue on the left of the valley, and deposits of siliceous sinter are being formed in small though well-defined terraces. Near this point other and distinct intrusions of plutonic rock are met with, in the form of augite- and elæolite-syenites. The former is almost identical in a hand-specimen with certain essexites, but microscopically it is seen to be more closely related to a syenite of the laurvikite type. The elæolite-rock, in which the coloured minerals are only subordinate, closely resembles foyaite.

Both of these intrusions appear to be of later date than the elæolite-syenite porphyry mentioned above, for, microscopically at least, they show no signs of having been subjected to dynamic action. This whole suite of igneous rocks is of typical 'alkaline' facies, and may be regarded as forming part of the great Brazilian province, which is thus shown to extend, as indeed might have been expected on *a priori* grounds, to the very flanks of the folded chains.

Sedimentary rocks, comprising dark slates and phyllites, are met with for the first time in the immediate neighbourhood of Ollachea, and when these are followed down the valley they are seen to pass into biotite-schists containing abundant rose-pink crystals of andalusite.

[1] Sci. Proc. Royal Dublin Soc. n. s. vol. xi, pt. 5 (1902) p. 568

We now begin to enter the densely-forested region of the Montaña, and any attempt to determine the relations between individual rock-exposures becomes well-nigh impossible.

The metamorphic schists, however, can be more or less continuously followed as far as Casahuiri, varying in character from time to time according to their original arenaceous or argillaceous nature. Here they once more pass gradually into phyllites, slates, and relatively unaltered sediments.

Midway between Ollachea and Urahuasi is exposed a large surface of rock having the appearance of a fault-plane: this dips steeply southwards, and breaks across the planes of schistosity, which at this point are inclined in exactly the opposite direction. Below Urahuasi Bridge further outcrops of plutonic rock are encountered which have the composition of a mica-syenite or durbachite. Locally traces of gneissic structure are visible, but the rock has evidently not shared to the full extent the dynamic metamorphism to which the older rocks of the district have been subjected.

Between Llinquipata and Puerto Seddon are numerous roadside exposures of more or less unaltered sedimentary rocks, chiefly in the form of black friable shales containing auriferous quartz-veins. They are, as a rule, highly contorted, but have a fairly-constant strike east-south-eastwards. Although these were closely examined in an attempt to determine their age, no trace of fossils was discovered until we reached the tributary valley of the Chaquimayo River, where the waterworn pebbles and boulders of the stream-bed were found to contain graptolites in some abundance.

The bed-rock is here almost entirely concealed from view beneath a thick clothing of tropical vegetation, and, although by following the valley to its source, occasional specimens were obtained *in situ*, no zonal sequence of the beds could be established. I am much indebted to the late Prof. Charles Lapworth for making a report on the graptolites from this locality, and he had very kindly proposed to publish this in the form of an appendix to the present paper. The fauna is essentially similar to that obtained by Dr. J. W. Evans from the Caupolican district of Bolivia, and was shown by Prof. Lapworth to be of Llanvirn age.

FAUNAL LIST.

Loganograptus logani Hall.
Goniograptus sp. nov.
Didymograptus bifidus Hall, var.
Didymograptus stabilis Elles & Wood.
Phyllograptus angustifolius Hall.
Glossograptus acanthus Elles & Wood.
Cryptograptus tricornis Hall, var.
Amplexograptus confertus Lapworth.
Amplexograptus cœlatus Lapworth.

PETROGRAPHICAL NOTES.

A 121. Elæolite-syenite porphyry. Rio San Gaban.

A coarsely-porphyritic rock, of which the phenocrysts form nearly half the bulk. These consist of greenish-grey elæolite, showing hexagonal and rectangular cross-sections, and a grey anorthoclase with characteristic rhomb-shaped outlines. The two minerals are not easily distinguished one from the other, except for the cleavage-faces of the felspar. The ground-mass is microcrystalline, and usually black or dark grey. Where it has undergone crushing, however, it frequently assumes a red or green tint.

Microscopic characters.—Large porphyritic crystals of felspar and elæolite are present in about equal proportions. The former (anorthoclase), showing microperthitic intergrowths, are slightly cloudy through decomposition, and include numerous prismatic crystals of elæolite. The larger phenocrysts of elæolite are irregularly cracked, and though glassy-clear in ordinary light, are seen, between crossed nicols, to have undergone considerable alteration; resulting in confused flaky aggregates of brilliantly-polarizing colourless mica (probably gieseckite).

Smaller crystals of a pale-green augite are present in some abundance, and more sparingly olivine in rounded grains with dense magnetite-rims. Apatite occurs as inclusions in the augite.

The holocrystalline fine-grained ground-mass is composed of minute prisms of augite, felspar-laths with straight extinction, abundant grains of magnetite, and a second generation of elæolite, the low double refraction of which causes it at first sight to appear isotropic.

In the crushed and banded rock the structure of the ground-mass has been almost obliterated, while porphyritic crystals remain for a time as uncrushed 'eyes' in the mylonitic matrix. With further crushing these also become ground down and drawn out into elongated lenticles.

The felspar-crystals show all the phenomena of mechanical deformation, the cracks in many cases being filled up with secondary growths of felspar substance. The original inclusions of elæolite have been converted into a colourless isotropic mineral, presenting the appearance of sodalite, and the same mineral has been produced (together with flaky aggregates of white mica) at the expense of the larger phenocrysts.

Lenticular patches composed entirely of serpentine and calcite represent original crystals of pyroxene.

A fine-grained quartz-felspar mosaic is characteristic of the final stages of crushing.

A 123. Elæolite-syenite. Ollachea.

A pinkish-grey holocrystalline rock of granitoid texture; containing orthoclase (pink), elæolite (dull white), sodalite (bluish white), and ægirine (black).

Microscopic characters.—The bulk of the rock is made up of alkali-felspars (orthoclase and perthite), and elæolite, to which the coloured minerals are subordinate.

The elæolite shows definite crystal outlines and is idiomorphic to the felspar; it has been almost completely altered into dense scaly aggregates of zeolitic material (spreustein).

Most of the felspar is in the form of perthite; it shows evidence of having been considerably crushed and fractured, the cracks in many cases being filled with secondary albite showing twin-lamellæ.

Sodalite occurs in some abundance, in irregular patches or veins.

The coloured minerals, which have crystallized after the felspar, consist of deep-green ægirine and brown acmite.

Accessory minerals are ilmenite altering to leucoxene; numerous prisms of apatite; and occasional crystals of zircon.

A 127. Augite-syenite. Ollachea. (Pl. II, fig. 6.)

A holocrystalline granitoid rock of medium grain, having a mottled black-and-white appearance, owing to the segregation of the coloured minerals into patches.

Microscopic characters.—The association of minerals is that commonly met with in syenites of the laurvikite type and the alkali-gabbros.

The felspars and coloured minerals are present in about equal proportions, the former consisting chiefly of orthoclase, slightly turbid through decomposition; albite and oligoclase are also present, and perthitic intergrowths are not uncommon.

Elæolite occurs as an accessory, but it has been largely decomposed.

The coloured minerals consist chiefly of a violet-brown titaniferous augite, in the form of large plates intergrown with a deep-brown biotite and containing abundant needles and prisms of apatite.

Magnetite and pyrites are present in about equal proportions; they are frequently intergrown one with the other and surrounded by biotite. A considerable amount of fresh olivine is also met with.

A 124. Mica-syenite. Urahuasi.

A dark-grey holocrystalline rock of medium grain, consisting chiefly of biotite and felspar, the former in excess of the latter.

Microscopic characters.—The felspars, which are subordinate to the ferromagnesian minerals, consist chiefly of plagioclase (oligoclase-andesine), but a considerable amount of orthoclase is also present.

A reddish-brown biotite is abundant, and this is commonly intergrown with yellowish-brown hornblende, the latter usually showing idiomorphic outlines.

A small amount of colourless to pale-green augite is also present.

Accessories include abundant apatite; a little sphene; brilliantly-polarizing prisms of zircon; magnetite; pyrites; and a green spinellid.

A 125. Andalusite-mica-schist. Casahuiri. (Pl. II, fig. 5.)

A finely-banded biotite-schist, containing numerous large crystals of a rose-pink andalusite.

Microscopic characters.—The parallelism of the constituent minerals is not well marked, and the structure as seen under the microscope approaches the granulitic.

The bulk of the rock consists of a fine quartz-mosaic, through which are scattered abundant flakes of biotite and some muscovite.

Andalusite occurs in the form of large well-defined crystals of a faint pink colour, containing few inclusions.

IV. General Summary and Conclusions.

The foregoing paper gives an account of the geological structure of the Andes of Southern Peru, as illustrated by a horizontal section drawn from the port of Mollendo to the Inambari River; and a comparison with a parallel section by the present writer across the Cordilleras of Northern Chile and Bolivia will serve to show that the main structural features there described still find expression in the district under discussion.

Several points of difference, however, will be noticed; gaps in the sequence have been filled in, whereas new gaps appear; vast areas of desert here conceal the continuation of many rocks that are exposed farther south, while in other cases where the exposures are more connected, the beds are frequently observed to undergo a change in character, and additional light is thus thrown on the distribution of land and sea in former geological times.

The rugged foreshore at Mollendo differs markedly in appearance from the stratified cliffs of Northern Chile. The deflexion of the coast-line towards the north-west has here brought to light a zone of ancient granite and gneiss, comparable with the rocks forming the coastal Cordillera of the south. These rocks are shown to be of typical 'alkaline' facies, and it is suggested that their origin dates from a very early period antecedent to the uprise of the main Cordilleras, which was accompanied by the intrusion of rocks of 'calcic' type.

The continuation of the Jurassic zone of the Morro de Arica and the Llutah and Palca Valleys, lies hidden beneath the desert sands of the Pampa de Clemesi and the Pampa de Islay, an occasional outcrop of barren quartzite on the foot-hills of Cachendo and in the neighbourhood of Ramal being provisionally regarded as the remnants of a formerly extensive Mesozoic cover. Jurassic strata, which proved to be of Bajocian age, were discovered, however, much farther inland at Lagunillas, and are probably also represented by the quartzites of the Sumbay district.

The granitic rocks which form the batholitic core of the Jamiraya district in Northern Chile, were found to be continued in the Palca and Moquegua Valleys, and once more reappear to form the Cachendo foot-hills and the Cerros de la Caldera near Arequipa. The plutonic complex here comprises at least three phases of deep-seated intrusion, represented by the granodiorite of Cachendo and Quishuarani, the augite-diorite of Huaico, and the adamellites of Huagri and Tiabaya.

An interesting example is described of the progressive dynamic metamorphism of a coarse-grained plutonic rock into a fine-grained gneiss. A characteristic feature of the district is the almost complete absence of tourmaline-bearing veins, which are so abundantly associated with the granodiorites of the south.

The line of giant volcanic peaks, which forms the outstanding feature of the Western Cordillera of Northern Chile, is continued into Peru, where Mount Pichu-Pichu, El Misti, and Chachani are seen as an imposing panorama from Arequipa. Many of the augite- and hornblende-andesites found in the neighbourhood of the cones, are of very similar character to those described from Mount Taapaca and Tacora. The volcanic outbursts, however, have chiefly given rise to rocks of a pyroclastic nature, and a wide stretch of country, comparable with that of the Mauri-River district of Bolivia, lies buried beneath a thick mantle of pumiceous tuff.

The red Cretaceous marls of the Coro Coro district, with their deposits of rock-salt and gypsum, are here represented by grey cherty limestones, evidently laid down in more open waters. These limestones are almost devoid of fossils; they are in places much dolomitized, and pass laterally into marls, when they have the appearance of reef-knolls. The transgressive character of the beds is very clearly displayed. At Lagunillas they rest horizontally, with a thick basal conglomerate, on strongly-folded Jurassic rocks, while farther east they overlie with marked unconformity the Devonian beds of Taya Taya.

The post-Cretaceous line of dioritic intrusion, formerly described as running through Coro Coro and Comanche in Bolivia, once more appears along the line of section at Maravillas; the mineralogical character of the rock is almost identical in the two areas, although in the present case it appears to have been somewhat modified by assimilation of silica during its passage through the Devonian quartzites.

The Devonian series, which crops out in the neighbourhood of Coniri in the south, and is continued beneath the Eastern Altaplanicie of the Viacha district to form the flanks of the Eastern Cordillera, is again exposed here between Maravillas and Las Huertas. The beds are highly fossiliferous, the fauna (of Middle Devonian age) being equivalent to that of the *Conularia* Shales of Steinmann, which have been correlated with the Lower Hamilton Shales of North America.

In the district west of Puno the remnants of a once-extensive sheet of basaltic lava, which appears to have been extruded in the form of a fissure-eruption, are found capping a series of buttes in the neighbourhood of Vilque.

The former extension of Lake Titicaca to the north is further shown by the wide alluvial tracts of the Juliaca area.

The Permo-Carboniferous fauna of Bolivia has not been discovered in the district now described; but rocks of similar lithological character, and probably of the same age, are met with on the shores of the lake near Puno, and again, east of Tirapata, where they overlie Devonian beds.

Fossiliferous beds of Lower Carboniferous age, representing the highest part of the Avonian sequence, occur near Macusani, where they lie unconformably on a much-faulted and folded series of older Palæozoic rocks.

The granitic core of the Bolivian Cordillera does not appear to extend into Peru, or at least is unrepresented along the line of section; an interesting series of alkaline igneous rocks, however, many of them nepheline-bearing, is met with in the Carabaya district near Ollachea. These, locally, show signs of intense dynamic crushing, and are associated with andalusite-mica-schists, which have the appearance of being highly-altered Palæozoic sediments.

The Palæozoic shales of the Caupolican district in Bolivia, described by Dr. J. W. Evans, are again met with in the Inambari district of Peru, and in the valley of the Chaquimayo River yield well-preserved graptolites of Llanvirn age.

An account having been given of the characters and distribution of the rocks which build up the Cordilleras of Southern Peru, it remains to apply the evidence thus accumulated towards elucidating the history of the folded chains.

Ancient igneous rocks, probably of Archæan age, fringe the coast at Mollendo; but, just as is the case in Bolivia, Palæozoic sediments older than the Devonian are confined to the eastern flanks of the Andes drained by the head-waters of the Amazon. After having been penetrated by plutonic intrusions, these rocks underwent a period of orogenic movement, and were subjected to intense dynamic metamorphism.

It is suggested that this folding took place prior to Carboniferous times, during the period represented by a gap in the succession between Lower Devonian and Upper Avonian deposits. A resistant horst appears thus to have been formed at a comparatively-early date, bounding the Cordillera on the east, and this seems to have been largely instrumental in confining the area of uplift to a narrow strip of country along the Pacific coast.

In Lower Devonian times the sea covered a large tract of the country now forming the Bolivian Altaplanicie and the district north and west of Lake Titicaca, fossiliferous deposits of this age having been determined as far west as Taya Taya.

During Upper Devonian and Lower Carboniferous times the country appears to have been elevated above sea-level, but towards the close of the Avonian period a further great transgression took place, and marine deposits of Upper Carboniferous and Permo-Carboniferous age were laid down over wide areas in the inter-Andean region of Lake Titicaca. In some places they appear to have extended still farther eastwards, and in the Viscachani Valley are seen to lie unconformably on the older Palæozoic rocks.

Indication of the existence of a land-area on the west is afforded by the presence of beds containing Coal-Measure plants on the peninsula of Paracas, south of the port of Pisco.

Marine Triassic beds are unknown in this area, and the complete absence of deposits of later date than Permo-Carboniferous from the Eastern Cordillera suggests that its elevation into a land-area took place about this period.

Further direct historical evidence, however, is wanting until Jurassic times. Rocks of this age form the foundation on which are situated the volcanic cones of the Western Cordillera; but they are largely concealed beneath a later covering of lava and tuff. The Upper Jurassic zone of Northern Chile, extensively developed in the Arica area, has been almost entirely stripped by denudation from the underlying batholitic core, but its continuation has been proved at more than one locality, and farther inland fossiliferous beds of Middle Jurassic age are met with at Lagunillas. On the upturned and steeply-dipping edges of the latter rest horizontal transgressive Cretaceous deposits, giving clear proof of post-Jurassic uplift.

From evidence obtained farther south, we know that volcanic activity had already broken out in Jurassic times, and further light is thrown on the nature of the igneous rocks of the period, now buried beneath later deposits, by the occurrence of numerous derived pebbles in the basement conglomerate of the Cretaceous Series. Among these are found rocks of plutonic origin which bear a striking resemblance to those forming the core of the Western Cordillera.

It would appear, then, that the batholitic invasion took place, in part at least, prior to or during the post-Jurassic uplift, and, moreover, that this was sufficiently great to bring the deep-seated core into the zone of active erosion before Cretaceous times.

There is, in fact, no direct evidence that Cretaceous rocks were ever laid down over the coastal region in this area, and the deposits of this age in the inter-Andean region may have been formed in a bay or land-locked arm of the northern sea. Thus we may seek to explain the gradual transition from the widespread fossiliferous limestones of the north into the red sandstones and gypsiferous marls of the south. The Cretaceous rocks shared in the folding which took place during Tertiary times, and, as is also the case in Bolivia, have been penetrated by later intrusions of diorite. The fact that these marine deposits are now found at altitudes over 13,000 feet above sea-level gives some idea of the magnitude of the Tertiary uplift.

Volcanic activity continued with renewed vigour, and the giant cones of the Western Cordillera were gradually built up to heights even greater than they possess at the present day. Some of them, although dormant or extinct, still retain, like El Misti, a well-preserved crater; others, like Chachani, have been dissected by long-continued erosion, and retain little of their original form.

With regard to the date and extent of recent uplift there is conflicting evidence. It has already been argued that the presence of an extinct mammalian fauna at 13,000 feet in the Desaguadero district of Bolivia can only be explained by the assumption of a considerable post-Pleistocene elevation, and it appears likely that the gently-sloping rock-platform fringing the coast of Southern Peru was formed at the same time. A still more recent elevation is indicated by the raised beach at Mollendo; but there appears to be no conclusive proof that any extensive movement has occurred during the period of human history.

It thus becomes clear that the area now occupied by the folded chains of the Andes has been subjected to repeated oscillations: periods of uplift, marked by folding and erosion, having alternated with periods of submergence, marked by the deposition of transgressive formations.

The general history of the Cordillera may be tabulated as follows:—

Deposition of Older Palæozoic rocks, up to and including the Lower-Middle Devonian.

Upper Devonian uplift.

Permo-Carboniferous transgression.

Permo-Triassic uplift.

Jurassic transgression.

Post-Jurassic uplift; accompanied by batholitic invasion.

Cretaceous transgression.

Mid-Tertiary uplift (amounting to at least 14,000 feet), accompanied by a great outburst of volcanic activity.

Post-Pleistocene uplift (probably amounting to about 1500 feet).

It may be as well to postpone any detailed discussion on the nature of the folding, until the description of the structure of the more northern districts of Peru has been completed. A brief statement of the observations made in the area now described may, however, not be out of place here.

A journey through the Pre-Alps of Chablais, made some years ago, under the leadership of Prof. Lugeon, enabled me to draw a comparison between the structure of a mountain-chain of Alpine type and that presented by the Cordilleras of the Andes. After becoming acquainted with the latter, I could not fail to be impressed by the complete dissimilarity of the two types of structure.

Preconceived notions of vast sheets or recumbent folds, transported over wide areas and separated from their roots to expose an underlying 'yoke,' were at once swept away. Throughout the Peruvian Cordilleras, inverted folds are the exception rather than the rule, and great zones of overthrusting appear to be entirely wanting. Any directional movement of the folding, moreover, is hard to determine, and the relationship between that part of Gondwanaland represented by the Brazilian platform and the folded chains of the Andes is, in the light of recorded facts, still obscure.

(Suess, in a summary of the structure of South America, makes the two following contradictory statements: 'In South America the Brazilian mass occupies the place of the backland within the arc, and the foreland lies beneath the ocean'; and later 'In about the latitude of the Bay of Arica the western promontory of Brazilia was overwhelmed by the folding movement directed towards the east.')

Relying on my own observations, I am led to believe that the folded chains of the Andes are the result of intermittent compression of a series of transgressive deposits, laid down in a geosyncline, between two ancient resistant masses, represented on the east by the metamorphic and plutonic rocks of the Amazon region, and on the west by the crystalline rocks of the coastal Cordillera. The trend-lines of the system, according to this theory, were determined at a comparatively-early date, and the areas covered by later transgressions were therefore limited by the continued rise of the chains on the east.

In the Alpine type of folding vertical uplift has been overshadowed by movement in a horizontal direction, whereas in the Andean Cordilleras the reverse is the case, and the terms 'backland' and 'foreland' as applied to the direction of movement have no longer the same significance.

Attention may once more be drawn to the fact that in the two marginal areas the igneous rocks are of 'alkaline' facies, whereas the later plutonic and extrusive rocks of the chains themselves are of 'calcic' type; and, if we assume that relief from increasing compression was eventually afforded by deep-seated dislocation, possibly in the form of submarginal thrust-planes, an explanation is offered for the great batholitic invasion of the chain by a granodioritic magma in post-Jurassic times.

V. Bibliography.

This list is a continuation of and supplementary to one published in a former paper of this series (No. 35 *infra*), to which reference may be made for further works dealing with the Geology of Peru and Bolivia.

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EXPLANATION OF PLATES I–VI.

Plate I.

Fig. 1. *Conularia africana* Sharpe, Lower Devonian; Taya Taya (Peru). Natural size. (See p. 37.)

2. *Conularia baini* Ulrich, Lower Devonian; Taya Taya (Peru). Natural size. (See p. 37.)

3. *Conularia quichua* Ulrich, Lower Devonian; Taya Taya (Peru). Natural size. (See p. 37.)

4 *a*. *Cyathaxonia* sp., Carboniferous Limestone; Viscachani (Peru). Transverse section of adult stage, showing solid central axis, and regular disposition of septa. Natural size. (See p. 46.)

4 *b*. Transverse section of adolescent stage, showing breaking-up of septal ring (cf. *Carcinophyllum simplex* Garwood). Natural size. (See p. 46.)

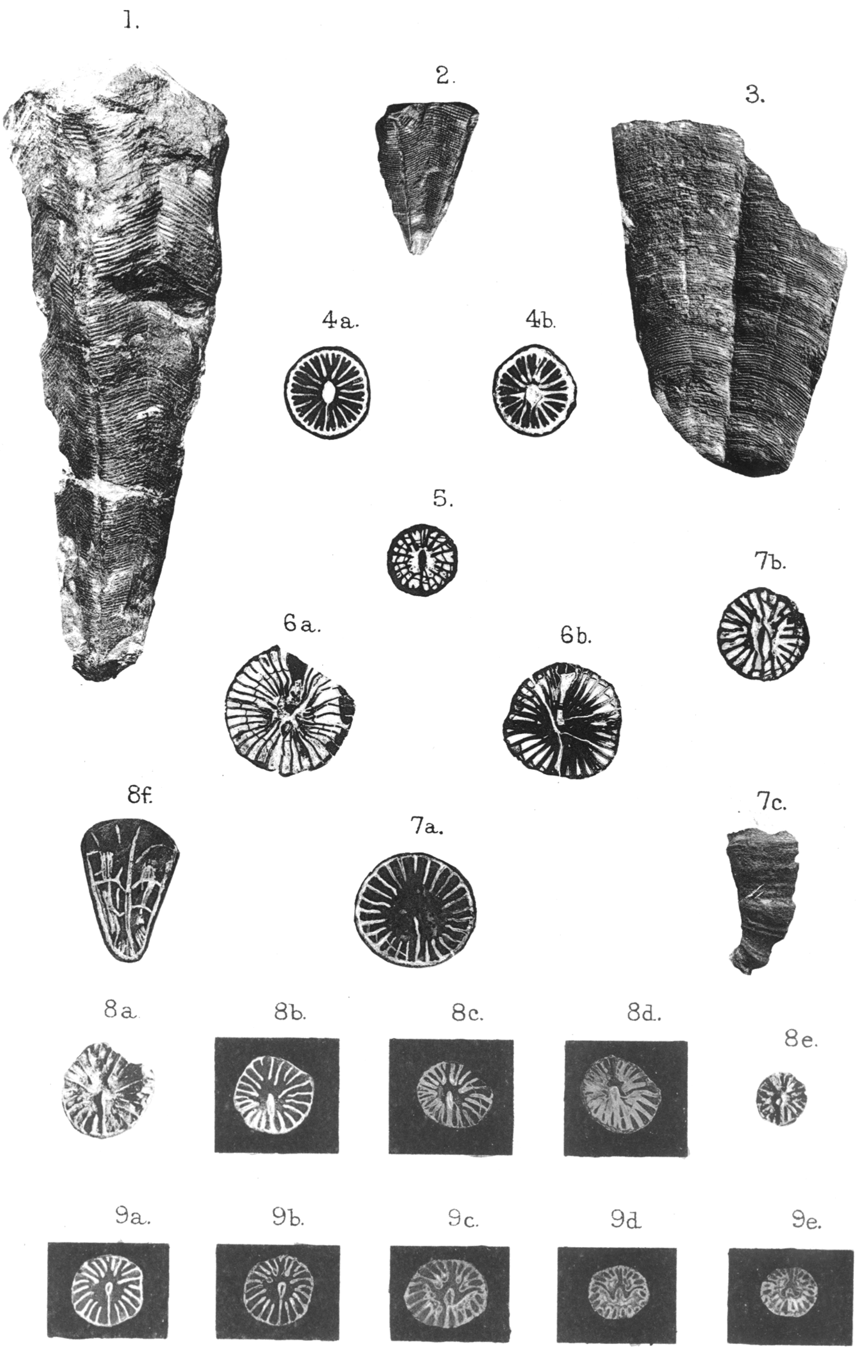
5. *Zaphrentis* aff. *eruca* (M'Coy), Carboniferous Limestone; Viscachani (Peru). Transverse section, showing Lophophylloid type of columella formed by the lateral thickening of the counter-septum, and the regularity of the tabular intersections. Natural size. (See p. 45.)

6 *a*. *Zaphrentis* aff. *enniskilleni* Edwards & Haime, Carboniferous Limestone; Viscachani (Peru). Transverse section, adult stage, near the floor of the calyx, showing the expansion of the cardinal fossula, and thin major septa with curvature convex to the fossula. Natural size. (See p. 46.)

6 *b*. Transverse section, adolescent stage, showing expansion of the narrow fossula near the wall, and thickened septa. Natural size. (See p. 46.)

7 *a*. Lophophylloid *Caninia*, Carboniferous Limestone; Viscachani (Peru). Transverse section, adult stage, near the floor of the calyx, showing the Amplexoid character of the septa, and the extension of the counter-septum. Natural size. (See p. 45.)

7 *b*. Transverse section of another specimen, adolescent stage. Natural size.



J.A.D., Photo.

Bemrose, Collo, Derby

FOSSILS FROM THE ANDES (MOLLENDO-INAMBARI SECTION).

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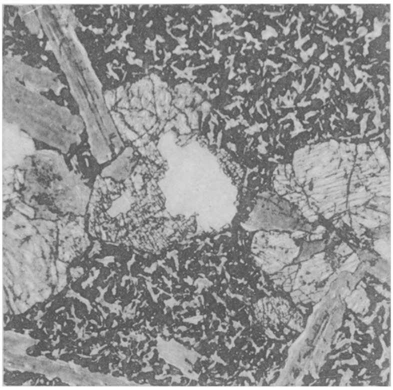

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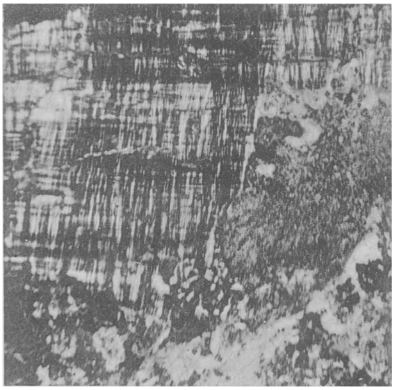

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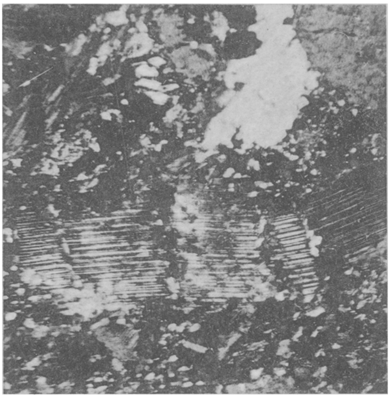

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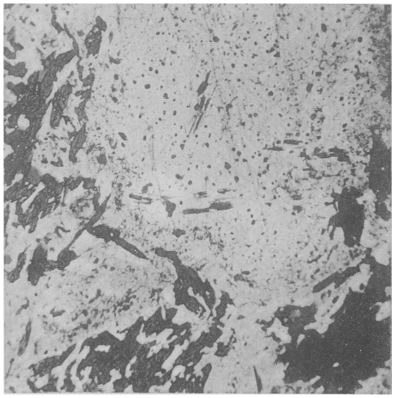

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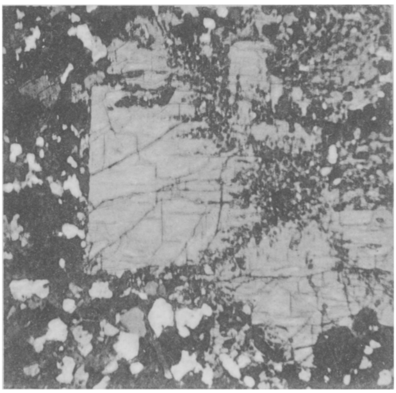
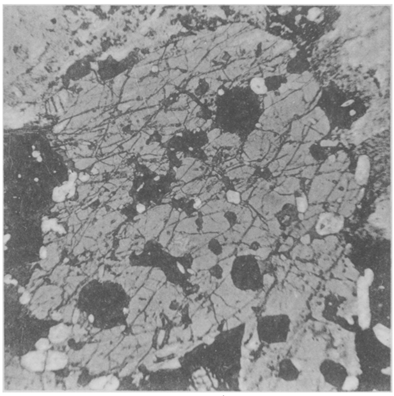


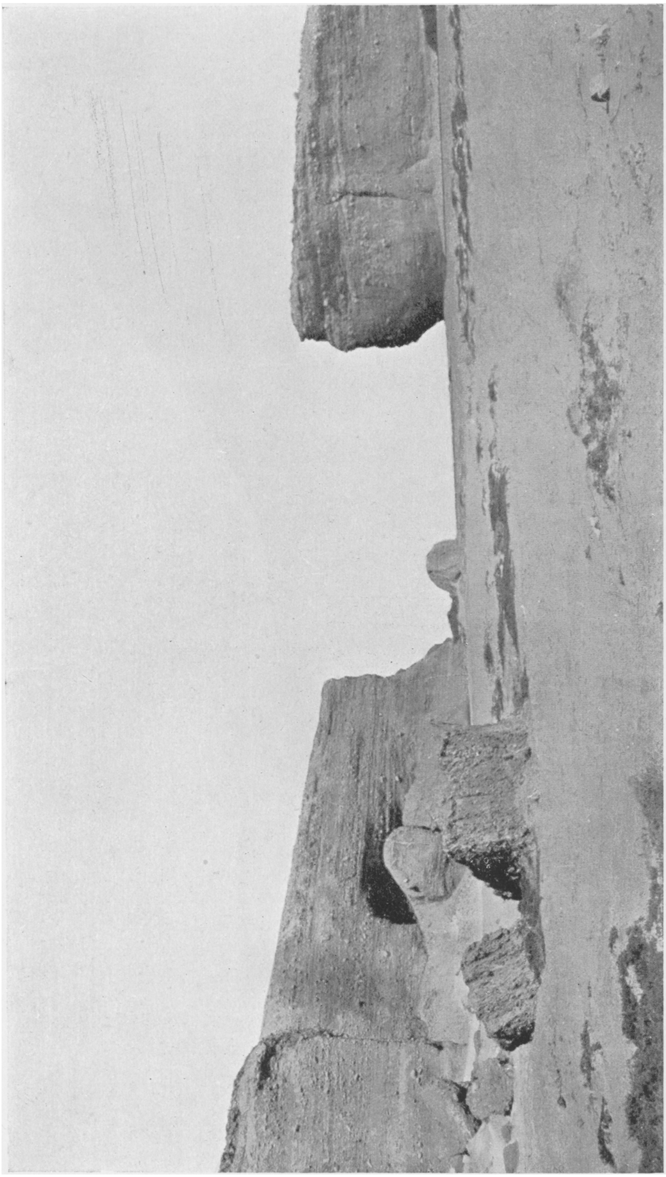
6.



J. A. D., Photomicro.

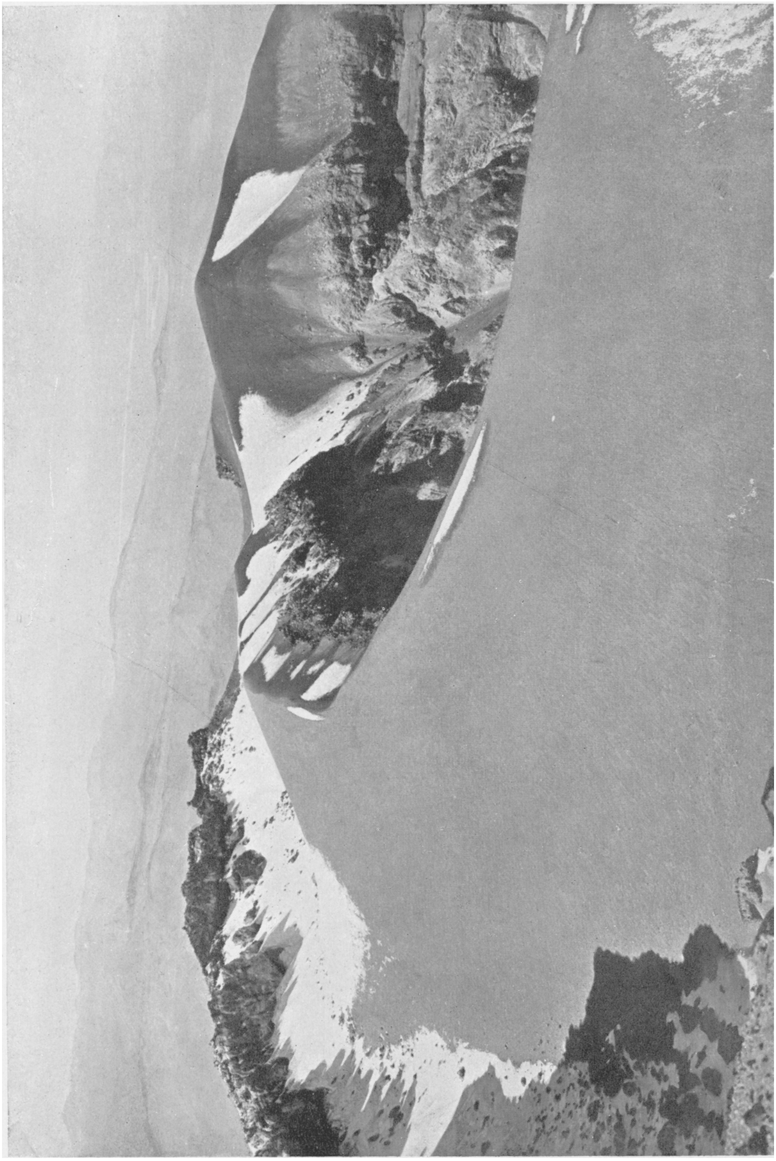
Bemrose, Collo., Derby.

IGNEOUS ROCKS FROM THE ANDES (MOLLENDO-INAMBARI SECTION).



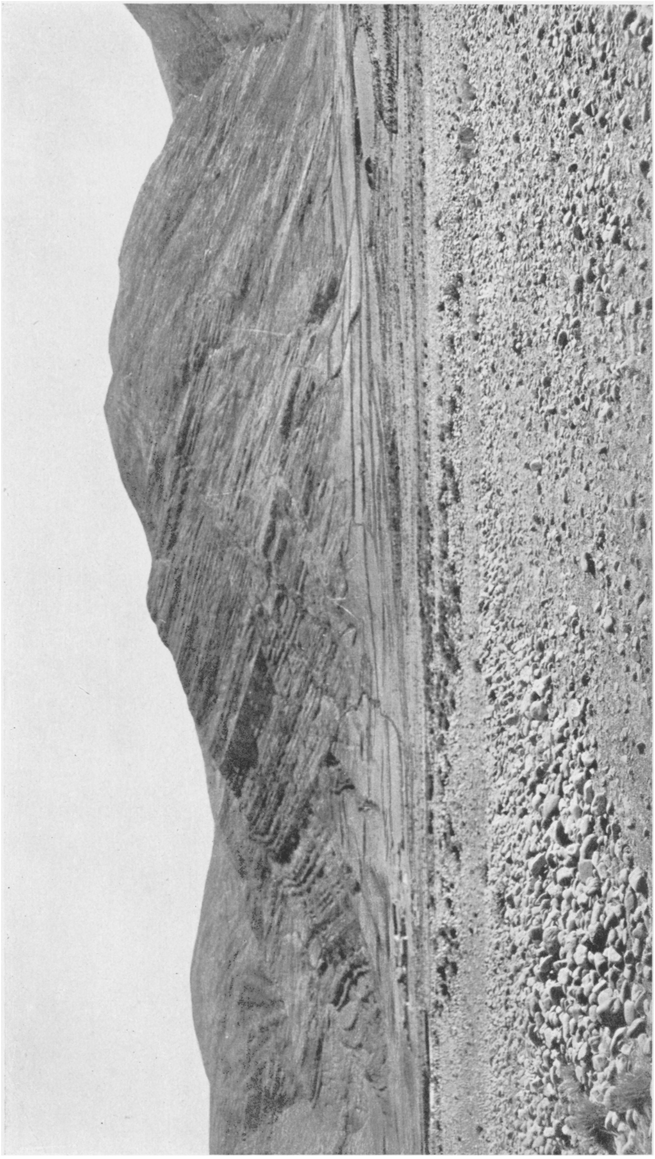
J. A. D. photo.

RAISED BEACH AT MOLLENDO.



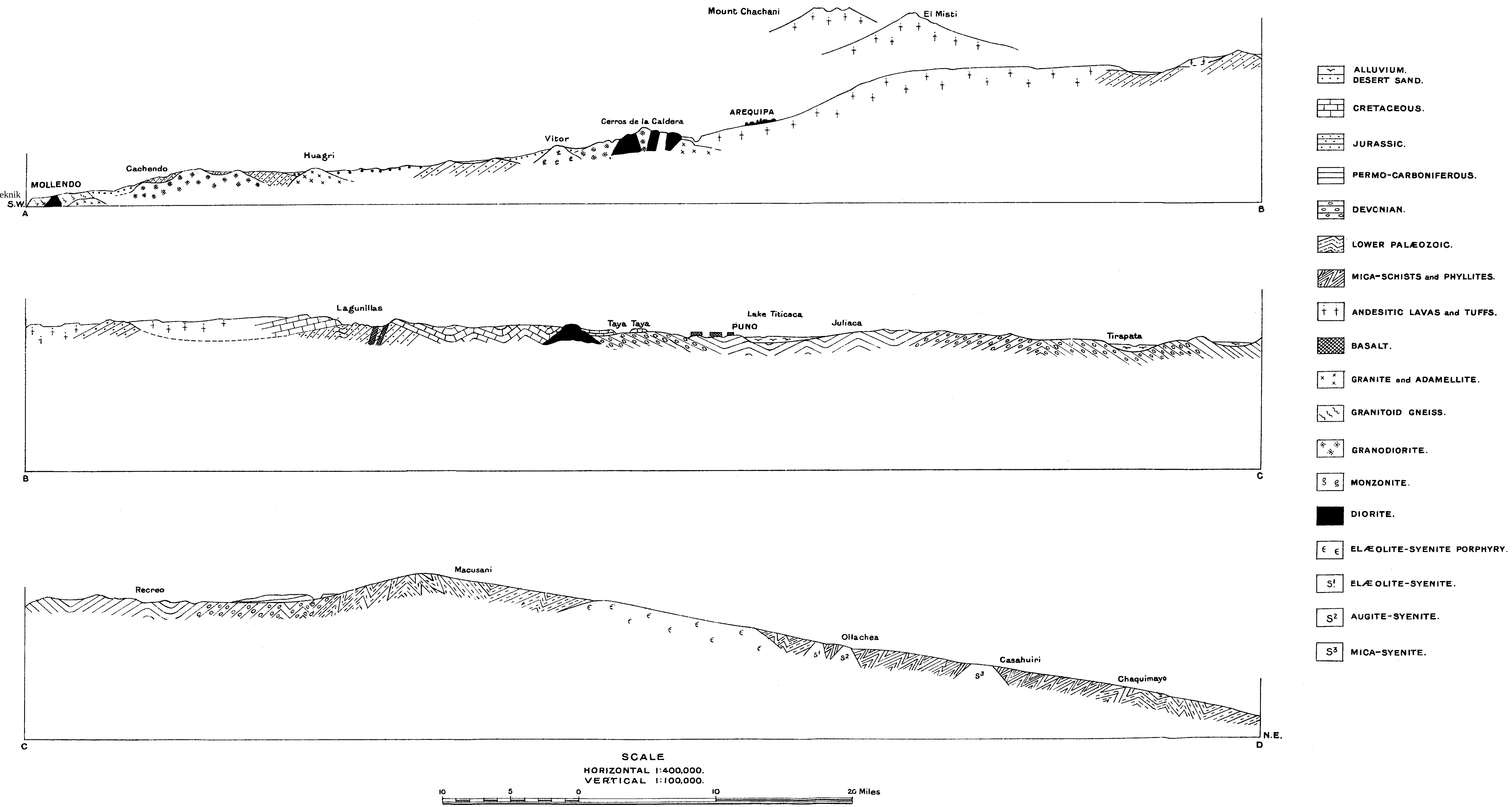
H. C. photo.

CRATER OF EL MISTI.



J. A. D. photo.

DEVONIAN BEDS OF TAYA TAYA.



GEOLOGICAL SECTION THROUGH THE ANDES FROM MOLLENDO TO THE INAMBARI RIVER.

Fig. 7 *c*. Profile view of a typical corallum, showing the irregular nature of growth. Natural size. (See p. 45.)

8 *a*. Lophophylloid *Zaphrentis*, Carboniferous Limestone; Viscachani (Peru). View of calyx. Natural size. (See p. 44.)

Figs. 8 *b* 8 *d*. Serial transverse sections showing septal development and Lophophylloid columella. Natural size.

Fig. 8 *e*. Weathered specimen of young individual, showing extension of the counter-septum through the central axis. Natural size.

8 *f*. Vertical section of another specimen through the centre of the corallum, at right angles to the counter-septum; showing the cut end of the latter as an axial rod penetrating the region of the cardinal fossula, as indicated by the depression of the tabulæ. Natural size.

Figs. 9 *a* 9 *e*. Lophophylloid *Zaphrentis*, Carboniferous Limestone; Viscachani (Peru). Serial transverse sections of a specimen, showing septal development and cardinal and alar fossulæ. Natural size.

[Figs. 7 *a*, 8 *b*–8 *d*, 8 *f*, 9 *a*–9 *e*, are of ground and polished specimens.]

Plate II.

Fig. 1. A 97. Dolerite, Mollendo: showing subophitic augite partly enclosing lath-shaped crystals of plagioclase (andesine), the cloudy appearance of the latter being due to the presence of minute schiller-inclusions. (In ordinary light, × 36 diameters.) See p. 11.

2. A 91. Granite, Mejia: showing a large crystal of microcline. (Between crossed nicols, × 24 diameters.) See p. 10.

3. A 79. Granodiorite, Quishuarani: showing the first stage in dynamic metamorphism, with distortion and fracture of plagioclase. (Between crossed nicols, × 24 diameters.) See p. 22.

4. A 76*a*. Xenolith in granodiorite, kil. 129: showing the result of the recrystallization of the component minerals. Andesine (clear), with abundant inclusions of magnetite and hornblende. Bluish-green hornblende (tinted); and biotite (black). (In ordinary light, × 24 diameters.) See p. 21.

5. A 125. Andalusite-mica-schist, Ollachea: showing a large crystal of andalusite. (Between crossed nicols, × 24 diameters.) See p. 52.

6. A 127. Augite-syenite (laurvikite), Ollachea: showing titaniferous augite; olivine; apatite; orthoclase; and magnetite (black). (In ordinary light, × 24 diameters.) See p. 51.

Plate III.

Raised beach at Mollendo.

Plate IV.

View of the crater of El Misti.

Plate V.

Devonian beds of Taya Taya.

Plate VI.

Geological section through the Andes, from Mollendo to the Inambari River. Scales: horizontal, 1 : 400,000; vertical, 1 : 100,000.

Discussion.

Dr. J. W. Evans congratulated the Author on the excellent work that he had accomplished. The ground that the speaker had the opportunity of examining in the Eastern Andes lay between the sections described by the Author in his two communications to the Society. It differed, in some respects, geologically from the region that had been dealt with on the present occasion. The Carboniferous formation occurred in the first and third synclines (counting from the west) in the Palæozoic rocks, but not in the second. Farther east the latter had been thrown into isoclinal folds, which included beds of Tremadoc and Llandeilo age, and possibly pre-Cambrian strata, but no crystalline schists; nor were there (with perhaps one unimportant exception) any soda-rocks. The low ground between the Palæozoic ridges was occupied by red rocks believed to be of Cretaceous age.

Prof. G. S. Boulger, having some years ago traversed the line of the Author's section throughout, thanked him for his admirable description of the geological structure of the country. He enquired as to the source of the lateritic deposits in the river-valleys at the eastern foot of the Andes.

Mr. W. Campbell Smith asked whether the Author had any evidence, other than the presence of the quartz-grains, to support his suggestion that the dioritic intrusion, shown in the section west of Taya Taya, had absorbed the Jurassic quartzite through which it was intruded, and that the quartz-grains were the relics thereof. The suggestion involved the acceptance of the 'stoping' and almost complete solution of a quartzite by a dioritic intrusion. This seemed an important point, on which further evidence was desirable.

Prof. W. J. Sollas also spoke.

The Author, in reply to Dr. Evans, said that he was himself convinced that the mica-schists of the San Gaban valley were largely the result of dynamic metamorphism, for the associated igneous rocks furnished clear proof of intense crushing. He did not claim, however, that this metamorphic zone was of wide lateral extent, and he had not met with it in the district east of La Paz. He was not surprised, therefore, to hear from Dr. Evans that it did not occur in the Caupolican area. This fact appeared to the speaker to lend strength to his suggestion that these ancient rocks had been instrumental in checking the advance of the folds into the Brazilian platform: for in the south, where they were absent, Dr. Evans had described subsidiary forefolds, and the Carboniferous transgression was of wider extent.

He agreed with Prof. Boulger that much of the soil in the forested region was due to lateritization; he had found extensive deposits of laterite in the Chanchomayo district, and regarded it as the normal product of weathering in these latitudes.

The Author found it difficult to account for the pre-Inca civilization of the High Andes, except on the assumption of a recent elevation; a corresponding depression of about 1500 feet would render the country round Tiahuanacu capable of cultivation. He referred once more to the pre-Spanish burial-tumuli, just above high-water mark near Arica, as precluding the possibility of any elevation of the coastal region since historic times. This, in his opinion, did not necessarily apply to the high plateau.

In conclusion, he expressed his gratitude to the late Mr. W. E. Balston, who enabled him to visit South America, and shared in Prof. Sollas's regret that Mr. Balston had not lived to see the result of the expedition which bore his name.