REPORT

ON THE

GEOLOGY OF SOUTH AMERICA.

BY

DAVID FORBES,

FELLOW OF THE ROYAL SOCIETY; FELLOW OF THE GEOLOGICAL AND CHEMICAL SOCIETY OF LONDON; MEMBER OF THE SCIENTIFIC SOCIETY OF CHRISTIANIA; ASSOCIATE OF THE INSTITUTE OF CIVIL ENGINEERS OF GREAT BRITAIN, ETC. ETC.

PART I.

BOLIVIA AND SOUTHERN PERU:

WITH NOTES ON THE FOSSILS

BY

Professor HUXLEY, F.R.S., Sec.G.S., &c.,
J. W. SALTER, Esq., F.G.S., &c., and
T. RUPERT JONES, Esq., F.G.S., &c.

(Communicated to the GEOLOGICAL SOCIETY Nov. 21st, 1860.)

LONDON:

PRINTED BY TAYLOR AND FRANCIS, RED LION COURT, FLEET STREET.

1861.

[*From the* Quart. Journ. Geol. Soc. vol. xvii.]

On the Geology *of* Bolivia *and* Southern Peru.

By David Forbes, Esq., F.R.S., F.G.S., &c.

[Plates I., II., III.]

Contents.

Introduction.
1. Tertiary and Diluvial Formations of the Coast.
2. Saline Formations.
3. Diluvial Formations of the Interior.
4. Volcanic Rocks.
5. Dioritic Rocks.
6. Upper Oolitic Series with interstratified Porphyritic Rocks.
7. Permian or Triassic Formation.
8. Carboniferous Formation.
9. Devonian Formation.
10. Silurian Formation.

Introduction.—In laying before the Society a statement of the observations made during an examination of Peru and Bolivia, in the years 1857, 1858, 1859, and 1860, I may observe that the present memoir is to be considered as the first part of a report of the results obtained during my travels in South America during these years; and, consequently, it is believed that the conclusions here arrived at will have more weight when considered in conjunction with the observations on the geology and mineralogy of the neighbouring republics of Chile and the Argentine provinces, which subsequently I shall have the honour to lay before the Society,—more particularly as several of the geological formations not well developed or examined into in the district forming the subject of this memoir exhibit themselves much more characteristically further south.

Many points will be found not so elucidated or examined into as could be desired, and might appear to have been neglected; this, however, has not arisen from oversight, but is due to the great difficulties and frequently severe privations encountered in exploring a country in many parts entirely uninhabited or in next to a savage condition, and further by my having been limited as to time and pecuniary resources, and hampered by other occupations and by the political state of the country.

In the construction of the accompanying Map and Sections (Plates I. & II.), Nos. 1 & 2 of which give a good idea of the structure and formation of the different mountain-ranges of the Andes, the horizontal distances are laid down from the best local information which could be procured, and from data furnished by the Bolivian Government-survey lately completed. For the vertical altitudes, in addition to those determined by myself barometrically, and occasionally by boiling-point and trigonometrical observations, I have employed some of the heights noted on Mr. Pentland's map, and, further, the

following series of observations made by a gentleman for some time my fellow-traveller, Captain Friesach, of the Austrian army, as given in the annexed Table.

Locality.	Elevation above sea in English feet.	Locality.	Elevation above sea in English feet.
Arica	20	La Paz (highest part)	12,270
Tacna	1,950	La Paz (Alameda)	11,930
Pachia	3,580	Millocato	8,150
Palca	9,700	Cotaña	7,990
La Portada	12,630	Hacienda de Illimani	10,010
Alto de Guaylillos	14,650	Santiago	8,940
Ancara	13,750	Rio de la Paz on entering Yungas	3,380
Uchusuma	13,910		
Rio Mauri	13,560	Rio de la Paz below Toca	4,204
Pailumani	14,725	Yrupana	6,870
Chulluncayani (pass)	13,680	River below Yrupana	4,570
Santiago de Machaca	12,770	Culumani	6,460
San Andres de Machaca	12,890	Rio de Tanampayo	4,320
Nasacara	12,710	Coripata	6,360
Surire	13,565	Corioco	6,530
Pacheta del Rio Colorado	14,210	River near Corioco	3,925
Coniri	12,950	Sandillan	7,040
Biacha	12,780	Highest point between Sandillan and Unduavi	11,830
Unduavi	10,780		
Highest points between Unduavi and La Paz	15,630	Copacabana	12,730
		Puno (shore of Lake Titicaca)	12,630
Tambillo de Laja	12,830	Ariquipa (plaza)*	8,840
Disaguadero	12,680	Summit of Misti, or volcano of Ariquipa*	19,876
Alto de Potosi	13,580		

* The height of the plaza of Ariquipa was determined by the Torricellian experiment, and found as stated above; the summit of Misti or volcano of Ariquipa was found to be 11,436 feet above the plaza by a trigonometrical measurement.

And lastly, in addition to these, the following Table of heights of mountains in English feet has been calculated from some of the results obtained by the recent Government-survey of Bolivia.

Mountain.	Elevation above sea in English feet.	Mountain.	Elevation above sea in English feet.
Illampu	24,812	Mururata	20,418
Illimani	24,155	Callinsani	20,530
Sajama (volcano)	23,014	Potosi	15,724
Coololo (Apolobamba)	22,374	Tunari de Cochabamba	15,608
Huayna Potosi	21,882	Hermoso de Aullagas	15,747
Cachacomani (volcano)	21,583	Portugalete	14,720
Quenuata, peaks of Tacora	21,252	Espejos	9,337
Chipicani (volcano)	22,687	Misti (volcano of Ariquipa)	20,150

The strike and dip of the rocks, when not otherwise stated, are given with reference to the magnetic meridian.

In the arrangement of my notes it was found most satisfactory to classify them according to the geological age of the deposits in question, commencing with the most recent.

1. *Tertiary and Diluvial Formations of the Coast.*—The older Tertiary beds of shells so characteristic of many parts of the Chilian line of coast do not appear to present themselves from Mexillones northward to Arica; but we find at intervals shell-beds, containing exclusively shells of species now inhabiting these waters, elevated to a small height above the sea: I did not, however, observe any beds reaching an elevation of 40 feet above the present sea-level; and although the whole line of coast shows unquestionable signs of recent elevation, still the evidence is not so satisfactory, and appears to point out a much more irregular action than further south along the Chilian coast-line.

At Cobija I discovered a bed of shells in the immediate neighbourhood, to the south of the port, about 25 feet above the present sea-level; and, on examination, this was found to contain only species at present inhabiting these waters. Among these shells I recognized the following genera:—

Concholepas.	Fusus.	Patella.
Mactra.	Oliva.	Fissurella (2 species).
Venus (2 species).	Trochus.	Chiton.
Mytilus.	Turbo.	Serpula.
Tellina.	Turritella.	Balanus.

I found also fragments of an Echinus and bones of a Seal. Whilst digging in this bed, I came upon a small piece of wood in a decayed state, which evidently had been shaped by human hands, and bore marks of having been cut by a sharp tool, most likely of steel, as some of the cuts appeared much too defined to be attributed to a stone or other dull instrument.

On the rocks close to the town are some deposits of guano, which are being worked to advantage, although in quality and thickness much inferior to the guano from the Chinchas Islands pertaining to Peru. These deposits are situated at from 20 to 40 feet above the sea-level, and in appearance are very similar to the Chinchas beds on a small scale.

On the surface of these deposits, and also between the beds of the same, my attention was attracted by a crust or bed of a harder substance, of a light-brown colour, varying in thickness from a few inches to one or more feet, and possessing a semicrystalline and rather saline appearance, with occasionally a faint ammoniacal odour. On examination I found it to contain a large amount of ammonia in a state of combination; and, at the request of the Bolivian Government, it was analysed by Mr. Francis Ignacio Rickard, of Valparaiso, who obtained the following per centage composition:—

Water	12·45
Organic matter	17·48
Chloride of ammonium	30·20
Phosphate of lime	10·00
Sulphate of lime	0·80
Chloride of sodium	16·03
Sand	1·60
	98·56

From the above results it is evident that this substance had been produced by the action of sea-water, probably thrown up in the form of spray, on the guano-beds. The amount of ammonia contained in this material being much greater than in the unaltered guano itself, this substance, formerly thrown aside as worthless, is now exported in large quantities, under the name of "Huano petrificado," realizing a price considerably higher than the guano with which it occurs. The low elevation of these guano-deposits above the present sea-level, and their thickness, which is frequently not less than 10 to 15 feet, sufficiently prove that, in parts at least, they are of later origin than the shell-beds previously described. Other similar guano-deposits are met with at Mexillones, Algodon Bay, the newly discovered San Felipe Islands, and at various parts along the coast.

At several places along the coast the raised beaches are strongly impregnated with salt, which occurs both in the form of small layers, or imbedded, as well as irregularly distributed in the diluvial detritus. This is the case at Mölle, Ceremoño, and Patillos, all to the south of Iquique, and several other places. These saline deposits are found at the height of from 10 to 40 feet above the present sea-level; at the two first-mentioned places the salt is so abundant that cargoes have occasionally been shipped from them. On the top of the Morro de Arica, a hill about 500 feet above the sea, small superficial layers of tolerably pure salt, from $\frac{1}{2}$ in. to 3 inches in thickness, are also met with; and the fissures on the side of the same hill are often found to be filled with veins of salt.

At Arica I was not successful in finding *Balani* and *Milleporæ* attached to the sides of the "Morro" hill, as described by Lieutenant Freyer*; and the many loose sea-shells met with on the sides and summit of the same I believe to have been brought there by the numerous sea-birds, probably assisted, on the south slope, by the action of the winds and shifting sands.

That no very perceptible elevation has taken place in the immediate neighbourhood of the Morro of Arica (or, if such an elevation had taken place, that it has been followed by a subsequent depression to nearly the same level) during the last 350 years, or since the Spanish conquest, appears from the numerous Indian tumuli found along the beach, for miles south of the Morro; many of these are not 20 feet, and some probably considerably less, above the present sea-level. That these tumuli have not been constructed since the

* Darwin's 'Geology of South America,' p. 47.

Spanish invasion may be inferred from the ornaments of gold found in them, along with the mummies, one of which I was informed had been found by Mr Evans, the Engineer of the Arica and Tacna railroad, enveloped in a thin sheet of gold.

Along the Coast of Chile, on the contrary, there is the fullest evidence to prove that, since the arrival of the Spaniards, a very considerable elevation of the land has taken place, over the greater part, if not the whole extent, of the line of coast.

North of Arica, if we accept the evidence of M. d'Orbigny and others, the proof of elevation is much more decided; and consequently it may be possible that here, as is the case about Lima, according to Darwin, the elevation may have have taken place irregularly in places; but at the same time a depression or submergence, as at Callao, could hardly have taken place without having destroyed these Indian tumuli, formed in the loose sand, and quite incapable of resisting the action of the waves, which produce a strong surf along this rugged coast.

With regard to the evidence of the rise of the land, deduced from the occurrence of sea-shells strewed over the surface of the higher ground further inland, it must be remembered that the numerous sea-birds which feed on shell-fish frequently carry their food to considerable distances from the sea, and likewise that shells are occasionally transported inland along with the sand in the shifting sand-dunes which are common enough along the coast; where the slope is gentle, as in the immense inclined plains to the north of Arica, this may frequently be the case. These sand-dunes appear to attain their greatest mobility during the hot season, when the parched sand rolls along impelled by the slightest breath of wind, and several times reminded me of the extraordinary mobility presented by silica and some other substances in a state of fine division when heated in a crucible or other vessel, especially if, as it were, provoked by the slightest touch of a rod.

An observer, travelling quickly over the ground, might easily be deceived, and regard as evidence of elevation the occurrence at some few spots of innumerable shells spread over a small area or patch in the midst of this desert landscape. On examination, these are found to be a land-shell (a species of *Bulimus*) about $\frac{3}{4}$ to 1 inch in length; and it is difficult to account for their presence in these spots, destitute of all vegetation, except on the supposition that they have made their appearance thus abundantly in years favoured with some showers of rain, which may have developed in these scattered spots a vegetation sufficient for their sustenance. I have noticed the occurrence of such spots covered with these shells in the midst of these desert-tracts, down to as far south as Choros Bajo, a little north of Coquimbo in Chile. Professor Philippi has also observed them at the Morro de Mexillones.

The coast from Mexillones to Arica is formed by a nearly continuous chain of mountains, rising abruptly from the water's edge, and attaining an average elevation of about 3000 feet, but diminishing in height towards their northern limit, the Morro of Arica, which

does not exceed 600 feet above the level of the sea. An occasional narrow strip of sea-beach is seen bordering this range, and is composed exclusively of the débris of the mountains themselves, which, being in many places nearly perpendicular, expose to the spectator, passing along in the coast-steamers, a fine section of the shales, claystones, and imbedded porphyries which here represent the Upper Oolitic series, and are occasionally seen disturbed and altered by the intrusion of dioritic rocks of a later age.

At Arica, however, this range of mountains suddenly recedes from the coast, leaving an intermediate space, about 30 miles broad and extending as far northward as examined, occupied by gently sloping plains, evidently ancient sea-beaches, which rise to the height of about two thousand feet above the sea-level. These plains, being for the most part entirely destitute of water (as no rain falls in these regions), are consequently entirely barren, and present to the eye of the traveller a most desolate and arid appearance. When, however, as in the valleys of Tacna, Sama, and Azapa, a scanty supply of water does occur, the soil, noted for its surprising fertility, produces a most luxuriant vegetation of a semi-tropical character.

These plains are composed of sand, earth, and gravel, with abundant fragments, more or less rounded, of the porphyritic, dioritic, and volcanic rocks forming the coast-range of mountains which bound them to the eastward. Even after a most careful examination, no single fragment or boulder of any extraneous rock was met with; so that no drift-action appears to have assisted in the formation of these beaches, which appear due solely to the action of the waves beating against the former rugged line of coast.

In the Sections No. 1 and 2, Pl. II., which cut through this district, it will be observed that a volcanic formation, apparently contemporaneous, is situated in the midst of these plains, which does not bear the appearance of having been injected into the diluvial beds forming them, but rather to have flowed over them, or more probably to have been deposited on the top of them whilst still under water, in the form of a tuff or volcanic ash, and subsequently to have again been covered up by similar diluvial matter; a more detailed examination, however, is necessary to settle the question. I may mention that Dr. Vance of Tacna informed me that near the railway at that place the ground in a cutting was found to be burnt and altered, as if by igneous action; this appears to me as more probably due to still later volcanic activity.

The rocks of this volcanic formation are all trachytic, and frequently present a most striking similarity to the domite of Auvergne, being, like that, composed of quartz, black or brown hexagonal mica, and a weathered-looking felspar, and form some four or six beds, superposed one on another, and of an average thickness of about 10 feet each; these are either a white trachytic tuff, like domite, with abundant imbedded fragments of pumice, or a compact trachyte of a reddish or white colour and similar composition.

These trachytic tuffs form an excellent building-material, from the ease with which they are worked and shaped, and are very exten-

sively employed for this purpose at Arica and Tacna. In the quarries of this rock near Tacna I discovered a mineral very much resembling allophane in external characters, but differing in only containing 28·49 per cent. of water: it occurs in fissures in the trachytes, forming veins of from a line up to some inches in thickness, and is probably derived from the decomposition of the felspathic element of the trachyte by the action of water.

2. *Saline Formations.*—Later in age than the Tertiary deposits, the saline formations so characteristic of this part of South America are not, as frequently supposed, merely confined to the country surrounding the port of Iquique, but appear at intervals scattered over the whole of that portion of the western coast on which no rain falls, extending further north than the limits of the map accompanying this memoir; whilst to the south they run entirely through the desert of Atacama, and even show signs of their existence further south than Copiapo in Chile, thus stretching more than 550 miles north and south; their greatest development appears, however, between latitudes 19° and 25° S.

They are generally superficial, but occasionally reach to some small depth below the surface, and then may be entirely covered over by diluvial detritus; they always, however, show signs of their existence by the saline efflorescence seen on the surface of the ground, which often covers vast plains as a white crystalline incrustation, the dust from which, entering the nostrils and mouth of the traveller, causes much annoyance, whilst at the same time the eyes are equally suffering from the intensely brilliant reflection of the rays of a tropical sun.

The salts forming these "Salinas," as they are generally termed, are combinations of the alkaline and earthy bases soda, lime, magnesia, and alumina, with hydrochloric, sulphuric, nitric, and carbonic acids, and occasionally with boracic, hydriodic, and hydrobromic acids,—and in combination present themselves as the following minerals in a more or less pure state:—Common salt, epsom-salt, glauber-salt, thenordite, glauberite, soda-alum, magnesia-alum, gypsum, anhydrite, along with chloride of calcium, iodide and bromide of sodium, carbonate and nitrate of soda, and in some places borate of lime and borax.

With the exception of the boracic acid compounds, the presence of which (as subsequently will be attempted to be proved) is due to volcanic causes, all the mineral substances found in these "Salinas" are such as would be left on evaporating sea-water, or by the mutual reactions of the saline matter thus left on evaporation on the lime, alumina, and organic matter found in the adjacent rocks, soil, and shell-beds; and as we have indisputable evidence of the recent elevation of the whole of this coast, and bearing in mind likewise that no rain falls in these regions, it appears very reasonable to suppose that all these saline deposits owe their origin to lagoons of salt water, the communication of which with the sea has been cut off by the rising of the land. When studying the structure of the mountain-ranges near the coast, it was also observed that, at all the

large saline deposits, the chain of hills to the westward or sea side of the "Salinas" is of such a formation as might on elevation be expected to enclose a series of lagoons, which, by means of the breaks or lateral openings in the chain itself, could for a longer or shorter period keep up a tidal or occasional communication with the sea when high, which thus would pour in a fresh supply of salt water to make up for the loss sustained in the lagoons from the evaporation produced by the heat of a tropical sun. It is therefore not necessary to suppose that the great amount of saline matter generally present in these deposits is due to the salts contained in an amount of sea-water merely equal to the quantity originally contained in the lagoon, or, in other words, to the cubical contents of the lagoons themselves.

The occurrence of salt at different places along the coast at very small elevations above the sea, previously noticed, is no doubt due merely to the tidal infiltration of sea-water into the porous shingle and other beds, and its subsequent evaporation; and must not be confounded with the much greater and more elevated saline deposits further inland, which are met with at three very different altitudes above the sea, as follows:—

(1) At, approximately, from 2500 to 3500 feet,
(2) „ 7000 to 8000 feet,
(3) „ 12,500 feet

above the present sea-level, and which appear to indicate three distinct and important changes in level in this part of South America.

(1.) The deposits situated at about 2500 to 3500 feet above the present sea-level include the important beds of nitrate of soda so extensively worked along this coast, and appear to run from latitude 19° southward into the northern part of the Desert of Atacama, showing themselves, according to the configuration of the country, at distances varying from 10 to 40 miles inland.

When in this part of the country, I had not time to make a more detailed examination of these saline deposits than was necessary to enable me to arrive at a conclusion as to their mode of formation and the origin of the nitrate of soda contained in them.

All the data that I could obtain appeared fully to confirm the "lagoon hypothesis" previously mentioned, and to prove that the original constituents of these beds had merely been such salts as would result from the evaporation of sea-water. The nitrate of soda and some other associated compounds are due to subsequent reactions, and consequent decomposition of the salt of the original deposit, mainly produced by the agency of carbonate of lime and decomposing vegetable matter.

The first step in the formation of nitrate of soda appears to be the decomposition of the chloride of sodium, or salt, by carbonate of lime (in the form of shell-sand, &c.) with the production of chloride of calcium and carbonate of soda, both of which salts have been shown to be present in quantity in the soil of these nitrate-grounds.

The carbonate of soda thus eliminated, when in contact with the mixture of shell-sand and decomposing vegetable matter which may

be expected to result from the luxuriant vegetation around such a tropical swamp, and from the abundant marine plants in the lagoon itself, would realize the conditions of the French artificial nitre-beds, substituting only carbonate of soda for the carbonate of potash there used: we may consequently, with all fairness, expect a similar result in the production of nitrate of soda on a still larger scale.

This view appears much strengthened by the occurrence of wood, reeds, or rushes, and other vegetable matter in the nitre-grounds at but little below the surface, as well as from the general position of the nitrate of soda in the saline deposit, as it invariably occurs in the margin or outer edge of these, representing the shelving sides of the hollow or lagoon-basin, the central part of which is composed of layers of sea-salt only, frequently several feet in thickness.

In seeking for nitrate of soda, the searchers always look to the rising edge of such salt-basins, and further judge of the probability of finding the nitrate from a peculiar moist or clammy state of the ground, which is due to the presence of the chloride of calcium produced by the decomposition above explained.

The quantity of sulphates, and more especially of sulphate of lime, included invariably in these deposits might, at first sight, appear to the observer too great to suppose it due only to the evaporation of the sea-water; but I believe that this impression will be dissipated when he sees the enormous amount of gypsum removed in the form of hard white cakes, or sedimentary crust, from the boilers of the large distilling machines in use along this arid coast for producing from the water of the sea a supply of fresh water for the maintenance of the inhabitants, beasts of burden, and even the locomotive engines of the railways along this coast. It appears not necessary to suppose, as has been put forth, that the sulphates present have been formed by volcanic exhalations acting upon the beds of salt. The boracic acid compounds met with appear, however, to be due to this cause; and the borate of lime met with in such large quantities appears to be indirectly produced by the condensed vapours of volcanic fumeroles, many of which are still in full activity in this district.

The gaseous exhalations of these fumeroles have, I believe, never been submitted to a chemical examination; so that the presence of boracic acid has not actually been proved; it may, however, be inferred from the general resemblance which these fumeroles bear to those of Tuscany, the Lipari Islands, &c., where it is known to exist.

The borate of lime is found only on the more elevated part of this saline district, occurring on the eastern side of the same, where the rising ground begins to form the western slope of the adjacent cordilleras.

As volcanic action is developed on a grand scale in this mountain-range, such solfataras or fumeroles, forming lateral orifices on the side of the mountains, are very common; and we may expect that the waters coming down this slope carry with them in solution the boracic acid contained in the condensed vapours of these solfataras, which, coming into contact with the lime of decomposed porphyry-

rocks, or the shell-sands of the plains below, would combine readily to form the nodules of borate of lime here met with.

It has been suggested that the nitrate of soda likewise owes its origin to similar causes; I consider, however, this view to be untenable where the vapours themselves, from the great amount of sulphurous and hydrosulphuric acid gases which they contain, are of so eminently deoxidizing a nature as to decompose any nitric fumes evolved by such volcanic action. I therefore believe the nitrate of soda wholly due to the chemical action previously expounded.

The saline deposits of this series do not rest directly on the rock itself, but on a beach more or less level, or hollowed out into lagoon-basins, and composed, as the present and the raised sea-beach previously described, of the débris of the adjacent porphyritic, dioritic, and volcanic rocks.

The deposits explored for nitrate extend from the river of Pisagua southward to Patillos, a distance of about 110 miles; but latterly new and extensive deposits have also been worked further south, inland from Tocopilla. There is, however, no doubt that they exist along the whole coast-line depicted on the accompanying map, at from 10 to 50 miles inland; the borate deposits, however, appear to recede from the coast, as they occur more to the south, and strike to the eastward, following the line of volcanic action, indicating thereby their connexion with the same.

(2.) The series of saline deposits next in elevation are situated at from 7000 to 8000 feet above the level of the sea, and are developed on a grand scale in the northern part of the desert of Atacama,—the great "Salina de Atacama" extending 100 miles or more from S.E. to N.W., with a breadth of 20 to 30 miles, and the lesser "Salina de Punta Negro" still further south (about 30 miles long and 12 broad)—two examples of immense salt-plains, apparently resulting from the drying up of such lagoons as those before described.

Not having made a personal examination of these, I am not in a position to give any detailed account of them; in fact, they are only known in name and extent, and have never been examined.

(3.) At an altitude of about 13,000 feet above the sea, saline matter is found to occur in a manner similar to that of the last-mentioned deposits. In Section No. 2 (Pl. II.), at "Laguna Blanca," extensive plains and salt-lagoons are found,—the latter still existing as lagoons, since they are now situated on the extreme borders of the rainless region, whereby the loss from evaporation is supplied, in part, by the rain which falls; and thus we generally find extensive plains covered by white crystalline salt, forming the circumference of some small and generally shallow lake, deserving only the name of a swamp except in the rainy season of the year. This saline formation, I believe, is seen more or less developed all the way to Oruro, and thence over the saline plains of Sora-Sora, it extends much further south, but, like the last, has not as yet formed a subject for more minute examination, and, from its occurring in districts exposed to a heavy annual

fall of rain, is naturally not so characteristic in its development as the two previously described formations, although at the same time it presents some very striking features, and in some respects strikingly reminds us of its supposed lagoon origin.

3. *Diluvial Formations of the Interior.*—The saline deposits last noticed are situated in the midst of what may be termed the great Bolivian plateau, having an average altitude of fully 13,000 feet above the sea, and bounded to the west by the Upper Oolitic rocks of the coast-cordilleras, whilst to the east it abuts against the Silurian range of the true Andes. This plateau is not uniform in its mineralogical nature; and when viewed in section from east to west, it shows considerable diversity of composition, arising from the ranges of hills which intersect it all bearing nearly north and south, and thus dividing it into so many longitudinal valleys (see Pl. II.).

These valleys are generally occupied by nearly level plains, formed of the gravelly spoil produced by the wearing down of the bounding ridges, with which they are consequently identical in lithological composition. The ridges themselves seldom attain a greater elevation than 2500 feet above the plateau, and are generally under this height; but occasionally volcanic cones thrust themselves up to more than 6000 feet above the plain, and consequently attain an elevation of fully 20,000 feet above the sea-level.

The character of this plateau is well shown in the Sections Nos. 1 and 2 (Pl. II.), by a reference to which it will be seen that it may be separated into three divisions—western, central, and eastern (Oolitic, Permian, and Silurian, according to the nature of the rocks originating the diluvial accumulations which fill up the intermediate basins or valleys).

The most western of these is essentially composed of Upper Oolitic detritus, with an occasional block of diorite, and in places abundant volcanic débris from the neighbouring eruptions. They are covered with but a very scanty verdure, if not entirely barren, and incrusted with saline matter, and are generally either entirely destitute of water, or possess some few springs at great distances from one another and of abominable quality—frequently, as at Rio de Azufre (Section No. 2), not potable, and even causing death to the animals which drink it, as sufficiently proved by the bones of mules, llamas, &c., scattered along the banks. At most places the water generally produces bad effects to those unaccustomed to it, even when it is comparatively tasteless.

From an examination of the waters from several localities, I may observe that in one or two cases it was perfectly astonishing what an amount of saline matter might be present in water which might be termed "palatable," but which produced strong purgative effects; on examination, such a water from the desert of Atacama was found to contain a very large amount of the sulphates of soda and magnesia (Glauber and Epsom salts), associated with common salt and carbonate and sulphate of lime; and I can only suppose that the bitter taste which the amount of sulphate of magnesia (Epsom salts)

present would alone produce had been neutralized or concealed by the admixture of the other salts.

In the midst of these plains at Ancara, I noticed some recent conglomerate-beds, of a brown colour, composed of small and very angular pebbles, and more like a breccia than a true conglomerate. They were of very small extent, and had an apparent strike nearly N. and S., with a low dip to eastward.

The central division of this diluvial formation is distinguished at first sight from either of the others by the redness and sandy nature of its soil, showing at once its derivation from the Permian or Triassic sandstones and marls; occasional patches are covered by volcanic detritus where the sandstone hills have been disturbed by the intrusion of the trachytic rocks, well illustrated in Section No. 1. The plains thus formed are well watered and frequently marshy, and are cut up by numerous rivers, at least in the northern part of the district here described*; we do not find the surface-water saline, as is invariably the case in the western division; but occasionally, as for example at Santiago and at San Andres (both on Section No. 2), we meet with brine-springs, which furnish the inhabitants with an abundant and cheap supply of culinary salt of excellent quality, by simply allowing the water to evaporate in the open air from the heat of the sun. These brine-springs are most probably due to salt-beds situated at greater depths in the sandstones of the formation itself, and not to be attributed to saline deposits of more recent origin.

The third or eastern division of this plateau is, in its turn, so different in character from either of the preceding, that it is at once recognized when encountered.

In Sections Nos. 1 and 2 (Pl. II.), this formation is seen as a great plain abutting to the east against the Silurian rocks of the highest range of the Andes, to the débris of which it owes its origin: whilst to the westward it is confined by the range of low hills of Devonian strata which separate it from the central division of this diluvial formation. The intermediate basin, occupying the space between these Silurian mountains and Devonian hills, is filled up to the level of the plain by an immense accumulation of clays and gravels, with larger pebbles and boulders of Silurian and granitic rocks,—the former being represented by grauwackes, indurated sandstones, clay-slates, and shales, which latter occasionally contain fossils of Silurian age.

Where, as in the valley of the river of La Paz (which from its abruptness might almost be termed a ravine), a section of this basin is disclosed (Section No. 2), its surprising magnitude is seen, as in this place. The thickness, reckoning from the level of the plain

* I may here mention that in a spring at Comanche, the water of which appeared to feel slightly warm on immersing the hand, I found numbers of a small univalve shell; and on submitting them to the inspection of Professor Philippi, of the University of Santiago, in Chile, he considered them identical with his *Paludina Atacamensis*, which he discovered in a tolerably hot spring at Tilopozo, in the northern part of the Desert of Atacama.

above down to the Alameda of La Paz, was found by measurement to be 1650 feet, consisting of alternating beds of grey, bluish, and fawn-coloured clays, gravel, and shingle-beds, along with boulders of clay-slate, grauwacke, and granite, frequently of enormous size, and well rounded as if by the action of water; the beds are nearly horizontal, or dip to the south. About 300 feet below the surface of the plain, there is seen in this section a bed of trachytic tuff, evidently volcanic, and about 20 to 30 feet in thickness. This is visible at a great distance as a white band, running along the precipices encircling this valley or ravine, and appears to be contemporaneous with the beds of clay, gravel, and boulders, which, with this solitary exception, form the rest of this diluvial accumulation, and which, except in the uppermost beds, do not contain, as far as I examined, any volcanic detritus.

No trace whatever of volcanic activity being found anywhere in the neighbourhood of La Paz, I was for a long time greatly puzzled to account for the occurrence of this very peculiar bed in the midst of diluvial strata. The general inclination of the beds themselves, dipping to the south, indicated that they had been drifted from the north or north-east, and they appeared to become narrower towards Lake Titicaca, near which I found the large volcanic outburst of trachytic and trachydoleritic rocks shown in Section No. 1, and from which doubtless the tuff forming these beds had emanated, and had been carried down by aqueous action, and deposited as a sedimentary bed in the series of clays, gravel, &c., forming this great thickness of drift.

The total thickness of these beds below La Paz must certainly exceed 2000 feet, and probably reaches 2500 feet, being certainly one of the most finely developed examples of this class of deposit, both as to magnitude and superficial area. I am unable to assign any correct limits to this formation, which appears to extend from north to south through the entire length of Bolivia; to the north, or towards the Lake of Titicaca, it appears to diminish in thickness, and may possibly wedge out entirely. The beds seem to have a general, but slight, dip to the southward.

I may here mention that in a small pool of water at a place called the Tambo de Perez, about half-way between La Paz and the Lake of Titicaca, I found numbers of a small fresh-water bivalve, which Professor Philippi, of the University of Santiago in Chile, kindly examined for me, and pronounces to be the *Cyclas Chilensis* (D'Orbigny), found first near Conception in the south of Chile, where it is common, according to Dr. Philippi, both in Valdivia and Puerto Montt. In these localities this shell is found at but a small elevation above the sea-level, in the coldest inhabited part of Chile; whereas in Bolivia, as above stated, we find it under the tropics, but at an elevation of about 14,000 feet above the sea; so that we may here regard this excess in elevation above the sea-level as equivalent to the difference of about 40 degrees in latitude.

Amongst the clay-beds of this diluvial formation, near La Paz, as also at the foot of Illimani and near Poto-Poto in the valley of the

River Chuquiaguillo, I found interstratified a bed of carbonaceous matter, approaching to lignite. In many parts this appeared as if wholly composed of carbonized marine or marsh plants, resembling rushes, reeds, and algæ; but I likewise found one or two pieces of unmistakeable lignite or carbonized wood. At all these places it is, probably, that it is but one and the same bed which appears at Poto Poto; this bed does not attain a thickness of more than from 6 inches to a foot. At the foot of Illimani it is, however, of much greater thickness.

A chemical examination, which I made of several of the clays from these strata near La Paz, showed that they contained but a mere trace of lime, as might be expected, knowing that the Silurian rocks of the high Andes, from which they appear to have been derived, contain but traces of limestone.

As the Silurian origin might indicate, this formation is everywhere eminently auriferous, and has been both since, and probably even before, the time of the Incas very largely explored for gold. The great quantities of gold found in Peru at the time of the Spanish conquest, had in greater part, if not wholly, been derived from these diluvial accumulations.

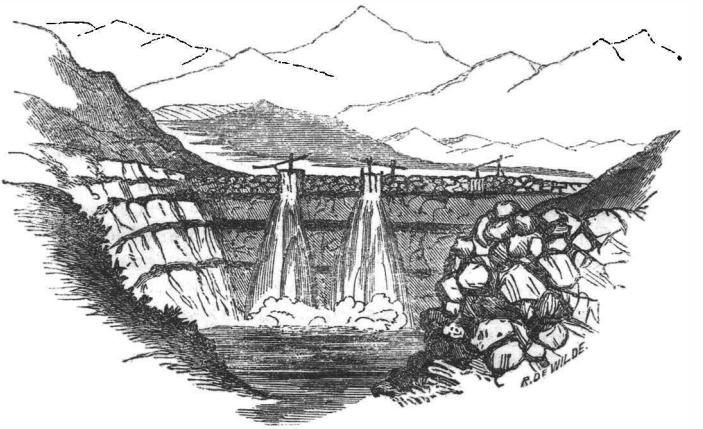
The rabbit-like burrows made by the Indian gold-workers into the more auriferous beds are everywhere visible along the sides of those valleys where a supply of water was not too distant to prevent these workers from transporting the auriferous earth for the purpose of working it: and frequently later explorations have disclosed the mummies or skeletons of unfortunate Indians, who have perished in these narrow and tortuous holes, from the falling in of the superincumbent earth, and been buried along with their mining implements.

This system of working is now entirely abandoned, and the mode of operating is very different at present, and can easily be understood from the annexed sketch (fig. 1), which may be supposed to represent a general view or sketch-section of the operations carried on at the gold-washings of Chuquiaguillo, near La Paz, belonging to Mr. Saienz of that city.

As will be seen in this sketch, the valley is, in the first instance, completely closed up, and the course of the river stopped, by a rude wall or dam of stones and earth, provided with sluices, and having a portion of the wall seen to the right hand somewhat lower, in order to carry off any overflow of water which otherwise might disturb the workings. A longitudinal excavation is then made close up to the one side of the valley, and of such breadth as can be conveniently carried on by the number of hands at disposal; and, in making this, the large boulders and stones, too heavy to be carried off by the rush of water, are piled up to one side, whilst the earth, gravel, and clay are merely loosened and flushed off by the water turned on from the sluices, allowing the force of the stream to carry them down the river. On arriving at the several successive auriferous beds, which are known from previous trials, and which are denoted by the dark bands running horizontally across the excavation, as seen in the sketch, more care is taken, but the whole of the auriferous earth is likewise

flushed off, and, being so much heavier than the rest, deposits itself at but a little distance from the workings, where it is collected and subjected to repeated washing in a trough until nothing but the gold-dust remains behind.

Fig. 1.—*Sketch of the Gold-washings on the River Chuquiaguillo.*



This excavation is deepened until the lowest available auriferous stratum has been reached, and then abandoned, in order to carry on the same operation parallel to it; the boulders and stones met with in the new working are thrown into the old excavation, and such excavations are continued right across the valley. In a valley of considerable breadth it would be impossible, except by employing an immense number of hands, to open out and lay bare the whole of the auriferous ground in one excavation.

The auriferous strata occurring in these diluvial accumulations are, in Bolivia, generally known by the name of "Veneros," and appear to correspond to what are technically termed "floors" by the gold-diggers of California and Australia, being, as it were, the floor or clay-bottom upon which the gold-dust had settled down, subsequently covered up by alternating beds of coarser sand, gravel, and boulders: above this a similar floor and coarser beds might in their turn be found, as in the sketch of the washings on the Chuquiaguillo (fig. 1): and where these diluvial strata are of still greater thickness, a proportionate number of "veneros" are generally found to occur.

These "diggings" are, as might be expected, confined to the sides of valleys and beds of rivers which contain water* sufficient for washing. The celebrated workings of Tipuani and those in the

* The rivers of this part of the world are too frequently "Rios Secos," a Spanish term which is generally adopted.

Yungas appear also to belong to diluvial accumulations of this same geological age.

The valley of La Paz, being entirely cut out of this great diluvial formation by the action of the river which traverses it, is, as might be expected, often exposed to considerable landslips during the extremely heavy rains of the wet season: when residing there, I witnessed such a landslip, which blocked up the valley and caused it to be inundated to a considerable distance by the damming up of the river. In many parts also the action of the rains and small rivulets formed by them, cutting through these immense clay and gravel strata, forms a most striking and picturesque landscape. The slope of the valley of La Paz, for example, is seen cut up into innumerable ravines of great depth, whilst pinnacles of more than 60 feet in height will be left standing in great numbers and of all variety of form, frequently quite isolated, and, from their slender proportions, often looking like needles or pillars formed artificially: the sides of these show a very pretty section of the variegated clays and gravels that previously had formed the beds from which these had been carved out and left as standing mementos.

At the same time the roads will be hollowed and traversed by chasms, natural arches, and subterranean holes, of the strangest form, too frequently proving dangerous to the rider passing over them. These effects, in general only seen in miniature elsewhere, present themselves on such an immense scale as to leave a very decided impression on the observer.

4. *Volcanic Rocks.*—Although these rocks are occasionally more recent than any of the deposits previously treated of, and are in places, as from the volcano of Ariquipa, &c., ejected at the present day, still it is preferred to consider them in this sequence, from the epoch so assigned to them being one in which they appear to have attained their maximum development, and in which they have produced such grand changes in the configuration and level of this part of South America.

They are, as seen in Section No. 2, contemporaneous with the great diluvial formations at La Paz, and possibly may there represent an early Tertiary period, from which time to the present they seem to have been in more or less continuous activity, and to have presented themselves with the same general characters and under very similar circumstances.

M. d'Orbigny* has classified these rocks as of two distinct ages, known by their differing slightly one from another in their state of aggregation and the presence of augite. An attentive study of these volcanic deposits showed how difficult it was to draw any such defined line of demarcation in rocks which, as before stated, possess all main features in common; and in fact seemed to show that M. d'Orbigny's two classes are in reality (at least in many cases) one and the same, presenting slight differences in mineral character on

* M. Pissis also, Annales des Mines, 1856: "Recherches sur le Système de Soulèvement de l'Amérique du Sud."

account of the one being subaërial, or injected between the strata, whereas the other has been subaqueous, and in consequence is frequently met with as a tufaceous bed interstratified with other strata of acknowledged sedimentary origin. As both such rocks might be at one and the same time in course of formation, this difference can hardly be looked upon as indicating a difference in geological age.

The Sections Nos. 1 and 2 (Pl. II.) are fully sufficient to show how important a part volcanic action has taken in altering the contours of the mountain-ranges here traversed: probably in no part of the world do we find volcanic phenomena more energetically developed or affecting so great a territorial area.

As will be seen from the accompanying Map (Pl. I.), the volcanic rocks forming at the north the active volcano of Ariquipa and others in that neighbourhood are cut through in Section No. 1 (Pl. II.); and still further south, in Section No. 2, they form the volcano of Tacora or Chipicani, 19,740 feet above the level of the sea; still further south they form the more or less active volcanos of Sajama (22,915 feet), Coquina, Tutapaca, Tucalaya, Isluga, Calama, Atacama, Licancau, Toconado, Llullayacu, and others intermediate, which, in conjunction, form an almost continuous range of volcanos into that part of the Desert of Atacama pertaining to Chile, through which country we find this volcanic range appearing at intervals; and still more to the southward it is doubtless in connexion with the volcanos of Patagonia, the north of Magellan's Straits, and Terra del Fuego. As will be seen from this, the general direction will be nearly north and south; and, from a study of the line of fracture and position of the intruded rocks, it would appear that the subterranean force here exerted had its centre to the west of this line, and had acted at a high angle from the west towards the east.

The beds of trachyte and trachytic tuff which are seen interstratified in the raised beach at Tacna, Azapa, &c., and also in the great diluvial formation of La Paz, have already been noticed. Further east, in Section No. 1, at Tarocache, a very peculiar volcanic conglomerate and tuff stratum was met with, remarkable for the columnar structure which presents itself on a very large scale on the side of the nearly perpendicular hill under which the road passes; the columns are so well developed, that, seen from the road, they look as regular as similar basaltic formations. On Section No. 2, at Palca, and still further east, at Questa Blanca, deposits on no great scale, of a white crumbly trachytic tuff, composed of more or less decomposed felspar, with quartz and hexagonal black or brown mica-plates and an occasional speck of augite, are met with as more or less horizontal beds, resting unconformably on the highly inclined strata of Liassic shales, &c.; both of these deposits, as well as the previously mentioned one at Tarocache, appear to be remnants of some more extensive bed of sedimentary origin formed of volcanic tuff and ashes from the volcanos situated still higher up the range.

In Sections Nos. 1 and 2, the great volcanic formation is seen a little further to the east, forming a high ridge or range of peaks averaging from 16,000 to 19,000 feet above the sea, visible from the

coast, and generally having their summits coated with snow. In both Sections (Nos. 1 and 2) this range breaks through the Upper Oolitic series of shales, claystones, porphyry-conglomerates, tuff, and imbedded porphyries, and above Tarata has enclosed, or at all events dislocated, a large mass of these (seen in Section No. 1), in which several strings of copper-ores were noticed: the volcanic rocks here are continuous with those forming the volcano of Chipicani, seen on Section No. 2. This I have not ascended; I have only passed along the sloping plain at its base, the fragments of volcanic rocks on which left no doubt of its character. Before coming to Uchusuma I noticed a step-like series of trachytic tufaceous beds, so characteristic of this rock when met with in this part of the world, each step being apparently a bed of great extent, and varying in thickness from 10 to 30 feet: these are called "Ancomarca" by the Indians, from their white colour; they extend nearly to the River Caño, at which place their formation is well illustrated in Section No. 2. It would appear that they had been erupted through long narrow fissures or dykes and poured out over the country either as lava or, in some cases, as light volcanic ashes* emitted from the fissures, and deposited on the ground in their neighbourhood, where they have gradually consolidated into beds. At the Rio Caño two such fissures are seen, bearing nearly E. and W., and dipping 15° to the south, the more western of which can be traced for miles as far as the eye can reach, appearing as a narrow white band or ridge, elevated one or more feet above the ground, from its having resisted the atmosphere better than the porphyry-conglomerate through which it breaks. Sometimes, as at the Rio Mauri (Section No. 2) and Chulluncayani, these are seen capping the rocks, and presenting the appearance of white bands running along the precipitous flanks of the hills or ravines; at Pisacoma, Section No. 2, this is also seen, as well as the occurrence of similar bands injected between the beds of the red sandstones, and sometimes continuous for miles. As might be expected, the contrast in colour between these white trachytic rocks and the dark-coloured Oolitic or Red Sandstone rocks which they cap, or with which they are interstratified, frequently at an immense height up the nearly perpendicular sides of these rugged and barren mountains, is wonderfully characteristic, and visible at very great distances. When breaking through sedimentary rocks, these lateral eruptions appear in general to conform themselves to the line of stratification, evidently from this affording less resistance, and there being always a much greater tendency for a fissure or crack to follow this line than to break through the more solid beds.

Between the Oolitic series and the Permian or Triassic sandstones in Section No. 1, as well as between these last and the Carboniferous basin of the Lake of Titicaca, we find great tracts which to the passer-by present to the eye no signs of other rocks than volcanic, and are occupied by plains or low rounded hills, covered on the surface with abundant fragments of trachyte and trachydolerites or with volcanic alluvium, composed of grains or sand of colourless quartz, white or co-

* Frequently containing much pumice.

lourless felspar, hexagonal brown or black mica, and black or green-black crystals of augite, alongwith black magnetic oxide of iron, always found as a black magnetic sand when a magnet is drawn along the surface. In passing over these plains the traveller's attention is attracted, and his eyes dazzled and wearied, by the glittering specks arising from the reflection of the sun's rays from the numerous small quartz-crystals strewed along the surface. The solid volcanic rock is only occasionally met with; but hillocks are frequently seen which, judging from their surface at least, are entirely composed of larger masses or fragments of trachytic and trachydoleritic rocks. I do not consider these tracts as representing spaces occupied by the actual protrusion of volcanic matter, but in some cases regard them as only covered by sheets of such trachyte or trachydoleritic lava poured out from longitudinal dykes or fissures such as before described; and in other instances I even suppose them to be, in part at least, composed of volcanic ashes, tuff, or débris, spread over the surface by the action of water*.

As far as I could observe, the volcanic rocks do not anywhere appear breaking through the Silurian rocks; but in the north of Bolivia they are seen on the Map (Pl. I.) as cutting through the Devonian series near Hachecache and the Lake of Titicaca, a distance of more than 200 miles from the coast in a direct line: this I believe may be considered as the most inland point at which volcanic phenomena make their appearance on the western side of the high Andes. These rocks are all *in situ*, and are true trachydoleritic and felspathic lavas which have broken through the strata, part of which are in consequence greatly altered. These lavas are further characterized by the peculiar parallel arrangement of their mineral constituents, which give that ribboned appearance due to the striæ of fusion, such as are frequently seen in more recent lavas.

Professor Philippi having allowed me to examine a series of rock-specimens which he had procured during his travels in the desert of Atacama, I found that the volcanic rocks from Punta Negra, Tilopozo, Toconado, Sorras, Atacama-Alta, &c. were all trachytes or trachytic tuffs, and precisely identical in mineral composition and character with those from the more northern part of Bolivia which I have more specially examined; and from his notes, which he also kindly placed at my disposal, I find that from San Bartolo to Chañaral Bajo, a distance of about 250 miles, we have, as in Sections Nos. 1 and 2, a ridge formed by an almost continuous series of lateral outbreaks of such lava cutting through and flowing over the dioritic rocks and the porphyries, shales, &c. of the Oolitic series, which, as at Chaco and other places, contained in abundance Liassic *Posidoniæ*, *Ammonites*, &c.

The large lateral overflow of lava, from 25 to 30 miles long and several miles in breadth, extending from San Bartolo to San Pedro

* The plain at Santiago de Machaca, Section No. 2, contains much volcanic alluvium, as described, and seems rather to have been formed by such aqueous action. I did not find sufficient evidence for colouring it as a sheet of trachytic lava, as M. Pissis has done.

de Atacama, is composed of a trachyte or trachytic tuff, consisting of a white or flesh-coloured felspathic base, in which are imbedded plates of hexagonal brown or black mica, and numberless perfect crystals of colourless quartz from $\frac{1}{4}$th to $\frac{3}{4}$ths of an inch in length and having both ends terminated by perfect pyramids; these quartz-crystals can be extracted from their matrix, leaving a perfect mould in the felspathic base, from which they had evidently been the first mineral element to crystallize.

The trachytic lavas of the other parts of Bolivia and Peru very commonly show the quartz so crystallized; and in Sections Nos. 1 and 2 such are also met with, but not so beautifully developed as from San Bartolo southwards. Both at Atacama-Alta, Toconado, Sorras, Tilopozo, and other places along the line of Dr. Philippi's route, the specimens also showed characteristic trachytic tuffs and trachydolerites. In some of the tuffs the quartz present was in the form of rounded grains, as if due to attrition, or more resembling the effect which igneous action would produce in rounding off the edges by fusion, or by the solvent action of some fluid compound in the lava acting on the crystals once formed.

There is but little variety met with in the volcanic rocks of this part of the world, those of Peru, Bolivia, and Chile being all very similar in external appearance and mineral composition: the principal rocks are trachytes, trachytic tuffs, trachydolerites, dolerites, and felspathic lavas.

The trachytes and trachytic tuffs are generally white, but occasionally of a pale flesh- or fawn-colour, and are composed of a felspathic base, probably only consisting of one felspar (frequently crystallized, but also met with in a more amorphous form), colourless quartz (always crystallized, and often, as described, in perfect crystals), and black or tombak-brown mica crystallized in small hexagonal plates, seldom more than $\frac{1}{10}$th of an inch across. From the smaller lateral fissures the eruptions are generally composed of trachytes; but it is extremely difficult to draw a line between the true trachyte and the trachytic tuffs formed from them, and which occasionally are met with as solid and compact as the original trachytes themselves, and only to be distinguished from the latter by the somewhat decomposed appearance of the felspar, the bronze-brown colour of the originally black mica and the included fragments of pumice, &c.*; they are, however, in general much more open or porous in texture, and often crumbly, so as frequently to be mistaken for white sandstones. They are everywhere largely quarried and used as building-stone, being durable and very easily worked; when cut into hollow cones they are used as filtering-stones for purifying water for domestic use, for which purpose they are well adapted from their porous texture. I have reason to suppose that these trachytes have frequently been

* I had expected that the decomposition of the felspar would probably give rise to the formation of alkaline or earthy carbonates in these trachytic tuffs, and so afford a means of distinguishing them from trachytes; in this I was disappointed, as several trachytic tuffs from Tacna, Azapa, La Paz, &c., on being treated with acids did not effervesce at all.

ejected whilst in a pasty state, after the quartz had crystallized and the temperature of the whole had become much lower than the fusing-point of the entire rock itself.

The trachydolerites differ from the trachytes only in having, in addition to the felspar, quartz, and mica of the latter, crystals of dark-green or black augite scattered through the mass, in which also the quartz does not appear so predominant; and the rock is frequently considerably darker in colour. They form eruptive masses much greater than the pure trachytes, and are seen largely developed on Section No. 1 at Batalla and Yunguyo.

Doleritic rocks I have only met with *in situ* on the eastern declivity of the volcanic range of mountains between Tarata and the River Mauri in Section No. 1; and in Section No. 2 they are seen as abundant large blocks scattered over the slope of the volcano of Chipicani. From their very compact structure, conchoidal fracture, and dark bluish-grey or greenish-grey colour, they much resemble basaltic rocks; but their crystallization is so close-grained that I could not distinguish whether olivine was present; and, in fact, their mineral composition is not recognizable by the naked eye, so that their exact nature is open to inquiry: they do not appear to form any great proportion of the mass of volcanic rocks here developed.

The greater volcanic rocks, at least those which have broken through as lava and remain *in situ* as a compact rock, are composed of a crystalline felspathic lava, much more basic in chemical character than the others (possibly if we except the dolerites), and which appear to be almost exclusively composed of one or more varieties of felspar. They generally possess that peculiar parallel structure frequently met with in all volcanic rocks, whether recent or more ancient, and apparently due to a cause similar to that of the striæ of fusion visible in glass. This striated appearance is frequently rendered more apparent from the different layers being of different shades of colour, reddish or whitish grey, or, as at Pailumani, where these rocks are very largely developed, of a dark grey colour, probably from some admixture of augite in a non-crystalline condition and intimately diffused through the felspathic mass so as not to be visible to the naked eye. These rocks sometimes are also found to contain a little mica or augite, in plates or crystals, but appear in general to be free from quartz. They are developed on a large scale between Hachecache and Tiquina, Section No. 1, and also at Pailumani, Section No. 2, where they appear to form the entire mass of the eruptive rock.

In neither Section No. 1 nor No. 2 do we cut across any volcano at present in activity, nor meet with any lava or scoria likely to have been produced more recently; at but very short distances, however, both to the north and south of these lines of section, volcanos were observed in activity; and during my residence in the country, the "Misti" or Volcano of Ariquipa was in eruption. In the immediate vicinity of Tacora various Solfataras might be seen in action; and their action on the Oolitic and Porphyry series was visible at great distances, on account of the brilliant yellow, red, and brown colora-

tions produced by the action of the volcanic fumes and acid vapours on these rocks, and the formation of various salts of iron, lime, &c. To the south of Tacora I noticed an evolution of smoke, as if from a similar solfatara; and my fellow-traveller, M. Friesach, informed me that, when he passed in October 1859, a volcano situated a little to the right of Sajama, and apparently one of the three cones named Las Tetillas on the new map of Bolivia by Mujica and Ondarza, was observed by him in eruption, vomiting forth immense volumes of smoke, and apparently also lava, not from the cone itself, but from a lateral orifice situated at the base of the cone. The volcano of Tutapaca is also situated in this direction, and is still in activity; and near this place M. Modesto Bazadre informs me he visited a valley containing several hundred of little volcanic cones emitting boiling water, and in many respects resembling the Geysers of Iceland; like these latter, the cones around the orifice of ejection are formed by the deposit from the water itself.

Although we find the volcanos of this part of South America presenting themselves as lofty cones, rising high above the surrounding plateau, we do not observe in general that crater-form of summit so usual in mountains of this class in other parts of the world: we certainly find, as in the Misti (or Volcano of Ariquipa), some well-developed small craters; but these seem rather to have served as so many safety-valves to the volcanic boiler, and to have played but a very subordinate part in furnishing the great amount of lava and other volcanic matter here met with, which appears in greater part, if not entirely, to have made its way up through the great lateral fissures or openings (similar in many cases to dykes) which appear to have poured forth sheets of lava, covering vast areas of the surrounding country. This class of eruptions appears peculiarly characteristic of the Pacific side of South America, where they seem to attain a magnitude unknown in any other part of the world. The southern part of Bolivia shows such lateral eruptions, covering the ground with trachytic lava for more than 300 miles continuously; and in the northern part, as seen in Sections Nos. 1 and 2, the same occurs, —some of these eruptions appearing to proceed from such lateral dykes or fissures, at the lowest estimate not less than fifty miles in length, if not much more.

The volcanic rocks here described are strikingly distinct from those which I met with during my examination of the volcanic islands of the Pacific Ocean and Polynesia: these latter are generally of very dark colours, are of a very basic chemical nature, and characterized by the abundance of augite and olivine and the absence of quartz; whereas here in Peru and Bolivia the rocks are invariably of lighter colour, generally even white, are of a much more acid or siliceous chemical nature, contain abundance of quartz, and only in some instances was olivine at all met with.

Before concluding this notice of the volcanic rocks, I may direct attention to a point connected with the crystallization of the same, and which, I believe, has not been previously noticed: I allude to the occurrence in the trachytic and trachydoleritic rocks of perfect

crystals of quartz distributed in abundance throughout the solid and compact rock-mass. In many instances, as, for example (as before mentioned), in the northern part of the Desert of Atacama, the greater part, if not the whole, of the quartz contained in the trachytic beds is so crystallized, and may easily be detached from the matrix as small six-sided prisms, terminated at both ends by pyramids, and beautifully smooth and lustrous. This could not have occurred unless the crystals had been formed whilst the rock was in a perfectly liquid state, and before the other mineral constituents had commenced solidifying.

This seems to point out one great distinction between volcanic and plutonic rocks. In the former case the quartz has been the first mineral element to crystallize from the liquid lava, as might naturally be expected from the much higher temperature requisite for its fusion. In the plutonic rocks (granite), however, the reverse is the case; the quartz has been the last element to assume the solid state and crystallize, and is not found in true crystals, except where the occurrence of drusic cavities or cracks in the solidifying rock have accidentally occurred—and even then we only find the one end of the crystal terminated by planes,—whilst at the same time the easily fusible felspar has invariably crystallized before it. It is evident that in these rocks the quartz has remained fluid or viscid at a temperature much below its point of fusion, as it occupies the spaces or intervals of the network formed by the crystallization of the other constituent minerals of the rock, which are infinitely more fusible than the quartz itself.

5. *Dioritic Rocks.*—In geological age, the next rocks which we come to are the diorites, seen in Sections Nos. 1 & 2, and which may be termed Post-oolitic, from their cutting through the strata here representing the Upper Oolitic series.

They are composed exclusively of a white felspar, together with a more or less dark-green hornblende; the rock itself is generally coarsely crystallized, but occasionally becomes so fine-grained in texture as to admit of its being termed a greenstone.

This rock is the same as that which occurs in Chile, and which has been described by Darwin in his 'Report on the Geology of South America,' under the name of "Andesite." I have preferred the name "Diorite" until chemical examination may prove it to be distinct; as in external appearances it cannot be distinguished from the ordinary diorites of Europe and other parts of the world.

Quartz is never found in this rock when normal; but at one or two places, as, for example, Cerro de las Esmeraldas and Comanche, where this rock breaks through the red sandstone beds, the diorite near to the point of contact occasionally contains some little quartz grains, which it evidently has absorbed from the rock through which it has broken; in such cases a specimen might be obtained which is mineralogically, but not geologically, a syenite.

The felspathic constituent is generally of a pure white colour, and triclinic in crystallization; but, as anorthite, albite, andesine, labradorite, and oligoclase also pertain to the triclinic felspars, it

will require a chemical examination to determine its nature satisfactorily.

These dioritic rocks show themselves as a series of more or less detached or isolated patches of rock, protruding themselves through strata of various ages older than the Cretaceous period, which last-mentioned system appears to be of still later geological age.

On the Pacific, or western side of the high Andes, from Peru to Puerto Montt in Southern Chile, a distance of some forty degrees of latitude, we find at intervals such diorites breaking through the other rocks; and lines drawn through the points at which they make their appearance show that there are two parallel systems of eruption running not far from north and south, and probably at a distance of about 100 miles from one another.

In the part of South America forming the subject of the present memoir, the most western of these lines commences from a little to the east of Paposo, in the Desert of Atacama, passes through the metalliferous district of El Cobre, runs along the cliffs at Cobija, and touches the coast at Gatica a few leagues to the north of Cobija; then passing through Tocopilla, Algodon Bay, and the Ansuelo Rocks near Iquique, again enters the mainland, and, after showing itself at several points before coming to Arica, is seen in Section No. 2 at Chuntacollo and Guanuni, and still further north in Section No. 1, between Tarocache and Tarata; and, from what I can learn, it shows itself still further north in Peru, and appears to run right through South America.

The eastern line of eruption, after breaking through the Lias-rocks between La Encantada and Sandon in the Desert of Atacama, shows itself at several points before coming to Tilopozo, from which place I have specimens brought me by Dr. Philippi; entering the central part of Bolivia, unexplored as yet by any geologist, it shows itself at the Cerro de las Esmeraldas south of Corocoro, and the Hill of Comanche to the north of that place; and, from a specimen sent me, it must appear in the neighbourhood of Tio Guanaco, at the southern extremity of the Lake of Titicaca, beyond which I have at present no data for following it further north.

The eruption of these diorites appears to have been generally accompanied by the evolution of much acid vapours, probably sulphurous, to judge from the effects produced on the rocks in immediate contact with the diorites; as, wherever they break through sedimentary strata, these latter are much changed in appearance and chemical composition.

Thus we find the Lias-shales and porphyritic clay and mudstones converted into a pure white matter resembling china-clay, by the abstraction of the lime previously contained in them; and when this change has proceeded a step further, and, besides, the lime has also removed much of the alumina present, we find these rocks converted into siliceous or hornstone-like compounds, which have by several observers been regarded as rocks entirely distinct from those from which they have originally been derived: thus the quartz-porphyries of M. Domeyko and M. Pissis are of this latter character;

and the Tofos mapped on M. Domeyko's geological map of Chile in the 'Annales des Mines'* pertain to the former. Both of these classes can be seen at many points in the district here treated of, and will be subsequently noticed.

This rock is occasionally itself metalliferous, as at El Cobre in the Desert of Atacama, where the diorite is very strongly impregnated with sulphurets of iron and copper. We always find, however, that the fissures or faults formed in the neighbouring strata by the protrusion of the diorite are converted into metallic veins by the injection of metallic compounds of sulphur and arsenic; and a very careful examination has shown that the metallic veins of the Oolitic and Porphyry series of Chile, Peru, and Bolivia, which constitute the great source of mineral wealth of these countries, are all due to the appearance of this rock. The silver-mines of Huantajaya and the copper-mines of Paposo, El Cobre, Cobija, Gatica, Tocopilla, La Portada, and the veins of iron- and auriferous pyrites frequently met with, are all of this origin.

In these mineral veins I have found the following metallic compounds to occur:—

Native Gold.
„ Silver.
„ Antimony.
„ Bismuth.
„ Arsenic.
„ Copper.
Arquerite.
Amalgam.
Bismuthic Silver.
Magnetite.
Specular Oxide of Iron.
Domeykite.
Darwinite.
Algodonite.
Discrasite.
Copper-nickel.
Cobaltine.
Realgar.
Stibnite.
Sulphuret of Bismuth.
Silver-glance.
Galena.
Zinc-blende.
Copper-glance.
Copper-pyrites.
Erubescite.
Cuproplumbite.
Stromeyerite.
Iron-pyrites.
Marcasite.
Covellinc.
Molybdenite.
Mispickel.
Danaite.
Glaucodot.
Pyrargyrite.
Proustite.
Enargite.
Tennantite.

And further, from the oxidation of the above minerals, the action of the carbonic acid in the atmosphere, and the elements in the salts contained in the sea (under which this country has been submerged since the appearance of these veins), we also find the following minerals subsequently produced:—

Malachite.
Azure Copper.
Atacamite.
Sulphate of Copper.
„ of Iron.
Iron-alum.
Manganese-alum.
Botryogen.
Condurrite.
Silicate of Copper.
„ of Copper and Manganese.
Oxide of Copper.
Chloride of Silver.
Chlorobromide of Silver.
Bromide of Silver.
Iodide of Silver.

* Quatrième série, vol. ix. 1846.

A little to the north of Cobija, where, from the configuration of the coast, the line of dioritic eruptions previously described runs into the sea, we find these forming small pointed or rugged rocks jutting up from the sea, as has been noticed and figured by Von Bibra* and D'Orbigny†.

M. d'Orbigny even supposes these form part of the rock "la plus ancienne de l'ensemble," and as pre-existent to the upheaval of the Cordilleras. A careful examination, however, proved to me that they are only, as before stated, a part of the general line of diorites, and consequently younger than the Oolitic series which at these very places they penetrate into and alter as before described.

The diorites on Section No. 2, at Chuntacollo and Guanuni, are classed and coloured by M. d'Orbigny as granite, thus confounding under one head rocks which, beyond their common igneous origin, are neither in external appearance, mineral character, chemical composition, nor geological age in any way allied. As far as my researches have gone, I have not met with any granite in South America which can be proved to be of later geological age than the Devonian period.

6. *Upper Oolitic Series with interstratified Porphyritic Rocks.*—The sedimentary beds which here represent the Upper Oolitic system are so interstratified with beds of eruptive porphyries, porphyritic tuffs, and porphyry-conglomerates evidently contemporaneous, that it is quite impossible to draw any line of demarcation between these rocks; and therefore I have followed the arrangement of Darwin in Chile, in placing all the analogous rocks of Peru and Bolivia under one head. Besides the above-mentioned porphyry-tuffs, conglomerates, and interstratified porphyries, we meet with claystones, mudstones, argillaceous shales and limestones, and other beds, many of which bear a striking resemblance to the rocks of similar age in Europe. In the south of the district here treated of, we find these rocks abundantly fossiliferous; and the fossil shells from the beds of the Desert of Atacama have yielded to the researches of MM. Bayle and Coquand‡, and Dr. Philippi, about thirty-three species of recognized Oolitic forms. My collection from the same regions contains a number not yet examined, and probably will yield further species. In the part further north the country has been almost entirely unexplored, and the fossils obtained by me as yet have only been *Lithotrochus Andii*, *Ammonites Domeykii*, *A. pustilifer*, Oolitic *Posidonice*, a *Gryphæa*, and the cast of a *Trigonia*, as well as some vegetable remains§.

These beds are continuous from Chile right through the Desert of Atacama; and, in combination with the fossil evidence, there can be

* "Die Algodon Bay in Bolivien," Denkschriften der k Akad. der Wissenschaft. Wien. Math.-Nat. Cl. vol. iv. 1852.

† Voyage dans l'Amérique Méridionale: Géologie, p. 97.

‡ Mém. Soc. Géol. France, deux. sér. vol. iv. part. 1e, 1851.

§ I have not here considered it necessary to go into details as to the fossils, both as my own collection from the Desert of Atacama has not yet arrived, and because most of these more properly belong to Chile, and will be considered in my next communication when treating of that country.

no doubt as to the extensive development of this formation, which, throughout its whole extent, is strikingly uniform in all other characters.

The thickness of these beds is very considerable; but it would be too hazardous to venture any estimate of its magnitude without more decided data than are at present at my disposal. The area occupied by these rocks, as seen in the accompanying Map, is likewise very great; and we find that nearly the whole of the coast-line is formed exclusively of the above-mentioned rocks, which here form the "Cordilleras de la Costa," whilst in Chile they constitute the back range, or "Cordillera de los Andes," a nomenclature which has caused some confusion, and has been the main cause of the inaccuracy with which the mountain-chains of this part of South America has been delineated by geographers.

If we except the small strip of land at Mexillones and the included dioritic eruptions, we find that the whole coast-line of Bolivia, and as far north as Arica in Peru, is formed of these rocks. At Cobija, in Section No. 3, the Upper Oolitic beds and porphyries strike about N. 20° W. (magnetic), and dip at an angle of 30° eastward, from having been tilted up by the dioritic eruption seen in the section, which has rendered metalliferous, and also considerably altered the nature of, the rocks themselves near to the point of contact. I noticed a vein here containing grey and yellow copper-pyrites, with a little atacamite, carbonate of copper, &c., showing itself on surface, bearing N. 60° E., with a dip of 12° S.E., and cutting through both the dioritic and porphyritic rocks and shales; the latter were bleached, and at several points converted into "Tofo," or a species of clay sometimes of a pure white colour. These clays, as previously noticed, have evidently been produced by the action of acid gases accompanying the dioritic eruptions on the felspathic base of the porphyry-tuffs, &c., and which, by removing the lime and iron contained in the same, leave behind a more or less pure silicate of alumina, in the form of a white clay, or "Tofo," as such are here termed; at the same time the volatilization of compounds of iron has coloured the surrounding rocks with various shades of yellow, red, and brown.

High up the sides of the mountains in this section, a copper-mine, called the Manto de Ossa, is being worked on a considerable scale; and in this mine the ore does not occur as a vein or lode, but as a regular bed, in amongst the other strata. The cupriferous stratum itself has evidently been originally a bed of porphyry-conglomerate, or breccia, in which the interstices between the pebbles, or, rather, fragments composing the bed, have been filled up with metallic sulphurets, most probably infiltrated or injected from some neighbouring vein.

Further north, at Gatica and Tocopilla, numerous veins of copper are worked in these rocks; and at the former place they appeared to have a general run of about north-east. The Mina del Toldo, which I examined, showed for many miles a constant strike of N. 80° E., dipping about 85° to the west. The metallic compounds in these

mines were native copper, atacamite, malachite, silicate of copper, black and red oxides of copper, purple and yellow pyrites, covelline, sulphate of copper, &c. These minerals frequently contained native gold in specks disseminated through them, but were stated to be unusually poor in silver.

The metallic veins which occur near La Portada, in Section No. 2, and above Tarata, Section No. 2, present features in every way similar to the above described.

In Section No. 2 is seen probably the best illustration of the arrangement and extent of the strata composing this formation. From this it will be seen that, after passing over a series of very highly inclined and thin-bedded Liassic shales dipping to the westward, we meet with the dioritic rocks of Chuntacollo and Guanuni breaking through them and altering them at the point of contact. Above these the same shales, bearing north and south with a dip of 30° to westward, are again met with, and continue, with occasional interstratification of porphyries, claystones, and porphyry-conglomerates, through Palca, Los Troncos, El Ingenio, Quebrada de la Angostura, up to Questa Blanca, where they have a north or south strike, and dip 50° to westward; here they have some beds of white trachytic tuff superposed upon them, as previously mentioned; and near this place we find an anticlinal, causing them now to dip to the eastward, which dip they retain up to the summit of the nearly 15,000-feet high Pass of Huaylillos. Shortly after passing Questa Blanca these rocks are very much altered, become flinty and siliceous, and continue so for a considerable distance, bearing N.N.W., with a dip of 50° east: in these rocks several old workings are seen on some strings of copper. The strike of the beds was at these mines found to be still N.N.W., with a dip of 20° eastward. The change in mineral nature here noticed is evidently due, as explained in a former section of this memoir, to the vicinity of dioritic rocks, and consequent metamorphic action produced by the intrusion, which also has developed the copper-veins before mentioned, and those near La Portada. The diorite is, as seen in the section, visible at one spot, and probably is much more extensive than would appear from the small eruption crossed in the line of section. From La Portada to the summit of Huaylillos the rocks are nearly all porphyritic conglomerates, frequently much altered and siliceous; and on the slope to the Rio de Azufre several beds of true interstratified porphyries are seen before coming to the great volcanic ridge of Chipicani.

Crossing these volcanic rocks, we next meet the strata pertaining to this formation at the River Caño, where they present themselves as beds of purple porphyry-conglomerate, dipping to the westward, and broken through by the lateral fissures or dykes of trachyte seen in the section both here and further eastward, at the Rio Mauri, at which place they cover unconformably the porphyry-conglomerates, as seen on both sides of the steep ravine through which this river passes. The beds here were thick porphyry-conglomerates of a purple colour and composed of smaller pebbles of porphyry overlying beds of porphyry and porphyry-tuffs, which in turn are suc-

ceeded by a second series of thick porphyry-conglomerates of the same character as the former ones. In the beds of porphyry-tuff I noticed fissures filled with a crystalline zeolitic mineral, probably stilbite *.

These porphyry-conglomerate beds continue up to the valley of Pailumani, where they are cut through by the great volcanic mass of felspathic lava seen in the section; and no trace was then found of them before coming to the eastern slope of the Pass of Chulluncayani, where we again meet with a series of porphyries which appear to belong to this series, and on the top of which I found several patches of altered red sandstone near Condorana, which evidently belonged to the Permian or Triassic series further to the east, and appear to have been carried up by the eruption of these porphyries.

In Section No. 1 another transverse view of the stratification of this series is obtained, which, however, is not so extensive as the one just described, owing to the protrusion of the great mass of volcanic matter to the eastward. The rocks met with in this section are precisely similar in mineral character to those met with and described in the former Section (No. 2), being composed of argillaceous shales, porphyry-tuffs, conglomerates, claystones, mudstones, and interstratified porphyries, cut through by dioritic and volcanic rocks, and at the western extremity of the section dislocated by a series of faults, which are easily observed on the nearly perpendicular sides of the great ravine which forms a passage through this chain from Quilla to the plains of Sama. They are seen to great advantage, and were easily sketched and followed out, from the occurrence of several bands or beds of different colours and consistency, amongst which several thick beds of coarse porphyry-conglomerate were very characteristic. This section itself will, it is believed, not require further description, as the general relations of the strata are not very complicated.

At the Morro de Arica, a hill situated to the immediate south of the town of Arica, and rising perpendicularly from the sea to a height of about 500 feet above the water's level, we also find a series of porphyries interstratified with sedimentary beds, but the age of which has not been as yet satisfactorily determined.

These beds are coloured by M. D'Orbigny as Carboniferous, from his having found fragments of *Productus* in limestone boulders enclosed in the porphyry of this hill. I have not considered it advisable at present, before more data are obtained, to separate them from the other strata with which they appear continuous, and which have yielded Liassic remains; but I admit that it requires more careful examination. A sketch-section of this hill, taken by me on my first visit to Arica in 1857, shows the following features.

Commencing from below upwards, we find at the base a series of much-burnt and altered shales, thin-bedded, and of a brown colour, but too much altered to admit of any recognition. Above this is a

* On examination, it specific gravity was found to be 2·14, the per entage of water ontained in it 17·62, and its hardnes 3·25; before the blowpipe it intumesces, becomes milk-white, and ultimately fuses into a white enamel.

mass of some hundred feet of intruded augitic porphyry, very characteristic, and different from all the other porphyries met with in these parts, from its containing black augitic crystals along with crystals of white felspar, in a brown, black, or grey felspathic base. Above these are seen shales similar to those at the base, of a red colour, and as if calcined*; these are succeeded by a black porphyry, on which rest altered shales, in the midst of which a thin bed of grey limestone is seen, with very indistinct traces of organic remains; above this a red porphyry, with white felspar-crystals and black specks of augite, succeeded by a second series of shales, with an intercalated bed of limestone similar to the first; above these shales a second red porphyry, then a third bed of shales, and, lastly, great beds of red porphyry and some pebbly porphyry-conglomerates, which contain agates and nodules of calc-spar, the latter frequently covered by a coating of a green mineral. I do not at present venture to pronounce any definite opinion on the true position and age of these beds, but only think that the evidence of their being Carboniferous is not sufficiently strong to be conclusive, especially when it is considered that we have no strata of that age anywhere developed along the coast of the Pacific.

Before concluding these remarks on the porphyries, I may also notice the occurrence of eruptive porphyries and some stratified porphyry-tuffs in the midst of the Silurian formation further inland. These are seen to the north breaking through the ridge which separates the valley of Illabaya from that of Sorata, a ridge which is in itself so sharp and steep as to make it appear very surprising to find it broken through by erupted porphyry, which has left the top of the ridge as a peak of somewhat hardened clay-slate: the porphyry is of a red colour, with white crystals of felspar.

Similar eruptions of porphyry occur near Oruro, breaking through the Silurian rocks. The latter are eminently stanniferous, from which circumstance, at the point of contact of the porphyry with the Silurian slates at one locality, the tin-ore or oxide of tin was found fused (M. Kroeber informs me) by the heat of the porphyry to a true white-tin enamel, such as is commonly made artificially.

In the Cerro de Potosi, celebrated for the richness of its silver-mines, and situated still further to the south, such porphyries are again found developed; and further south of this probably they run into the porphyries of the Desert of Atacama, which are, as before mentioned, contemporaneous with the Upper Oolitic beds (these eminently fossiliferous).

Drawing a line through these three points, which are coloured on the accompanying Map (Pl. I.), we find they are in one and the same direction, and have a general bearing of nearly north-west and south-east.

7. *Permian or Triassic Formation.*—The rocks now about to be treated of and considered as representing in Bolivia either the Permian or Triassic formation of Europe, are seen cut through in their

* On the top of these is a bed of saline and recent accumulation, often very calcareous, and about from 1 to 2 feet in thickness.

entire thickness in Sections Nos. 1 and 2, in which, although at first sight they seem of much greater magnitude, they do not in reality appear anywhere to attain a maximum thickness of more than 6000 feet, and generally are found to be much under this estimate. This is due to the great number of folds doubling up the beds, and also, as seen in Section No. 2 (from Santiago to Nasacara), to a series of faults which repeatedly bring up the same beds to the surface.

D'Orbigny has in his section across the same line of country coloured the greater part of these beds as of Devonian age: at Corocoro he makes a part of them Carboniferous, and at the Disaguadero (Nasacara) puts in a little strip of Triassic. As he cites no fossil evidence for these divisions, and in fact admits that he has no fossils whatever from any part of this section, this cutting up into formations beds conformable to one another, and strikingly analogous in mineral composition, seems unexplainable except by imagining that here, as generally throughout his 'Geology of Bolivia,' he proceeds with the supposition that no link in the chain of geological formations should be deficient.

The strata so classed under these different denominations can in some instances be shown to be part of one and the same series of beds, and, taken as a whole, possess all main features in common.

I have therefore not considered myself justified in retaining these subdivisions, until at least more evidence is produced, and for the present have grouped the whole of these beds as one series, under the name of Permian or Triassic. The balance of evidence appears in favour of the Permian epoch, although at the same time I admit that the absence of satisfactory fossil-evidence still leaves the question an open one for inquiry.

These beds are penetrated, upheaved, and altered by the linear eruption of dioritic rocks which runs through the whole extent of Peru, Bolivia, and Chile, and which are contemporaneous with the Cretaceous period. The section from Pisaca to Comanche shows an example of this. That they are more ancient than the Upper Oolitic series, is shown by their having been broken up and elevated by the porphyries which are found imbedded or interstratified in this system, and are inseparably connected with the same in geological age. At Condorana (Section No. 2) this will be seen to be the case. Still further north, between Condorana and Pisacoma, these beds appear to dip beneath the whole Oolitic series; but the nature of the ground was not favourable to a perfectly conclusive examination.

Fossil plants are everywhere found in this formation; but generally they are very indistinct. In some places, as at Pontezuelo, large trunks of trees silicified are found in abundance; and several specimens of carbonized wood which I procured from the sandstones of Corocoro are as yet not examined *.

* Since the above was written, sections have been made of two of these woods, and prove them to be Coniferous; but the structure is too indistinct to allow of further recognition.

I was informed that a complete Saurian head had been extracted from the same beds by M. Ramon Due, but was not successful in obtaining it, nor some fossil bones and teeth now in the museum of Avignon, in France, sent there by M. Granier, of La Paz.

These beds are superposed quite unconformably on the Devonian strata at Coniri (Section No. 2), where the red conglomerates, considered as the lowest beds of the series, abut against the nearly vertical Devonian shales.

The mineralogical characters of this system so strikingly remind one of the descriptions of the Permian rocks of Russia by Murchison, Keyserling, and De Verneuil, that when reading it subsequently to my arrival in England, it seemed as if treating of these very strata.

They consist of red, greenish, and variegated marls, saliferous and gypseous marls, gypsum beds, along with fine red sandstones, thin grey pebbly conglomerates, and red conglomerates. The marls are particularly well developed from Santiago to Nasacara (Section No. 2): at Laguna del Toro (Section No. 2) and at Corocoro (fig. 2, p. 41), we have brownish-red sandstones, with indistinct vegetable impressions, capped by thin gypsum beds and variegated marls. The gypsum beds are frequently of great thickness and extent: in some places, as at Belenguela, they are quarried to some extent, and produce abundance of fine alabaster, extensively used for the purposes of architecture (for example, the fountain in the Alameda of La Paz, &c.): some of the slabs of this material are so transparent, that tablets of it, until very lately, have been in general use in this part of Bolivia as a substitute for window-glass: I noticed that the windows of the church at Pisacoma were formed of this material in slabs of about two inches thick. The sandstones vary from red to brown in colour, and generally are not very compact, much resembling occasionally the sandstones of this formation in England, as at Pacheta (Section No. 2) we find them lighter in colour, and sometimes yellowish. The conglomerates, when intercalated with the sandstones, are generally of very insignificant thickness, often not many inches across, and contain principally small rounded quartz-pebbles, of the size of a nut, as at La Guardia (Section No. 1); those at Coniri are of considerable thickness (probably some hundred feet), and are of a deep red colour, and consist exclusively of rounded fragments of quartzites, grauwackes, clay-slates, and granite, all similar to those found in the eastern division of the diluvial formation before described, and evidently of the same origin.

As in the European Permians, brine-springs are very common in this formation; and the cupriferous sandstones, here so well developed at Corocoro, Pisaca, San Bartolo, Santa Barbara, &c., appear as the representatives of the similar cupriferous beds of Russia, the Thüringerwald and the Harz; and a further curious coincidence may be found in the determination by Mr. Kroeber of the presence of the rare element vanadium in the Corocoro copper-sandstones,—an occurrence long known as peculiarly characteristic of the Thuringian Kupfer-Schiefer.

As seen in the accompanying Map, this formation extends from the Lake Titicaca in Peru, southwards, nearly, if not quite, through the republic of Bolivia, and possibly runs right into the Argentine provinces to the back or eastern side of the volcanic range of the Desert of Atacama, and everywhere presents the same characteristic features. The cupriferous sandstones, for example, which are so characteristic of this formation, show themselves all along this extent. Beginning their appearance in the north (in the district of Puno), they are seen at the Pacheta (Section 2), then at Pisaca, Corocoro, Chacarilla, El Turco, Santa Barbara, San Bartolo, and even further south; and Mr. Villamil informs me that they are also visible in the district of Andalgalla, in the Argentine republic,—a distance of fully 500 miles from north to south. The breadth of country over which they are found is probably from 50 to 80 miles across; and the Sections Nos. 1 and 2 show the general character of their transverse section, exhibiting a series of longitudinal ridges, elevated to no great height above the general level of the plateau, seldom higher than from 1500 to 2500 feet above it, and formed by a series of anticlinals having a general strike of from N.10°W. to N.W. with varying dip.

A few of the more important observations of the strike and dip of the strata met with in Sections Nos. 1 and 2 are here appended:—

	Strike.	Dip.
Hill east of Santiago de Machacá. Soft red sandstones, with red and white marls	N.10°W.	15° E.
Hill at San Andres de Machaca. Red and white marls	N.20°W.	16° N.E.
Hill east of Nasacara. Red clay, with pebbles and compact red shales		20° N.E.
Hill further east of Nasacara. Red and purple clays		10° N.E.
Pacheta de Antarini. Soft red sandstones and red marls	N.W.	45° N.E.
Laguna del Toro. Brown-red sandstones, with gypseous beds	N.W.	50° N.E.
Little east of Laguna del Toro. Red-brown sandstones, with cupriferous beds	N.W.	70° N.E.
Pacheta. Red-brown sandstones, with cupriferous beds	NN.W.	40° W.
Pacheta (further east). Red and yellowish sandstones	N.E.	30° S.E.
Pacheta (still further east). Red and yellowish sandstones		20° S.E.
Ditto. ditto		10° SE.
Ditto. ditto		30° S.E.
Ditto. ditto	N.E.	20° NN.E.
West of Tambillos. Light reddish-brown sandstones, with finely contorted lamellar structure, and the stratification marked by rows of peculiar black spots	NN.W.	25° N.E.
El Tambillo. Red sandstones	N.W.	45° N.E.
Between El Tambillo and Coniri. Red conglomerate, large pebbles of quartzite, grauwacke, and granite, occasionally a fragment of clay-slate	N.W.	40° N.E.
La Guardia (Section No. 1). Red sandstone and grey pebbly conglomerate, with colourless quartz pebbles	NN.W.	45° S.W.
East of Pisacoma. Thin fine red grey and white sandstones and pebbly conglomerates	N.10° W.	20° S.E.

In the accompanying Map (Pl. I.) it will be seen that at Peñas, near the south end of the Lake of Titicaca, a small patch is coloured

as Permian, quite detached from the rest of this formation, with which it has been grouped merely from its general resemblance in mineral character. It rises in the midst of the eastern plateau or "Puna" (as it is generally termed by the natives) as a steep ridge, broken in the centre so as to form a steep anticlinal, with the strata dipping respectively to west and eastward. The centre of this anticlinal is formed of red sandstones with gypseous seams; at Peñas the gypsum frequently occurs in crystalline plates of great purity; above these, to the westward, are some beds of coarse red conglomerate, which, in turn, are succeeded and covered by a second series of red sandstones. At Peñas the gypseous sandstones which form the anticlinal have a strike of N. 20° E., and, after dipping at a high angle to the east, gradually become less inclined, and rise, with a reverse or westerly dip, in a little hill to the eastward, thus forming a shallow intermediate basin; the red conglomerates which should overlie them do not come to the surface.

The well-known copper-mines of Corocoro (which, besides the supply for the home-consumption, exported from the port of Arica in one of the last years washed copper of the local value of 2,450,000 dollars) are situated in the red sandstones of this formation, and have been worked by the Indians from time immemorial. They were found in operation at the time of the Spanish conquest, and since then, up to the present date, have gradually increased in importance, notwithstanding that many of the mining and metallurgical processes are conducted in a manner more indicative of the times of the Inca dynasty than of the nineteenth century.

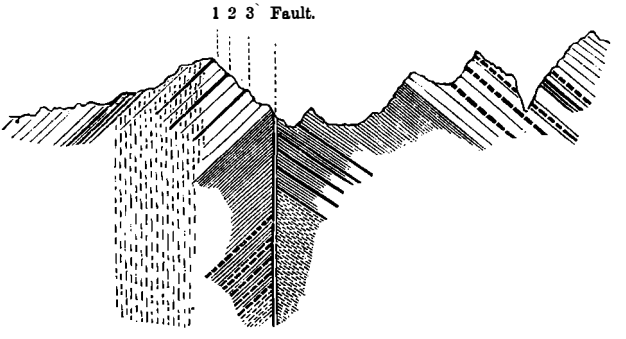
The copper occurs native as metallic grains or larger masses, disseminated irregularly in certain beds of sandstone; but combinations of copper with oxygen, arsenic, &c. are also found occurring in a similar manner to the west of the line of fault; the metallic copper, however, is the main object of exploration, and in a state of powder, resulting from the crushing and washing of the cupriferous sandstones, is exported in large quantities to Europe under the name of "copper-barilla." The want of coal or wood in this barren region prevents the other or mineralized ores of copper being worked or concentrated to a sufficiently high percentage for exportation,—the only smelting works in operation for the supply of the country, and for some little ingot-copper for exportation, being supplied with fuel from the excrements of the Llamas—it being considered that 100 quintals (each quintal = $101\frac{1}{4}$ lbs. English) of Llama dung will smelt 80 quintals of "copper-barilla*.' The furnaces employed are

* Owing to a wise provision of nature, the Llamas, when pressed by the calls of nature, do not, like the sheep, scatter their excrements over the ground at random, but resort to fixed spots, which they select themselves for the purpose, which circumstance enables an almost incredible quantity of this material (especially when we consider that in size the excrements do not materially exceed those of the sheep) to be collected for the use of the copper-smelters, and for the general supply of the inhabitants with fuel in a country otherwise destitute of combustibles. The other animals allied to the Llama (Alpaca, Vicuña, and Guanaco) also follow this laudable custom.

reverberatories with two chimneys instead of one as generally used for coal or wood.

The mode of occurrence of the cuprifcrous deposits of Corocoro is shown by the accompanying sketch-section (fig. 2), not drawn to a scale, but affording a pretty good general idea of the main features of this important mining-district. In this section the beds of cupriferous sandstone which are known and worked are denoted by continuous black bands, whilst those supposed to exist, but not yet proved, are shown by interrupted black bands.

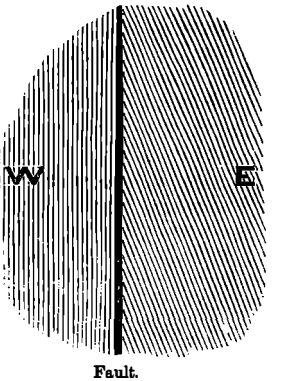
Fig. 2.—*Diagram-section of the Corocoro Copper-mines.*



1. Veta del Buen Pastor. 2. Veta de Rejo. 3. Veta Umacoia.

In the centre of the section a great fault is seen bearing nearly but not quite N.W., and dividing the whole metalliferous district into two parts; and on examination it was found to have produced both a horizontal and a vertical disturbance in the original position of the beds. Horizontally, the beds which, if merely broken and lifted up vertically on one or both sides of the fault, would naturally show parallel lines of outcrop, do not so; but on the right hand or east side of the fault they are skewed round, so as to make an angle of about 10° to the fault and the outcrop of the beds on the west side. This will be fully understood by reference to the annexed woodcut (fig. 3), which is supposed to represent a ground-plan of the present outcrop of the lines of stratification on both sides of the fault, and will not require further explanation.

Fig. 3.—*Ground-plan of the Fault.*



Still further westward, at Pontezuelo, out of reach of the immediate action of the fault, the beds were found as follows (commencing from the westward):—

N. 35° W.	Dip. 50° S.W.	Fine red sandstone beds. Found to affect the magnetic needle.
N. 35° W.	45° S.W.	Coarser red sandstones, about 150 ft. thick.
N. 35° W.	45° S.W.	Fine laminated and thick beds of red sandstone.
N. 40° W.	45° S.W.	Fine grey sandstones.
N. 45° W.	40° S.W.	Coarse grits and fine conglomerates, consisting of white quartz-pebbles, hardened grey, black, and greenish slates, and fragments of red sandstone.

Starting from the westward, over a series of fine-grained red sandstones, we come upon some coarser and more gritty strata, in which are imbedded several seams containing copper, visible on the surface by the green colour acquired by oxidation (they are not worked, being considered too poor); pebbly conglomerates are then passed over, some of which are also impregnated with copper; and we then arrive at the Veta de Buen Pastor, a fine-grained sandstone, impregnated not only with copper, but also with native silver, disseminated in fine metallic grains through the mass of sandstone. As the silver is of more value than the copper associated with it, this bed is worked exclusively as an argentiferous exploration. The succeeding strata are still coarse grits and fine conglomerates; and we come upon the Veta de Rejo, or Veta Copacabana, which also differs essentially from all the others from being rich in copper in a mineralized state of combination with arsenic, sulphur, &c. The ore from this mine being very dark in colour, from the presence of much arseniate of copper, this stratum is frequently termed the "Veta Negra," or black vein. Still lower in the same class of beds, the Veta Remacoia, or main seam of copper, is encountered and found to produce native copper, disseminated irregularly through a coarse grit, in grains, irregular lumps, or plates, sometimes of very considerable size. This seam is considered to have been the most anciently worked deposit of Corocoro, as it had been extensively worked by the Indians before the Spanish conquest; at present it is regarded as nearly exhausted, notwithstanding its extent of several miles, over which it has been explored. It is probable that by "exhaustion" is only meant a miner's mode of expressing that the depth of the workings and difficulty of keeping them free from water does not equal the value of the produce.

Below this metallic bed we find some gritty strata, and then have a characteristic bed of fine-grained crumbly red sandstone of immense thickness, the upper edge of which is seen on the surface close to the line of fault. Nothing is now known of the strata, metallic or otherwise, which may exist in depth on this (western)

side of the fault; but the metallic beds depicted in the section are supposed by me to exist, for reasons which will subsequently be explained.

Crossing now over to the east side of the line of fault, we find an immense development of the same fine-grained sandstones as those noticed as composing the last bed met with on the surface to the westward of the fault; and in the lower part of this bed we find developed a series of metalliferous beds differing considerably in their features from the "vetas" (or veins,—more properly, beds) previously described as seen and worked on the surface at the other side of the fault. These, from their being of much less thickness, are called by the miners "ramos," or branches; and, for the sake of clearness, only five of these are drawn in the section, whereas many more exist, as known by the mining explorations in them: for example, in the "Mina de Cimbani" there occur five principal or workable "ramos" and nine lesser ones; and possibly a still greater depth may bring others to our knowledge.

The strike of these "ramos" is tolerably constant, and only affected by purely local circumstances; but the dip was found to be higher as we approached the fault: thus, in the Mina del Pozo the following observations were taken:—

Strike N. 25° W.	Dip.	80° E.	
N. 20° W.	„	75° E.	
N. 35° W.	„	70° E.	(Ramo de San Jose.)
N. 35° W.	„	35° E.	
N. 25° W.	„	30° E.	

the angle decreasing with great rapidity as we get away from the fault, showing that a sort of bend or curve had taken place in the beds on settling down or coming to rest after the dislocation.

A considerable amount of gypsum is found in the form of strings or veins, also as small crystalline particles disseminated through these and the beds of red sandstones of this whole series.

These cupriferous beds are very extensively explored in Corocoro, and produce a large portion of the supply of copper derived from this district. The ore obtained from the "ramos" is very different and in a much finer state of aggregation than that from the "vetas:" this probably arises from the latter being situated in the midst of much coarser and more porous or open beds of grit and conglomerates of small pebbles. In both cases the ore is seldom continuous for any great distance, but is found scattered through the metalliferous sandstones, in irregular patches or spots of a white or greenish-white colour, full of small grains of metallic copper: the colour of these spots, forming a striking contrast with the deep red colour of the rest of the bed, affords, at first sight, a sure indication of the presence of the metal. This discoloration (for such it evidently is) seems to indicate some chemical change having taken place, apparently connected with the reduction of the copper to the metallic state, and the formation of the sulphate of lime (gypsum) in these beds.

An attentive study of this interesting formation has led me to

the conclusion that this change has been caused by the evolution of sulphurous fumes, disengaged, and penetrating into the pores of the strata, at the time of the eruption of the dioritic rocks of Comanche and the Cerro de las Esmeraldas, situated respectively to the north and south of the metalliferous district of Corocoro, and the protrusion of which through these Permian beds I consider as having caused the fault itself and the accompanying dislocations of the strata.

The sandstone I suppose to have been, previously to this disturbance, calcareous, and more especially so in the cupriferous parts, in which I regard the copper as having been present in the state of oxide or carbonate associated with carbonate of lime. Sulphurous acid, by combining with the oxygen of the oxide of copper to form sulphuric acid, would reduce the copper to the metallic state, whilst at the same time the sulphuric acid thus formed, acting upon the carbonate of lime, would produce the sulphate of lime (or gypsum) invariably accompanying these deposits.

It would have much simplified our ideas as to the geological age and origin of the occurrence of copper in South America if these deposits could have been shown to have had their cupriferous contents injected into them at the time of this dioritic eruption, which, as previously has been stated, is the direct cause of all the copper-veins which I had previously met with in Peru, Chile, and Bolivia. The question deserves further investigation; but the facts in hand appear contrary to this view, and to point out the copper as originally present in these sedimentary beds, probably, not as metallic copper, but in a state of combination, and subsequently reduced to the metallic state as before explained,—in corroboration of which it may be mentioned that these dioritic rocks can be everywhere proved to have been accompanied by a great evolution of sulphurous acid and other gases, by which the rocks in immediate contact have very generally been greatly metamorphosed. The supposition that the sandstones were calcareous is only in accordance with the frequency of calcareous beds met with in the unaltered parts of this formation.

The eruption of these dioritic rocks may, however, have possibly been the cause of our finding certain beds (or rather portions of beds), to the west of the fault, containing metallic silver, and impregnated with arsenic, sulphur, &c., by which arsenides, sulphides, &c. of these metals have been formed as domeykite, condurrite, copper-glance, &c.

One of these compounds, occurring in the Veta del Buen Pastor (previously mentioned), in the form of grey metallic grains disseminated in the sandstone in a similar manner to the usual occurrence of native copper before described, was analysed by me and found to be domeykite, the analysis affording—

Copper	71·13
Silver	0·46
Arsenic	28·41
	100·00

It would appear very probable that this had been formed *in situ* by the action of arsenical vapours on the metallic copper dispersed in the bed. That such a result can be thus produced may easily be experimentally demonstrated by holding a small piece of Corocoro copper-ore over a heated crucible containing arsenic.

Only a certain portion of the beds appear to have been so affected; and the spotted portion in fig. 2, p. 41, is supposed to represent this line of arsenical and other impregnation, from which it will be seen that the Veta del Buen Pastor and Veta de Rejo are altered from the surface; but the main bed, or Veta Umacoia, is, I believe, not affected at the surface; but it is so deeper down, since we find that the native copper from the Mina Cimbani contains arsenic, as seen from an analysis which is given a little further on: and I am informed that silver has been met with in depth in the Mina de Quimse Cruz; possibly this impregnation of arsenic, silver, &c. might (or in greater depth be found to) present itself as a vein of these metals.

The metallic copper of Corocoro is not only found as small grains in the sandstones, but also in nodules, irregular lumps, and plates or sheets interposed between the beds of sandstone, occasionally assuming crystalline and beautiful dendritic forms. In the Socabon de la Paz, on the Veta Umacoia (main seam), pseudomorphic crystals of native copper are found as hexagonal prisms without terminal planes; an analysis of one of these by Mr. Kroeber is annexed:

Copper	98·605
Silica	0·015
Silver	(trace)
Iron (as lost)	1·376
Metallic matter (insoluble in NO_5HCl)	0·004
	100·000

Some are solid; but others, when sawed through, exposed a nucleus of carbonate of lime, which would lead to the inference that these pseudomorphs had been formed by the action of a solution of copper on crystals of carbonate of lime, and by some subsequent chemical change the carbonate of copper so formed had been reduced to the metallic state.

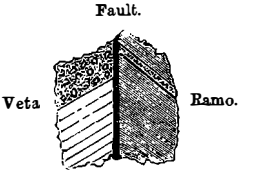
As is well known, the Permian Kupfer-Schiefer, or cupriferous bituminous shales of Thuringia, are characterized by the occurrence of the rare metal vanadium entering into their chemical composition; it appeared to me, therefore, of considerable interest to know whether this also was the case here in Corocoro, where strata occurred of very different mineral character, but supposed to represent the same geological epoch. Not having a laboratory at my command, Mr. Kroeber kindly undertook the examination; and his analysis of the washed copper-ore from the Mina de Cimbani, previously mentioned, afforded the following results:—

Water	3·500
Copper	63·341
Iron	1·200
Silver	0·003
Sulphuric acid	4·301
Sulphur	2·102
Arsenic	21·341
Carbonic acid	4·032
Vanadic acid	0·412
Sand	0·100
	100·332

from which it will be seen that even here in Bolivia, so far distant, the same chemical agencies had been in operation, and we find the metal vanadium playing a geological *rôle*, if such a simile be allowable.

As the respective names of "veta" (vein) and "ramo" (branch) denote, the metalliferous beds situated to the east of the fault had most probably, from their lesser thickness, been regarded as branches or offshoots of the former,—a supposition apparently supported by finding in the Mina Cimbani the actual contact of the former with one of the latter (Ramo de San Prudentio); and a large hand-specimen in my possession, taken from this point, and kindly given me by General Brown, the proprietor of this mine, shows, as in fig. 4, the two inclined at an angle one to another, strongly cemented together, and presenting the peculiar characters of each of these different deposits and the adjacent rocks in which they are situated. This circumstance is naturally due only to the different inclination of the strata on each side of the line of fault, causing the veta to cross the upper ramos; it is, however, interesting as showing how intimately the fault has been closed up by the grinding and sliding action which accompanied its formation.

Fig. 4.—*Sketch of the Hand-specimen, showing the Fault.*



Attempts had been, at various times, made by the miners of Corocoro to pursue their workings on these ramos through and on to the other side of the fault, and also to discover the representatives of the vetas on the eastern side of the same; but researches made without any preconceived idea of the true state of the case were not likely to be successful; and, up to the time I left Corocoro, they had not been attended with other results than pecuniary loss. Time did not permit of my making a correct section across this interesting metalliferous district, and so deciding the question; but a study of the immediate neighbourhood of the fault, and particularly the discovery to the west (and close up to the line of fault) of the upper beds of fine-grained red sandstones, very different from the coarser beds

above them, and so analogous in character to those on the east side of the fault (and which also I could find developed further west), furnished me with a clue to the explication of the question as represented in the section. I have further reason to believe this to be correct from finding, much further to the west (as marked in the section), coarser and pebbly beds and traces of the outcrop of cupriferous beds, which, on examination, may possibly prove to be the representatives of the western half of the dislocated "vetas." *

Before taking leave of Corocoro, I must mention the occurrence of fossil wood in the beds of the mine of Quimse Cruz, in a carbonized state, and occasionally having the pores filled with metallic copper; also the occurrence of a fossil skeleton of a Mammal in the mine of Santa Rosa† in 1859, part of which I was enabled to obtain through General Brown, and which Prof. Huxley, having kindly examined it, pronounces to be the skeleton of a mammal of the Camel tribe, allied to the Llama, but presenting marked differences from it: it has been called by him *Macrauchenia Boliviensis*‡. See p. 73.

The occurrence of a Mammal of the post-pleistocene period in strata considered as so much older appears only to be accounted for on the supposition that the animal had fallen into a fissure in these rocks, and been subsequently covered up by the crumbling sandy débris of the adjacent rocks, which has gradually consolidated. The mine of Santa Rosa being situated close to the fault, it might be also possible that some portion of the fault itself has not been closed up, and has thus left a fissure, which might account for the depth at which these remains were found under the surface. The bones themselves are in some instances almost converted into copper, or at least the pores are filled with that metal,—a circumstance easily accounted for in strata so highly impregnated with it.

I have gone into this detailed description of the cupriferous formations of Corocoro, because they are at present the object of the most important metallic explorations in the Permian rocks of Bolivia; but from all I can learn, the other mining districts in this formation present quite analogous features, and in some cases, as at San Bartolo in the south of Bolivia, are developed on an equally large scale,—the occurrence of the metallic copper in them being exactly as described in Corocoro §.

The disturbances or convulsions which have affected the Permian

* I cannot but express here the obligations I am under to Fieldmarshal Brown, M. Pedro Saienz, and other friends at Corocoro for the kind assistance they afforded me in my researches in this part of the country.

† The former of these mines belongs to Mr. Teare, the latter to Mr. Griffiths.

‡ The occurrence of an animal allied to the only known larger mammals of this part of Bolivia (the Llama, Alpaco, Guanaco, and Vicuña) is further interesting as showing that the great Bolivian plateau, at so much earlier a period, was inhabited by animals generically allied to those found there at present, and two of which (the Llama and Alpaco) are known to be indigenous, and not to occur elsewhere in the world.

§ Mr. Abel of Copiapo has, in a letter, kindly forwarded me the following

or Triassic strata in this part of the world are referable to three distinct epochs:—

1. Their upheaval by the porphyries of Oolitic age.
2. The protrusion of the still later dioritic rocks.
3. The eruptions of the volcanic rocks, properly so called.

All these have been already treated of more or less in detail; and in the sections accompanying this memoir (Pl. II.) these occurrences are in themselves sufficiently obvious to require no further explanation.

8. *Carboniferous Formation.*—The rocks of Carboniferous age met with in Bolivia, to the west of the high Andes, appear, at intervals, as small, elongated, basin-shaped deposits, the longer axis of which is more or less north-west and south-east; these basins are situated in the midst of the great western diluvial plateau, showing themselves to the north at the Lake of Titicaca, and, further south, in the provinces of Arque and Oruro.

The portion of this formation examined by me is shown in the accompanying Map (Pl. I.) and Section No. 1 (Pl. II.), where it forms the Isthmus of Copacabana in the Lake of Titicaca, the projecting headland on the other side of the Straits of Tiquina, and the islands in the lake itself. It is of very small extent when compared to the immense areas occupied by the other sedimentary formations here treated of; but it is everywhere highly fossiliferous, and presents a fauna which leaves no doubt as to its geological age: the lowest elevation of any part of it visible is about 12,500 feet; and it ascends from that height up to fully 14,000 or 15,000 feet above the level of the sea.

The unfortunate circumstance that war was declared between the republics of Peru and Bolivia when I was in this part of the country prevented me making anything but a most superficial examination. As this isthmus is divided between the two nations by such a serpentine line of frontier that in a day's journey in a straight line the traveller enters and leaves the territory of one or the other of these republics no less than seven times, and both lines of frontiers were occupied by the respective hostile armies, a geologist was placed in a very suspicious and uncomfortable position—as I had reason to experience. I was therefore glad to get over the ground as quickly

analyses of the copper-sands from San Bartolo, showing the composition of the ores found there in the cupriferous sandstone:—

	1.	2.
Copper	57·3	34·3
Insoluble matter Silica, &c.	35·4	50·2
Alumina, Iron, &c. Soluble in acids	4·4	7·3
Carbonate of lime	1·4	6·9
	98·5	98·7

the deficiency in the above analyses being due to a portion of the copper being in a state of oxidation in the ore: thus, in No. 1, 9·9 per cent. of copper were dissolved in dilute hydrochloric acid.

as possible, and was only enabled to make observations on the immediate route; so that the section of this basin is to be regarded as a sketch merely; but, at the same time, I believe that it represents pretty accurately the real state of the case.

Starting from the eastern portion of this section, from Hachecache, after traversing the volcanic rocks and a series of highly contorted beds supposed by D'Orbigny to be of Devonian age, we arrive at the Carboniferous series, represented in the section as being unconformable to, and abutting up against, the last-mentioned beds, owing to the occurrence of a fault: this appeared to be the case; but I admit that it is not determined with as much precision as I could have wished.

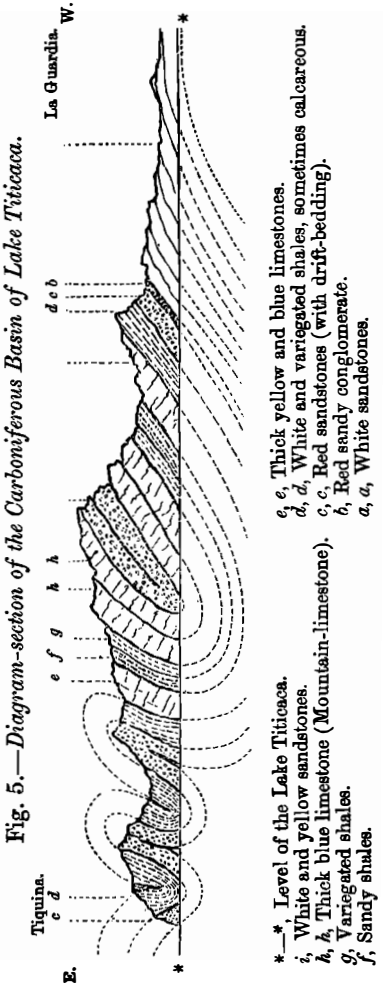


Fig. 5.—*Diagram-section of the Carboniferous Basin of Lake Titicaca.*

The strata first met with are red sandstones covered by some white sandstones, both of which alternate with and are succeeded by a rather nondescript rock, probably igneous, as the overlying beds of shales appeared to be altered as if by such agency; above these are some thin calcareous beds (fossiliferous), but the fossils I met with were too indistinct for determination; and then greenish shales, compact greenish shales, and red shales, succeeded by beds of red sandstone, forming the beach at Tiquina, at the Lake of Titicaca.

The Straits of Tiquina, which here separate the lower from the upper part of the lake, appear to the eye not to attain a breadth of more than from one-half to one English mile across, and, from the appearance of the stratification on both sides, are most probably the seat of a great fault which has broken up the continuity of the Carboniferous series.

Hitherto in the section these strata have all shown a dip to the westward, at pretty high angles, up to Tiquina: on crossing the straits, however, we meet

with red sandstones, apparently identical with those on the other side, but so dislocated as to present the appearance of the broken half of an arch; and a few yards further from the beach the beds are brought to a vertical position; and thus forming a fan-shaped contortion, they commence dipping to the eastward at angles at first very high, but becoming lower and lower as we proceed westward. The relations and order of succession of these rocks are, however, much better seen in fig. 5, showing a section of the Carboniferous series, from Tiquina to La Guardia, in an east and west direction. This section appears to represent the entire thickness of this formation.

The above section will require no further explanation or description of succession; but with reference to the fossils, I may state that those which I was enabled to extract from these beds have been named by Mr. Salter as follows:—

Productus semireticulatus, *Martin.* (P. Inca, *D'Orb.*)	Athyris subtilita, *Hall.*
Productus Longispina, *Sow.* (Capacii, *D'Orb.*)	Orthis resupinata, *Sow.*?
Spirifer Condor, *D'Orb.*	—— Andii, *D'Orb.*
—— Boliviensis, *D'Orb.*	Rhynchonella (new species).
	Euomphalus (Phanerotinus?).
	Bellerophon; like *B. Urii*, Flem.

along with numerous fragments of Corals and Crinoids in too imperfect a state to admit of being recognized.

A *Phacops*, named in Plate IV. *Phacops Pentlandii*, was brought from Aygatchi at the south end of the Lake of Titicaca, by Mr. Pentland in 1838, and supposed by him to be in the Carboniferous rocks there; but, according to Mr. Salter, this is an Upper Devonian type. It might possibly come from the sandstone series at the base of the Carboniferous, as the rock in which the specimen is imbedded seems to point out; in such a case these sandstones may be of Upper Devonian age.

I have not had an opportunity of visiting the Carboniferous beds in the provinces of Arque or Oruro; from the former, Colonel Lloyd some time ago sent home the following species:—*Spirifer Condor*, *S. lineatus*, *Productus Cora*, *P. Inca*, *P. Boliviensis*, and *Orthis Andii*.

The Carboniferous rocks of the Department of Santa Cruz appear to form a perfectly distinct series from the above-described isolated basins, being situated at a much less elevation above the sea, and cut off from all connexion with the others by the intervening mountain-chain of the Andes. According to M. D'Orbigny they are of much greater extent; and the fossils which I have seen appear in much more perfect preservation. Mr. Cumming brought to England the following fossils, stated to be from Santa Cruz:—*Terebratula millepunctata*, *Rhynchonella Peruviana*, *R. Pleurodon*, *Spirifer Boliviensis*, and *S. Condor*.

M. D'Orbigny has coloured on his map as Carboniferous a small patch around and including the "Morro de Arica," which is seen in Section No. 2 as a steep hill rising perpendicularly from the water's edge to the height of about 500 feet above the sea. The evidence he adduces is the occurrence of traces of a *Productus* in blocks of lime-

stone brought up by the porphyries which constitute the greater mass of this hill. This evidence does not appear to me sufficiently conclusive to warrant its being separated from the other strata, which appear continuous, and which are decidedly of Upper Oolitic age,—more particularly as we have no example of the occurrence of Carboniferous beds anywhere along the coast of the Pacific in South America. I have therefore classed them along with the Upper Oolitic series until a more careful examination, which I hope soon to make, may afford data for determining their exact position.

9. *Devonian Formation.*—The rocks which in Sections Nos. 1 and 2 are represented as of Devonian age have only been so coloured since my arrival in England: when these sections were made in Bolivia I had always regarded them as forming part of the Upper Silurian series, and coloured them accordingly.

I have been induced by Mr. Salter to look upon them as possibly Devonian, although far from being convinced of their being so in reality. The evidence of their geological age is as follows. No fossils were found in the beds of either of these sections by myself; but M. D'Orbigny cites one single specimen as occurring near Hachecache, a new species of *Orthis*, called by him *Orthis pectinata*, and regarded as decidedly Devonian by him, although Mr. Salter, judging from the figure and description of M. D'Orbigny, allows that it might pertain to any formation from Silurian to Carboniferous. The *Phacops Pentlandii*, from Aygatchi, is from near the junction of these rocks; but, as previously observed, it may possibly (as Mr. Pentland supposes) come from the base of the Carboniferous basin, the beds at the base of which might consequently be of Devonian age; but the exact locality of this fossil is too uncertain to allow it to be considered in settling this question. A series of beds of somewhat similar mineral composition occurs in the same strike as these at Oruro, in which a white sandstone contains great numbers of an *Orthis* considered by Mr. Salter as Devonian or Carboniferous from its belonging to the group of *Orthis resupinata* and *O. filiaria*. The Carboniferous series having been also developed, as previously mentioned, in Oruro, this *Orthis* might possibly belong to the sandstones at the base of the same. A *Favosites* also found near Oruro does not afford any satisfactory evidence, and we have only one fossil admitted to be truly Devonian—the *Phacops latifrons*, found in a rolled pebble in the diluvial plain near Oruro, and which is believed by Mr. Salter to agree in all essential particulars with the European and American species.

Any evidence derived from thickness of strata in a case where the Devonian, Upper Silurian, and Lower Silurian formations united, as exhibited in the sections here laid before the Society, are not considered to attain a collective thickness of more than 20,000 feet, cannot be taken as in any way conclusive against grouping the whole of these strata under the Silurian formation, when the magnitude of similar strata in other parts of the world is taken into consideration.

Having frequently heard of the immense development and thick-

ness of quartz-rock in Bolivia before having visited that country, I afterwards paid considerable attention to this point; but in the districts traversed by me, although containing a vast area composed of more or less compact sandstones and impure siliceous beds, with interlaminated partings of blue, olive, or brownish-red shales or slates, I did not meet with any very extraordinary thickness of them.

A superficial observer, particularly if passing rapidly over the ground, might, in several places, easily be deceived into the belief that such a thickness really occurred, from finding the strata dipping to one side over a great distance, as, for example, between Hachecache and Tiquina, where the beds passed over might for this reason appear to form part of an immensely thick series. As shown in Section No. 1, these beds are in reality contorted and doubled up into an almost innumerable series of extremely sharp, small folds; and in this case I counted no less than 23 such folds in the short distance between Hancoamaya and the commencement of the Carboniferous series, owing to which the appearance of a very general dip to the eastward was presented.

In the annexed map (Pl. I.) the Devonian series is coloured together with the Silurian with one tint, from my being unable to draw so definite a line of separation as is found in M. D'Orbigny's map: their mode of occurrence is so well illustrated in Sections Nos. 1 and 2, that a description would be superfluous.

The strata themselves consist of white sandy beds more or less compact, yellowish impure sandstones and grits, and, as is seen in Section No. 1, at Hachecache, quartzite-like rocks, showing themselves both to the east and west of that place, and easily recognized in section from their rugged and shattered appearance, due to their having been too rigid to bend along with the other beds; interstratified with these are blue, olive-green, or reddish-brown shales, and beds of blue clay-slates.

Sir Roderick Murchison, some years back, in his 'Siluria,' when reviewing the Devonian formation of Bolivia as described by M. D'Orbigny, expressed himself thus:—"In the absence of sufficient proof, doubts may be entertained whether these sandstones and quartz-rocks of the Andes may be of Upper Silurian rather than of Devonian age;" and my own researches have tended to make me adopt this opinion: at the same time, however, I think it probable that there is in Bolivia a true Devonian system at the base of the Carboniferous strata, consisting of white, yellow, and brown-red sandstones, with intercalated shale-partings, which collectively do not attain any very great thickness nor occupy any very extensive superficial area*.

* These beds probably are of Upper Devonian age. I have not examined any part of the country which lies on the eastern slope of the main chain of the Andes and is coloured by M. D'Orbigny as Devonian. As will be seen from the comparative sections appended to this memoir (Pl. III.), M. Pissis does not entertain the same opinion, but in his section he represents these beds as being lower in position than the whole of the very thick strata which I am now about to describe as representing the Silurian epoch.

10. *Silurian Formation.*—The rocks which I have grouped together as pertaining to the Silurian epoch show themselves continuously, or very nearly so, over an extent from north-west to south-east of more than 700 miles; and the area occupied by them cannot be estimated at less than 80,000 to 100,000 square miles. They form the mountain-chain of the high Andes, rising to an absolute height of 25,000 feet above the sea, and, in the part of South America more particularly the subject of this memoir, continuous through Peru from the north of Cusco over the snowy ranges of Carabaya and Apollobamba, across the provinces of Munecas, Larecaja, La Paz, Yungas, Sica-Sica, Inquisivi, Ayopaya, Cochabamba, Cliza, Misque, Chayanta, Yamparez, Porco, Tomini, and Cinti, throwing off spurs along the eastern side of the main chain, right through the province of Caupolican, down to the River Beni in Mojos, into Yuracores, Valle grande, Santa Cruz and Chuquisaca, and to the east into the provinces of Oruro, Potosi, and Chichas*.

Some of the greatest rivers of the world have their sources in this mountain-chain. The Amazon, with its mighty affluents the Purus, Madera, Beni, Mamore, Rio Grande, as well as the Pilcomayo and other branches of the River Plata, are fed by the snows of this great Silurian region.

In this range also we meet with the loftiest mountains of South America, second in height only to the Himalayas. Thus we have Illampu (Sorata) 24,812 feet (25,200, Pentland), Illimani 24,155 (24,200, Pentland), Huayna Potosi 21,883, Coloolo 22,374, and many others, rivalling these in height, but the elevation of whose peaks has never as yet been ascertained. These peaks do not, as M. D'Orbigny's published researches would lead us to suppose, consist of mighty cones or bosses of granite, but are in reality composed of Silurian strata,—fossiliferous, as I have proved in the case of Illampu (the highest of them all) up to its very summit†.

The Silurian series in these regions present a physical configuration, as well as other features, so unmistakeably analogous to those of their equivalents in Europe, that, notwithstanding the much grander scale on which they are developed, the geologist cannot but imagine himself breathing the air of Siluria, even before an examination of the rocks themselves confirms this suspicion.

The extensive development of clay-slate, shales, and grauwackes, along with the metallic contents of these rocks, present mineral cha-

* I have visited, of course, but a small portion of this vast territory, but have availed myself of all procurable data and many specimens of the rocks of these provinces, principally from mining adventurers and others who have explored these districts, from whom I have received much information and assistance.

† M. D'Orbigny presents us in section with the lofty Illimani as an immense cone of granite. When there, I could not find a trace of this rock; and Mr. Pentland, who ascended the side of Illimani to a much greater elevation than I did, assures me that he met with only clay-slate, and found no trace of granite or other eruptive rock. Mr. Horner has also directed my attention to the annexed paragraph in Naumann's 'Lehrbuch der Geognosie,' 2nd edit. 1858, vol. i. p. 97:—"Die beiden höc sten Gipfel der östlichen Andeskette von Bolivia, nämlich der Sorata (19,974 F.) und der Illimani (19,834 F.), bestehen aus Grauwackenschiefer, und sind keine Vulcane."

racters very similar to the Lower Silurian series in Europe, particularly as we do not, as far as I have examined, meet with the limestone beds and calcareous shales generally accompanying the Upper Silurian series. The examination made by Mr. Salter of the fossils extracted by me from these beds appears, however, to show that we probably have the whole Silurian series, from lower to upper, fully represented, notwithstanding the general uniformity in mineral character of the beds.

Starting from the north, at Tipuani, we find this auriferous region principally composed of blue clay-slates, which, from information communicated to me, I believe to cover a vast area, extending down to the River Beni. In these strata no fossils have as yet been found*; but they appear to be quite continuous with the beds which contain fossils near Sorata, about five miles south of which town I found, at a small Indian place called Cotaña, on the east side of the river, an *Orthis* (apparently *O. Aymara*), *Strophomena* (species undetermined), Annelid-tubes well defined, and small round bodies of pyrites with a hole in the centre like the joint of an Encrinite, about one-third of an inch in diameter, occurring in the blue slate†.

Still further south, on the north-west slope of Illampu, I found in loose stones, at a place called Cochipata, traces of *Cruziana Unduavi* (Pl. V. figs. 7, 8), and a little further, at Ucumarini, also on the east side of the river, Annelid-burrows and the *Cruziana Cucurbita* (Pl. V. figs. 4–6). The burrows were of varied forms and sizes, and perfect counterparts of those from Unduavi in Yungas, although this place is situated some 120 miles distant on the other side of the Andes.

Still further south I fixed my head-quarters in the Hacienda de Millepaya, and by extensive excursions from that point, and ascents as far as possible up the steep western slope of Illampu (or Sorata, as it is generally but erroneously termed‡, from the town of that name situated at its base), I was enabled to form the section of the strata represented in Section No. 1, and to examine the beds as to their fossil contents. The results of this examination are given below, premising that above the shales forming the uppermost beds repre-

* It requires an attentive search in order to discover fossils in a new country. The small number of Bolivian fossils at present known is not to be ascribed to the poverty of the rocks, but to the insignificant proportion which the few isolated spots hitherto examined bear to the vast area of this republic: as far as I have explored, this country shows evidence of being eminently fossiliferous. I believe, however, that I have, during my recent and short travels in this country, brought home more fossils than any explorer before me, notwithstanding that M. D'Orbigny and M. Pissis (who lived eight years in Bolivia) had much better opportunity than myself.

† I have to thank Mr. Salter for his great kindness in carefully examining the fossils of the Silurian, Devonian, and Carboniferous series. The names here given are those affixed by that gentleman, who has communicated a paper illustrative of the fossils which I brought home from Bolivia. See p. 62.

‡ The mountain itself is called in Bolivia by the original name of Illampu, at the foot of which, to the north, the town of Sorata is situated; and the snowy range above this town being frequently called the "Nevados de Sorata" has led to the mountain Illampu (the highest peak of this range) being called, more particularly by English writers, Sorata.

sented in this section are several beds of a quartzitic sandstone, which again are followed by the strata coloured as Devonian. The beds enumerated in the annexed table are numbered from W. to E., or in descending order, commencing with the highest:—

1. Thick blue clay-shales	No fossils found.
2. Brown micaceous slates. Strike N. 5°W. Dip 50° W.	Annelid-burrows, some globular bodies, and a fossil supposed by Mr. Salter to be a *Cruziana*; also a curious *Patella* or *Pileopsis*.
3. Blue, hard, and slightly micaceous beds	*Orthis Aymara*.
4. Less laminated micaceous beds	No fossils found.
5. Blue clay-shales	
6. Blackish-blue shattered clay-shales ...	
7. Thin bed, about 6 inches of slightly calcareous shales	
8. Shattered blue shales of great thickness	
9. Thin blue slates at Hacienda de Millepaya, much jointed	
10. Slightly micaceous blue beds	*Orthis* with fine striæ. *Orthis Aymara*, *Cruziana Cucurbita*, Annelid-burrows, and several indistinct bodies.
11. Siliceous grauwacke sandstone beds, about 100 feet thick	No fossils found.
12. Thin shales	
13. Grauwacke, thin bed, sandy	
14. Thin shales	
15. Grauwacke	
16. Thin shales	
17. Grauwacke	
18. Thin shales	
19. Grauwacke	
20. Clay-slate, dirty-blue colour	
21. Thin-bedded micaceous clay-slate	Annelid-burrows.
22. Bluish slates.....	No fossils found.
23. Thin grauwacke	
24. Clay-slate	
25. Thick grauwacke-slates	
26. Rather hard, greyish-blue, sandy shales	*Orthis Aymara*, Worm-burrows, *Ctenodonta* (*Nucula*).
27. Clay-slates	No fossils found.
28. Grauwacke-slates.....	
29. Hardened clay-slates	
30. Whitish grey, hard grauwacke-slates, or sandy shales	*Homalonotus* (new species).
31. Grauwacke bed.....	No fossil found.
32. Micaceous clay-slates	Annelid-burrows.
33. Blue siliceous clay-slate, or more or less sandy shale; weathering white on the surface	*Orthis Aymara*, *Phacops*, *Proetus*, *Cucullella*, *Ctenodonta* (*Nucula*), *Arca Brownii*, *Bellerophon*, *Tentaculites Saienzii*, *Raphistoma?*, *Homalonotus Linares*, Annelids, and several other fossils, indistinct. This bed seemed to abound in the above-mentioned fossils.
34. Hard, white, altered clay-slates, cut through by metallic veins.....	No fossils found.

35. Similar slates; still more altered	*Tentaculites supremus* and a Cup-coral; also several indistinct fossils, amongst which many bodies about 3 to 4 inches long, looking like *Orthoceratites*.
36. Similar strata, whitish brown or purplish	*Homalonotus Linares*, *Tentaculites supremus*, *Ctenodonta*, and a Cup-coral.

This bed is the lowest in position of the strata here examined; and, being tilted up as shown in Section No. 1, it forms the summit or knife-like ridge of this mountain which separates the barren alpine plains of the Puno, on the west, from the verdant tropical regions of the Yungas, to the eastward. On a clear day the line of bedding of the last-mentioned strata can easily be followed by the eye, up to the very highest point of the ridge itself, the steep and highly inclined sides of which prevent the perpetual snow crowning its top from showing itself as a continuous envelope, and only allowing it to lodge itself in the hollows, crevices, and offsets formed by the strata, which, as it were, prop up its summit.

The section across these beds shows also that the valley of Millepaya is merely due to erosion, and not to a fault or break in the stratification as its peculiar configuration might lead us at first to suspect; it becomes gradually narrower as it ascends, and loses itself as a ravine in the western slope of Illampu. The following observations of strike and dip were taken:—Bed No. 2: Brown micaceous slates, N. 5° W., dip 50° W. Bed No. 34: Hard, white, altered slates, N. 25° W., dip 32° W. Bed No. 35: Hardened brownish-white clay-slate, N. 10° E., dip 35° W. Other observations gave the same strike; but the dip was found respectively to be 25°, 30°, 38°, 42° W.; and still higher up in this bed the observed strike was N. 10° E., and the dip 40° W.

In these slates abundant furrows and deep grooves were observed, sometimes very deep, and running from N. 80° E. to E. & W.; also veins of spathic iron-ore, arsenical pyrites, and auriferous pyrites; veins of mispickel or sulpharsenide of iron were found running N. 50° E. to N. 60° E., and dipping to S.E. at an angle of 75°, cutting through and altering the strata.

On the sides of this mountain are also found veins of argentiferous galena, gold-bearing quartz, and metallic bismuth, the latter sometimes in large masses, occasionally faced, or incrusted on the sides, with metallic gold, sometimes in crystals. Iron-ore is also abundant*.

About ten miles to the south of Millepaya, on the west slope of Illampu, at Capara, I found, in the loose blocks of soft blue slate there, *Orthis Aymara*, a trilobite (probably *Homalonotus*), a Cup-coral, and abundant Annelid-burrows, also a Trilobite (possibly a *Calymene*) in hard grauwacke.

Still further to the south, at Umapozo, I found *Ctenodonta* (*Nucula*),

* I was informed by M. Villamil of a recent discovery of anthracite-beds in these strata; but, as yet, I have not received any satisfactory confirmation of the same.

Orthis Aymara, *Orthis* (Pl. IV. fig. 15), and *Cucullella*, all in sandy shale, and in a soft blue clay-slate, apparently the equivalent of the uppermost beds of the Millepaya section, the *Beyrichia Forbesii*, associated with an abundant small species of *Tentaculites*, which appears to me to be quite different from the *Tentaculites supremus* and *T. Saienzii* of the lower beds, both of which attain a length of occasionally more than 2 inches, whereas this small species never appeared to exceed one quarter of an inch.

Between this last-mentioned place and La Paz, I have not examined the beds for fossils, and only accidentally met with some Annelid-tubes in blue slate, about thirty miles north of that city: the position of these is uncertain.

From La Paz, to the eastward, as far as a short way below Unduavi, in the Yungas, I was enabled to make the section across the Silurian strata between these places, as shown in Section No 2. This appears to cut through the whole of this formation, from the upper beds, which before were met with at Millepaya, down to the Lower Silurian slates with *Bilobites*, a thickness of probably about 15,000 feet.

Starting to the eastward from La Paz, and crossing the great diluvial formation, with its imbedded stratum of trachytic tuff, which in the section is seen to be disturbed and dislocated by several faults, we come upon the first appearance of solid rock some miles to the east of Chuquiaguillo, and find it to consist of crumbly and much weathered clay-slate, apparently of considerable thickness, and resting upon greyish impure sandstone, which at the river of Taxani is succeeded by an alternating series of shales, slates, and grauwackes or arenaceous beds, the lowest of these being a blue clay-slate of considerable thickness*, in which an anticlinal is seen, bringing the former beds again into sight. I noticed before coming to La Lancha the occurrence of frequent frictional striæ and grooves or furrows, the bearings of several of which I found to vary from N.N.W. to N. and S., and to N.N.E. At La Lancha these slates again form an anticlinal, which from the precipitous sides of this immense ravine could be accurately delineated; further up, the clay-slates are very much contorted in the line of bedding; but towards the summit they become nearly horizontal, or rather slightly basin-shaped; and in descending, we have the dip always to the eastward until we come very close to Unduavi. To the west of the summit I did not find any fossils; but shortly after commencing the descent, the sandy shales were full of Annelid-tracks, in such abundance that rarely was a slab found that was not more or less covered with these burrows and markings. At the Mina Emma, a vein of argentiferous galena, running from 20° to 35° E. of N., and with varied but nearly vertical dip, is being worked; and there I noticed abundant elongated round bodies in the slate, which from their configuration, and from having invariably a hollow tube in the centre, appeared like *Orthoceratites*: they were composed chiefly of carbonate of iron.

* On the top of these highly inclined strata is seen a small patch of diluvial conglomerate, apparently a remnant of the formation further to the west.

The rocks from this mine to Pongo, and from that place down to Unduavi, consist entirely of more or less arenaceous shales, thin-bedded and containing frequently indistinct traces of fossil forms. As seen in the section, these slates are dislocated by three faults, which faults are filled with metallic matter, and form the veins on which are worked the mines "Delphina," "Mercedes" (60° N.E. strike, 85° E. dip), and "Pilar," producing argentiferous galena more or less antimonial, for the supply of the furnaces at San Felipe.

In M. D'Orbigny's map, the greater part of these slates are coloured as granite; and, according to him, Pongo is situated in the midst of the granite, which in his map here forms a broad band, constituting the centre of this range of the Andes. As seen in the section, no trace of granite visible to me occurs here; and, in fact, no granite whatever is crossed in the direct line of section from La Paz to as far east of Unduavi as I examined. The small outburst of granite seen at Silla Tuncari does not occur in this line; and I have purposely deviated the section from the direct line in order to show it. Granite is also met with in the Nevado of Chucura, at Yoja, and at Takesi (to the south of this section); but it does not form the continuous band seen on M. D'Orbigny's map, which appears in this, as in many other instances, to have been coloured from imagination*.

The granite of this chain of the Andes shows itself at various localities, apparently isolated one from another†, and appears to be of the same age as the auriferous granites of the rest of the world, with which it is identical in mineralogical and chemical composition, being composed of white orthoclase, colourless quartz, and black or white mica, and containing frequently spots of iron-pyrites, which sometimes, as at Silla Tuncari, stains the granite of a brown colour from oxidation. The gold in this is found in the quartz, or along with the pyrites; and it would occasionally, at least, appear that this rock is more auriferous in proportion as it contains more pyrites. As the whole of this Silurian formation is eminently auriferous, and contains everywhere frequent veins of auriferous quartz, usually associated also with iron-pyrites, a study of the occurrence of these gold-veins leads me to attribute all such veins to the proximity of granite, and to regard the veins of quartz, iron-pyrites, &c. as having been directly injected from the mass of granite itself. We know that, during the cooling and solidification of granite, the quartz

* In the map which accompanies this memoir (Pl. I.) the granite is not separately coloured, on account of its forming here a subordinate part of the Silurian district. It being difficult to get details into so small a scale, the Devonian and Silurian, along with the granite rocks which disturb them, are coloured with one tint. I must also confess that, without more data, it would be impossible to do otherwise without falling into errors similar to those of M. D'Orbigny.

† I must observe that I am not alluding to the great granitic range which occurs, according to M. Pissis, still further to the east, near Coroico. I, unfortunately, was unable to pursue my section further, from the rainy season having rendered the rivers impassable: an attempt to ford the river below Unduavi having resulted in the loss of two animals with all the baggage, made it more prudent to retrace my steps, however unwillingly, to La Paz.

present in some is the last mineral element to crystallize and become solid; it seems probable that, during this cooling, the consequent expansion due to the crystallization of the constituents has forced those components (quartz, along with iron-pyrites, gold, &c., which latter, from their very low fusibility, would remain longest of all in a fluid state), still fluid, into the fissures of the neighbouring rocks, and so formed such auriferous quartz-veins, which observation shows are only developed in the slate-rocks at no very great distance from granitic eruptions, either visible or such as, though hidden, may reasonably be inferred to exist. This granite is the same which is everywhere met with in the diluvium of the eastern plateau, as large blocks, frequently used as a building-material where solidity is required*.

Although we do not meet with any actual granite on the direct line of section without diverging (as I have done in order to show the granitic outburst of the Silla Tuncari), we find, a little to the west of Unduavi, these beds broken through by a fault, probably due to this eruption. The granite has also caused an anticlinal in the strata, which hitherto, from the summit of the pass, had constantly dipped to the east, but now become inclined to the westward, and continue so to San Felipe, near which place, however, after presenting some contortions in their bedding, they again resume their western dip, having at the Angostura, below San Felipe, a strike of about N. 30° E., with 50° westwardly dip.

At San Felipe the hard sandy shales, of a blue colour and slightly micaceous, contained frequent Annelid-tracks and -burrows, and a great number of small nail-shaped bodies like the spines of an *Echinus*, also others horn-shaped, with concentric rings, both of which Mr. Salter attributes to Annelids. Along with these were frequent specimens of the *Cruziana Unduavi* (Pl. V. fig. 7); and I also noticed several specimens of the *Boliviana bipennis* (fig. 11). Traces of other fossils were everywhere frequent, but too indistinct to permit determination.

About half a mile further down the valley, Annelid-tracks were found in abundance in the hard blue siliceous slate, as well as imprints of *Cruziana*. About one mile further down, the thin-bedded sandy and highly-indurated rocks were literally covered in all directions with Annelid-tracks and -burrows, the same nail-headed bodies previously described, and a variety of other and peculiar markings. I also found some indistinct specimens of *Boliviana Melocactus* and *Cruziana Cucurbita*, and several better ones of *Cruziana Unduavi*, which last were found a little lower down the valley. Ripple-marks are everywhere visible in these beds.

In another valley, called the "Quebrada de Aceromarka," situated a little to the south of Unduavi, in similar beds, specimens of the shapeless *Cruziana Cucurbita* were found in abundance, in company with the *Boliviana Melocactus*, and a single specimen of the *Boliviana*

* The corinthian columns of the new cathedral at La Paz are hewn out of this granite, and are most creditable to the architect, especially when it is considered that the cutting of this hard material has been entirely executed by the Aymara Indians of the district.

*proboscidea**, with numbers of other still more indistinct fossil impressions.

I have not a doubt that these beds, on careful search, would yield a rich harvest to the palæontologist; but I had not time to devote to more than a very rapid survey of the country†.

The thickness of the Silurian strata seen in this section cannot be less than 10,000 feet: opposite San Felipe a good section is seen on the nearly perpendicular face of the mountain called "Perolani," which, by measurement, is 6000 feet above the valley; and, as the strata in the centre of this mountain are nearly horizontal, the thickness of strata in that place cannot differ much from the totalheight of the mountain above the level of the valley; and it is not too much to add 4000 feet for the strata visible both above and below these beds.

The Silurian strata have been disturbed by the following igneous outbreaks, in succession. Commencing with the most ancient,—

1. Intrusion of the auriferous granite, along with its associated auriferous, and probably other metallic, veins: in parts it has metamorphosed very considerable areas of the Silurian beds.
2. The porphyritic eruptions of Hillabaya, Potosi, Oruro, &c.
3. Protrusion of the metalliferous diorites.
4. Still later trappean dykes, which, I am informed, occur at several localities; but I have not personally come across them in Bolivia.
5. Volcanic eruptions near the Lake of Titicaca, &c., breaking out at the borders of this formation, but which, as far as I am aware, do not anywhere disturb the main chain of the Silurian Andes of Bolivia. On inquiry, I found that this district was exempt from the earthquakes which are so prevalent and destructive both in this and the adjacent Republics.

The metallic veins‡ which occur in these Silurian strata contain the following minerals:—

Metallic Gold.
Silver.
Bismuth.
,, Antimony.
Oxide of Iron (magnetic).
,, of Tin.
Tin-enamel.
Chloride of Silver.
,, of Lead.
Fluor-spar.
Selenide of Lead.
,, of Cobalt and Lead?
Sulphuret of Antimony.
,, of Molybdenum.
,, of Silver (Silver-glance).
Blende.
Galena.
Magnetic-pyrites.

* I have to thank Mr. Kroeber, the Director of the San Felipe Mining and Smelting Company, for his hospitality, and the assistance afforded me in my search for fossils in this region.

† Mr. Kroeber informs me of some anthracite-deposits, more like fissures filled up than true beds, and, according to his description, like some in Shropshire. This, however, requires confirmation.

‡ I refer here to such veins as are not (so far as can be determined by superficial examination) in connexion with the eruption of the metalliferous diorites previously described as of Post-oolitic age.

Iron-pyrites.	Fahlerz.
Copper-pyrites.	Silver-fahlerz.
Tin-pyrites	Zinc-fahlerz.
Sulphuret of Copper and Bismuth?	Wolfram.
Jamesonite.	Calc-spar.
Plagionite.	Carbonate of Iron.
Zinkenite.	,, of Lead.
Lonchidite.	Sulphate of Lead.
Mispickel.	Phosphate of Lead.
,, (nickeliferous).	Arseniophosphate of Lead.
Danaite.	

The above enumeration is doubtless far from complete; but it is quite sufficient to show at a glance how strikingly the mineralogy of these older strata differs in its general features from that of the more recent rocks before described.

I may here notice some rocks which occur on the immediate line of the Bolivian coast, and which, for the present at least, I class along with the other metamorphic Silurian strata of this part of the world, not from being able to prove with certainty that they are of Silurian age, but because, from their position and their relations to the newer formations in contact with them, they appear to be only a continuation of the beds which in Chile form the Silurian series of the coast.

They are so very much altered by the effects of the eruptions of granite, porphyry, and diorite, which here break them up, that even their sedimentary nature can hardly be recognized except at some few localities.

To the south, in the Desert of Atacama, they appear as gneissic or metamorphic schistose rocks, broken through in all directions by granitic outbursts, the granite itself being precisely identical in external appearance and mineralogical composition with the previously described auriferous granite of Silurian age in the Eastern Andes. It is composed at Mexillones, for example, of white orthoclase, colourless quartz, and dark mica. Further southward the sands arising from the disintegration of this granite have been proved to be auriferous.

At Cobija, the black rock which forms the rugged low cliffs and detached rocks in the sea and along the shore appears also to belong to this series, although in appearance it frequently resembles a compact trappean rock or a black porphyry. On closer examination, I am disposed to consider it as a clay-slate or other argillaceous or calcareo-argillaceous rock, fused *in situ* by the action of the masses of porphyry or diorite resting immediately upon it, or of the granite which has upheaved and broken it up, and which, although not itself visible at the Port of Cobija, is seen a little further to the south. This rock varies in colour from a bluish-grey to grey or bluish-black, and, like all altered rocks of this class, contains green epidote frequently disseminated in it, or forming imbedded geodes: geodes of quartz or calcedony also occur; and when the rock appears to have been completely fused I have noticed some dark-

grey felspar-like mineral in it; in texture it then much resembles a basaltic or trappean rock. It is extremely hard and tough, and is cracked, fissured, and jointed in all directions. Occasionally one set of joints presents pretty regular and parallel lines of fracture. Many small strings of copper-ores (sulphurets, carbonates, and oxychlorides) are seen cutting through them, with various bearings, from N.E. to E. and W., dipping at very high angles.

Conclusion.—In conclusion, I must direct attention to the three comparative sections of the country from Arica on the Pacific to the Yungas on the eastern side of the High Andes of Bolivia (Plate III.). Although this plate is, of course, to be regarded only as a diagram, it represents correctly a summary of the conclusions at which M. D'Orbigny*, M. Pissis†, and myself have arrived in traversing the same line of country.

On examination, it will be observed that great and unaccountable differences are here depicted; and it must be left to the reader to judge, from the perusal of the different memoirs of the three authors, how far each of them may be sound in his views.

This plate does not require any further explanation than the remarks which have been occasionally made under the heads of the different formations; but it is particularly important as showing at a glance these several discrepancies, and in its bearings on the general tenor of the results here brought forward. Subsequently it will be required for reference in the second and third parts of the memoir of which this communication is the first part, and which will treat of the Geology of Chile and the Argentine Provinces; it will then be found most essential in explaining and reconciling the various statements which have been made in reference to the geology of these countries.

On the Fossils, *from the* High Andes, *collected by* David Forbes, Esq., F.R.S., F.G.S. By J. W. Salter, Esq., F.G.S.

[Plates IV. & V.]

I have examined this unique series with some care; and with a collection of above 200 specimens there should be no unusual difficulty in assigning the true geological date. The specimens are generally perfect enough to show the generic characters, though in very few cases is their preservation complete; and it is thought better at present (especially as Mr. Forbes intends returning over this difficult ground) to figure all the chief forms, and give specific characters only to the more prominent fossils. All the specimens from the slate-rocks are distinct from those previously published.

* Voyage dans l'Amérique Méridionale, tome iii., Partie Géologie. Par M. Alcide d'Orbigny. Paris, 1842.

† "Recherches sur les Systèmes de Soulèvement de l'Amérique du Sud." Par M. Pissis. Annales des Mines. 5me sér. tome ix. 1856.

Of the Carboniferous forms little need be said. They are the same as those described long ago in D'Orbigny's large work; and similar specimens were brought home by Mr. J. Cumming during his explorations for recent shells in Bolivia. The resemblance to British fossils of this epoch is most striking, and some of the species are identical.

The Devonian gives us very scanty traces, yet scarcely doubtful. Occurring, as it does, between the Carboniferous basin and the slate-rocks, it falls naturally into the place indicated by the few fossils known to us. Mr. Pentland brought home from Aygatchi, in Bolivia, a Trilobite from this formation.

The age of the slate-rocks, however, was for a long time doubtful; and the aspect of Mr. Forbes's collection is so unlike that of any British or American type, that, while their discoverer was strongly urging their Silurian age, my own prejudice gave them a Lower Devonian character. The large *Homalonoti* (the only conspicuous Trilobites) are, on the whole, more like Devonian forms than Silurian; and the shells are of just such types as might be referred to either of these systems. The *Tentaculites* would bear the same interpretation; but a small *Beyrichia*, very rare, occurs just at the top of the whole series, and this particular form of the genus is not known in Europe to trespass beyond the Uppermost Silurian limit, or the basement-beds of the Devonian at furthest. Again, the *Bilobites* (whatever these obscure fossils may be) are all of Silurian age, and they are numerous in Mr. Forbes's collection. They have generally been regarded as Lower Silurian forms, and are, indeed, far more plentiful below the Caradoc rocks than elsewhere. But too much stress must not be laid on this; for one characteristic species occurs in the Llandovery or Clinton group of New York; moreover, all the specimens from the Andes, whether the large ones described by D'Orbigny, or the smaller ones now brought home, are of species distinct from those known in other districts. I do not believe them to be plants, but have no definite idea of their true structure, further than that they were tough hollow crusts, not soft solid masses as sea-weeds generally are.

One other remark before proceeding to notice the separate species. Wherever we meet with new areas of Silurian rocks, we find we have in them new Natural-history provinces of these old seas: it is so in India, according to Colonel Strachey's researches; and it is so in Australia: no species from either region is, I believe, identical with those of Europe. The same cannot be said of the Devonian fossils, which ranged very widely during the later part of that epoch; and the Carboniferous types are almost cosmopolitan, many of the same fossils ranging from the North Pole to Australia, and from North America and the Andes to Nepaul. It is, I think, chiefly due to this circumstance that we have been accustomed to regard the Palæozoic types as having an almost universal diffusion. This is nearly true as regards the genera, but, except in the remarkable case of the Mountain-limestone fossils, without much evidence in the case of species.

CARBONIFEROUS.

From the small basin of these rocks at the Isthmus of Copacabana, in the Lake of Titicaca, the following species were obtained:—

Productus semireticulatus, Martin. (*P. Inca*, D'Orb.) Pl. IV. fig. 1.
—— *Longispina*, Sow. (*P. Capacii*, D'Orb.) Pl. IV. fig. 2.
Spirifer Condor, D'Orb. (*Sp. striatus*, Sow.?)
—— *Boliviensis*, D'Orb.
Orthis resupinata, Sow.?
—— *Andii*, D'Orb. (from a Santa Cruz specimen). Pl. IV. fig. 3.
Athyris subtilita, Hall. (*T'er. Peruviana*, D'Orb.) Pl. IV. fig. 4.
Rhynchonella (a species with three raised ribs, very like some varieties of *R. Pleurodon*; also from a good Santa Cruz specimen). Pl. IV. fig. 5.
Euomphalus, with separated whorls (possibly a *Phanerotinus*).
Bellerophon, sp.; a close ally of *B. Urii*, Flem. Pl. IV. fig. 6.

Corals, also, and Crinoids, all imperfect. D'Orbigny describes a *Favosites* and a Cup-coral, a *Fenestella*, &c.; and Col. Lloyd's collection from Arque, as well as Mr. Cumming's from Santa Cruz, both include such specimens. I see no essential difference between the *Productus semireticulatus*, so common in Britain, and the so-called *P. Inca* of D'Orbigny; and I think it would puzzle any one to draw a clear distinction between his *P. Capacii* and our own familiar *P. Longispina*, found everywhere in the Carboniferous Limestone. The *Spirifer Condor* has certainly rougher ribs than the ordinary varieties of *Spirifer striatus*, and may be distinct. We figure (Pl. IV. fig. 3) one remarkable form, said to be from Santa Cruz, but, at all events, from the Carboniferous Limestone of the Andes, of which less perfect specimens occur in Mr. Forbes's collection. It is a beautiful species of the *Orthis resupinata* group, and has received the absurd name of *O. Andii* from D'Orbigny.

Our figure of the *Rhynchonella* (Pl. IV. fig. 5) is also from this collection, which was sent home by Col. Lloyd many years back.

DEVONIAN*.

Orthis, sp. Pl. IV. fig. 7.

Internal casts only. It belongs to the group of *Orthis resupinata* and *O. Michelini*, and thus may be either Carboniferous or Devonian.

Locality. Oruro. Sent from thence by Col. Lloyd. (Mus. Practical Geology.)

* Of the seven species considered Devonian by D'Orbigny, only four appear to be *certainly* supra-Silurian; and these four may (from their type) be either Devonian or Carboniferous. They are—*Rhynchonella Peruviana*, *Spirifer Boliviensis*, *S. Quichua*, and *Orthis Inca*. *Spirifer Quichua* is from Chuquisaca, the other three from Cochabamba.

The *Orthis pectinata*, on which D'Orbigny lays stress, seems to me to be very unsatisfactory. It is only the cast of a single valve, without hinge or teeth, of a shell destitute of any marked characteristics. I should not like to speculate as to its age; but M. D'Orbigny may have seen Devonian species like it.

PHACOPS LATIFRONS, Bronn. (*P. Bufo*, Green.) Pl. IV. fig. 8.

In all essential particulars this agrees with the common Devonian species known in Europe under the name *P. latifrons*, and in America by Dr. Green's appellation *P. Bufo*. Comparing it with either Spanish or American specimens, I see no difference, except a somewhat flatter axis, and perhaps one rib fewer in the tail-piece. The group of *Phacops* to which it belongs sometimes occurs in Upper Silurian strata; but this species is nevertheless a most characteristic Devonian form, and has an immense geographical range.

Locality. Near Oruro. In a rolled pebble.

Mr. Pentland found near the town of Aygatchi, Bolivia, another *Phacops*, which, from its type, belongs most certainly to Devonian rocks. It is one of the group *Cryphæus*, distinguished by having the border of the tail spinose; moreover, it is not far removed in affinity from the characteristic *Phacops Caffer* and *P. Africanus* of the Cape of Good Hope. *P.* (*Calymene*) *Verneuilii* of D'Orbigny appears to belong to the same section, and is probably of the same age.

PHACOPS (CRYPHÆUS) PENTLANDII, n. sp. Pl. IV. fig. 9.

Rather more than 2 inches long, and $1\frac{1}{4}$ inch broad, convex, long-ovate, with a subtriangular head; the tail pointed, ribbed throughout, and with a tubercular or subspinose border.

Head $\frac{3}{4}$ inch long, blunt-trigonal; the glabella broad, inflated in front, the forehead-lobe rhomboidal and blunt-pointed, but not overhanging; the facial suture supra-marginal. The margin itself is thin in front, thickened only round the sunken cheeks, and is cut near its (spinose?) posterior angle by the facial suture. Eye prominent, of many moderate-sized lenses, set far forward, but not close to the glabella.

Body-rings (much broken) with the axis very prominent, and with four spines on each ring, besides one *within* the fulcrum on the pleura, and one (or two?) *outside* it; pleural groove deep, broad; ends of pleuræ truncate.

Tail-piece triangular, 6 lines in length, wider than long, with a very convex axis reaching the tip, and marked by six or seven strong rings, the rest indistinct. The sides are about the same width as the axis, with six strong curved ribs (the upper ones duplicate), not furrowing the narrow border, but faintly continued on it into marginal tubercles. Both the lateral ribs and the axis have tubercles on them. The terminal spine, if one existed, is broken off.

There are several Bohemian species of *Phacops* which resemble this in the tubercular ornaments of the body; but none that I know have a tuberculate-spinose border to the tail; and this character, combined with the inflated forehead-lobe, will certainly restrict the fossil to either Upper Silurian or Devonian: it cannot be Carboniferous.

Locality. Aygatchi (*Mr. Pentland*, 1827). It comes, according to that gentleman, from beds of the Carboniferous series; it would ap-

pear from Mr. Forbes's statements, that it could only be from the sandstones at their very base; and I must claim these as Upper Devonian.

FAVOSITES (?), sp. Pl. IV. fig. 10.

I find no pores in any of the tubes (but only some tubercles), and very few traces of tabulæ. Possibly it is not of this genus.

Locality. Given to Mr. Forbes (by Mr. Bogen, of Tacna) as having been found near Oruro.

UPPER SILURIAN.

All the thick beds of sandstone, intercalated with many layers of sandy shale, appear to lie in the upper part, or middle part at least, of Mr. Forbes's Silurian section; and in these the chief part of his fossils were found. The lower beds (chiefly shale and thin sandstones) contain the *Bilobites* (or *Cruziana*) and very little else; and, seeing that his sections gave a measured thickness of at least 15,000 feet (all of which, as he judges by the mineral aspect, belongs to one and the same series), there is much reason for supposing the lower part to be of Lower Silurian date. This is borne out by the presence of the *Bilobites*, which, as above noted, is chiefly a Lower Silurian type.

D'Orbigny has figured a Graptolite, with one row of cells, from South America; and this alone would prove the presence of Silurian rocks, upper or lower. It is from Tacopaya, Santa Cruz.

HOMALONOTUS LINARES, n. sp. Pl. V. figs. 1 & 2.

Body (?) faintly trilobed (fig. 1 *a*); pygidium (fig. 1 *b*) $1\frac{1}{4}$ inch long, and about as broad, triangular, regularly convex, with the sides not abruptly bent down. The axis is but faintly marked, quite as broad as the sides, and scored by about sixteen rings; the sides show nearly as many furrows, none of which reach the margin. The apex is pointed, the tail gradually tapering to it, not abruptly acuminate. The sides (apparently from fig. 1 *b*) are bent inwards beneath; and the apex also shows some indications of a broadish triangular space. The whole surface appears smooth.

The species is not unlike *H. delphinocephalus*, Murch., but has many more ribs, and a longer axis.

Locality. From the highest point reached by its discoverer: he found it on the all but inaccessible face of Mount Illampu, at the height of 20,000 feet. Named in honour of his Excellency the President of Bolivia.

HOMALONOTUS, sp. Pl. V. fig. 3.

Not perfect enough to describe. It has a blunt rounded shape, like that of *H. obtusus*, Sandberger, and several other German and French species from Devonian rocks. The axis is more strongly ribbed than the sides, and the surface is roughly granular.

Locality. From the same mountain as above, at a somewhat lower level (about 15,000 feet).

Proetus, sp. (a fragment). Such fragments are common both in Upper Silurian and Devonian rocks.

Locality. Same mountain (16,000 feet).

[Beyrichia Forbesii, Jones, n. sp. Pl. IV. fig. 13 *a*, *b*, *c*, nat. size and magnified.

Carapace-valves oblong-ovate; straight on the dorsal and obliquely curved on the ventral edge; obtusely tapering at one end, obliquely truncate at the other; bordered below and at the ends with a slight rim: surface raised into four, equidistant, unequal, transverse, rounded ridges; the one next to the narrow end of the valve lowest and shortest, the next one highest and longest of all.

This is nearly allied to *Beyrichia Bussacensis* from the Lower Silurian rocks of Portugal (Quart. Journ. Geol. Soc. vol. ix. pp. 141, 160, pl. 7. figs. 5 & 6); but it is narrower, and its ridges are differently proportioned. It also approaches in form to the figure of a *Beyrichia* that has been published (without description) by Prof E. Emmons among some Silurian Fossils of North America in his 'Manual of Geology,' 2nd edit. 1860, p. 100, fig. 90.

This little fossil is seen in some numbers (together with *Tentaculites*) on a small piece of dark-grey calcareous schist from the western slope of Illampu in the Bolivian Andes. It is dedicated to its adventurous discoverer, Mr. David Forbes.—T. R. J.]

Tentaculites supremus, n. sp. Pl. IV. fig. 11.

Nearly an inch long, diameter 2 lines, cylindrical, slowly tapering until near the apex; marked at intervals of about a line by cord-like ridges, strongly projecting, and often in pairs. Between these are close concentric annuli, or fine ridges, about thirteen in the space of a line.

The strong double ridges which ornament this species occur chiefly on specimens which have the rings more distant than others. They remind one much of the *Tentaculites* in the Wenlock strata of the Isle of Gothland. I believe this species to be a new one; it is a good deal like *T. ornatus*, Sow.

Locality. On the snowy ridge of Illampu, in company with *Homalonotus Linares*. A *Ctenodonta* and a Cup-coral are found with them.

Tentaculites Saienzii, n. sp. Pl. IV. fig. 12.

Tapering more rapidly than the last, and marked by numerous equidistant rounded rings [with no intermediate annuli?]. The want of annular striæ may be only a comparative character; but the regularity of the somewhat oblique rings seems to be specific.

Locality. It occurs in the grey shaly beds between the grits of Illampu, and is dedicated (by Mr. Forbes's request) to Señor Saienz, whose kind and efficient help was of great service to him in his explorations.

Smaller *Tentaculites* (fig. 13 *a*) occur in some of the slabs with the

Beyrichia above noticed; but they are probably the young of one of the foregoing species.

In Europe the strata in which *Tentaculites* are conspicuous are—Caradoc Sandstone, Llandovery rock, and Lower Devonian. In North America (New York) they appear to be more specially confined to the Devonian strata. They are known all over the world in Palæozoic rocks.

Burrows and Casts of Marine Worms.

Such impressions as these attract the attention of every close observer. The peculiar habits of marine worms, introducing, as they do, the sabulous matter from one stratum into the more clayey beds of another, have a special tendency to render the rock compact and tough-bedded. Mr. Forbes found the worm-markings of all sizes, both in the upper and lower beds of the Silurian rocks, and either as double burrows, single vermicular casts, or in groups, just as we find them in our own Ludlow, Devonian, and Carboniferous strata.

ORTHIS AYMARA, n. sp. Pl. IV. fig. 14.

Variety (?) of *Atrypa palmata*, Morris and Sharpe, Quart. Journ. Geol. Soc. vol. ii. pl. 10. fig. 3: *Orthis palmata*, Sharpe, Trans. Geol. Soc. 2 ser. vol. vii. p. 207.

Circular, or only slightly transverse, strongly ribbed, with a very short, almost obsolete hinge-line; ventral valve convex, gibbous near the beak, with a depressed central rib near the margin; upper or dorsal valve flat, with two slightly raised ribs in the middle; ribs about 14, acute, no intermediate ones. Diameter about half an inch.

The above may stand as the obvious characters of this abundant species. As distinguished from the common southern form above quoted, the size is less, and the ribs not quite so prominent; but the chief difference is in the interior, which shows (in *O. palmata*) very strong dorsal teeth, and the ventral hinge-plates thick and short. Ours has but thin plates, and moderate-sized teeth.

I hardly see sufficient reason for considering *O. Aymara* a distinct form. It is very similar to the common African species above quoted, which also occurs at the Falkland Islands. The same fossil appears also to be frequent in the Lower Devonian rocks of Gaspé, Canada. But these localities being all Devonian, one is scarcely justified in uniting with these the Silurian shell from the Andes, if there be any structural differences. *Orthis palmata* is evidently a common shell; and such species have, as Edw. Forbes first showed, a wide range in time as well as geographically: *Atrypa reticularis* is a case in point, ranging, as it does, from the Middle Silurian to the Upper Devonian, and as a frequent shell throughout. The *O. Aymara* may, very probably, when we have more specimens, turn out to be the Silurian variety of a shell which attained a fuller development in Devonian times as *O. palmata*.

Localities. Valley of Millepaya, and other localities on the western side of the Andes.

[The Aymara Indians are supposed to have been the original inhabitants of these mountains. They still linger there, having never been completely conquered, and never having amalgamated with the Quichua or Inca race.—D. F.]

ORTHIS, sp. Pl. IV. figs. 15 & 16.

A small *Orthis*, which may be equally compared with varieties of the *O. elegantula*, Dalm., or with the Devonian forms, *O. opercularis*, &c., from the Eifel. The striæ seem to be pretty regularly interlined with smaller ones. In the absence of more perfect specimens, I do not give it a name. It is certainly not a young specimen of the *O. Humboldtii* of D'Orbigny.

Locality. Valley of Millepaya, and further south on the western slope of Illampu.

STROPHOMENA, sp.

A mere fragment or two of a small thin-shelled species, with fine radiating striæ.

Locality. Cotaña, about five miles south of the town of Sorata.

CUCULLELLA, sp. Pl. IV. fig. 17.

The transverse, oval and convex form of this shell reminds us of *C. ovata*, Sow., rather than *C. antiqua* of the same author. Both are Ludlow Rock species: but there are Lower Devonian forms very like them both in Britain and South Africa. The muscular plate extends, vertically, two-thirds across the shell.

Locality. West face of Illampu.

CTENODONTA (NUCULA), sp. Pl. IV. fig. 18.

This is figured, because it is rather common. Such transverse forms, concentrically striate, and a little antiquated in the lines of growth, are known in all Palæozoic formations.

Locality. Valley of Millepaya; also further south, on the western slope of Illampu.

ARCA ? BROWNII, sp. Pl. IV. figs. 19 & 20.

Broad-oval, more than $2\frac{1}{2}$ inches wide, and $1\frac{3}{4}$ deep; the beak at the anterior fourth not very prominent, the hinge-line tolerably straight, not curved down. The posterior side is nearly as broad as the depth of the shell beneath the beak, slightly angulated along the posterior slope, and rounded at the posterior angle. The anterior side is somewhat produced, and straight along its hinge-margin. Surface marked by rather distant lines of growth, and covered all over the central parts of the disk by fine radiating striæ, sharply impressed, very unequal in size and depth, wavy in their course to the margin, and interlined by lesser ones. They are altogether absent on the anterior and posterior fourth. On our large specimen this effacement of the striæ is gradual; but in some others it is sudden, and the central striated area in these specimens is sunk below the general surface. These may be of a distinct species.

Fig. 20 represents a young specimen. The outline is much more rounded, however, if that be not due to pressure; and the duplicated striæ cover all the surface.

Locality. West slope of Illampu. [Fieldmarshal Brown, a well-known general of the War of Independence, and after whom this shell is named, showed much interest in these researches, and was of great assistance to the author of the foregoing memoir.—D. F.]

BELLEROPHON, sp.

About 1 inch wide, having a large body-whorl, a small spire, and the whorls not at all involute; umbilicus quite open, and the whorls sloping towards it. Striæ of growth arched backwards to the carinate margin, which, however, is obtuse, not sharp-edged.

Locality. Common enough in some hand-specimens from the west side of Illampu.

PATELLA or PILEOPSIS ?

An extraordinary specimen of a subovate clypeiform shell, an inch and a half in its largest diameter, and rather more than an inch wide, has an excentric blunt umbo, and a rather wavy margin. The surface is covered with close concentric ridges, which show equally well on the external and internal cast. The general appearance is that of an oblique *Patella*, or rather one of the *Calyptræidæ*. But it is too imperfect to decide upon. Patelliform shells are known in the Silurian, but they are very rare.

Locality. West side of the Valley of Millepaya.

LOWER ? SILURIAN.

CRUZIANA, D'Orbigny.

It seems hardly worth while to separate these obscure fossils into several genera while we know so little of them; but certainly they cannot all belong to one group. The distinctly grooved and bilobed form, which induced M. Cordier to apply the name *Bilobites* to them, is characteristic of the species described by D'Orbigny, and of some others found in N. America. The more elongate strap-shaped species found in Europe have already received names from M. Rouault in his memoirs on the Silurian Rocks of France. And the species here figured belong to such various plans of form that, if we only knew a little of the nature of the bodies in question, we should be bound to give them separate names; at present I only propose one for the sagittate forms—*Boliviana*. Mr. Forbes did not meet with either of D'Orbigny's species, which, from that author's description, came from Lower Silurian beds*. Those here described are also the lowest fossils in the section.

* "C'est le premier corps organisé qui se montre au-dessus des phyllades schistoïdes, dans les phyllades micacés brunâtres."—Voyage, &c. vol. iii. part 4 (Paléontologie), p. 31. Mr. Forbes thinks, however, that there is no evidence of their being so low in the series.

CRUZIANA CUCURBITA, n. sp. Pl. V. figs. 4, 5, & 6.

Three inches long, elongate, clavate, curved into a shape more or less sigmoid, subcylindrical in section, compressed; rounded at the anterior end, tapering posteriorly; smooth, except a few irregular wrinkles, but with a raised longitudinal rib throughout (down each side?).

I am not sure whether the raised rib which runs from end to end of these shapeless masses is an external marking, or arises from an internal hard cylinder. Fig. 6 shows some irregular transverse wrinkles; but, except these, there is no marking whatever to distinguish this form, which may be recognized by its blunt clavate shape, like many of the gourd-fruits, whence the name.

Locality. Very plentiful on the surfaces of grey schist. Valleys of Unduavi and Aceromarka.

CRUZIANA UNDUAVI, n. sp. Pl. V. figs. 7 & 8.

Three or four inches long, subcylindrical, but often flexuous, slowly tapering. Surface marked with numerous (9 or 10) longitudinal ribs, which run for short distances only, and alternate, leaving some parts smooth. The general direction of the ribs is longitudinal, but wavy.

Localities. Valleys of Aceromarka and Unduavi, where it is most abundant.

BOLIVIANA, gen. nov.

Form obcordate or sagittate, tuberculate or ridged, without a central furrow, and produced behind into two barbs or wing-like appendages. (A peduncle or stem occurs in some species.)

These broad arrow-shaped forms differ so much from the true *Cruziana*, that it does not seem premature to separate them. (I leave the elongate forms at present all in one genus.) And the general term *Bilobites* may still be conveniently used for the whole group, though not now accepted as a generic term.

BOLIVIANA MELOCACTUS. Pl. V. fig. 9.

Three-quarters of an inch long, obcordate, deeply notched behind, and pointed and produced backward on each side. Surface gently convex, rising into a ridge along the median line, which projects a little in the middle of the deeply emarginate posterior edge. Six longitudinal ridges, narrower than the central one, run along the whole length, with irregular tubercles on them, arranged so as to form tranverse rows, seven or eight on each side.

A rough resemblance to the mammillated plants so common in the region of the Andes suggests the name.

Locality. Valley of Aceromarka, north-eastern slope of Illimani.

BOLIVIANA PROBOSCIDEA. Pl. V. fig. 10.

This appears to be only about half of the disk, and it is therefore described as if the longitudinal ridge (*a*) were central. An inch and a half long, narrow-sagittate, lanceolate, convex; with a very

prominent central ridge, produced behind into a thick blunt spine. Posterior edge doubly emarginate, but with the angles scarcely at all produced. Six longitudinal ribs on each side of the central one, all closely tuberculate, so as to form transverse rows.

The projecting mass is supposed to be the stem, and is nearly as long as the frond, very thick, obtuse, attached to the posterior margin, and shaped like the siphon-sheath of a bivalve shell.

Locality. Valley of Aceromarka.

BOLIVIANA BIPENNIS. Pl. V. fig. 11.

Mr. Forbes observed the other part of this specimen in the rock, but could only detach one half. The outline is therefore added to our figure.

Frond semioval, emarginate behind, gibbous at the sides, and with the posterior angles produced into strong divergent tapering spines. Surface marked by ridges and furrows parallel to the curve of the front and back margins. Spines also furrowed near the base. Stem (apparently attached) long filiform.

Locality. Valley of Unduavi, eastern slope of the Andes.

Summary.

The number of species that we recognize in this collection, made with so much perseverance and at great personal hazard, are—

5 Lower? Silurian (Bilobite-schists).
14 Upper Silurian (grey sandy schists and sandstones).
3 Devonian.
13 Carboniferous.

D'Orbigny's collection of Silurian fossils contained 10 species, of which none have occurred to Mr. Forbes. They are—

Cruziana rugosa.
—— furcifera.
Orthis Humboldtii.
Lingula marginata.
—— Muensterii.
—— dubia.
Graptolites dentatus.
Phacops (Calymene) Verneuilii.
—— (C.) macrophthalma?
Asaphus Boliviensis.

There is some doubt about both his species of Phacops. They are probably Devonian.

Adding these to our list, we obtain 27 or 29 Silurian species for the Central Andes, belonging to a fauna specifically different from that of any other quarter of the world. I venture without hesitation to assert that the identifications by D'Orbigny with European forms, where I am acquainted with the species, are wrong. I am obliged to say this much, since that distinguished author has fearlessly united things which differ by the most obvious external characters, and has lent the sanction of his great reputation, on such evidence as this, to a former community of species, and an equable diffusion of heat. In regard to the Carboniferous forms, where M. D'Orbigny is unwilling to allow more than a close analogy between the two continents, I am again compelled to differ from him, but it is in an opposite direction.

EXPLANATION OF PLATES IV. & V.

Illustrating Mr. Salter's paper on some Palæozoic Fossils from the Bolivian Andes.

PLATE IV.

Fig. 1. Productus semireticulatus, *Martin*. Isthmus of Copacabana.
2. P. Longispina, *Sow.* Isthmus of Copacabana.
3. Orthis Andii, *D'Orb.* Santa Cruz.
4. Athyris subtilita, *Hall.* Isthmus of Copacabana.
5. Rhynchonella, sp. Santa Cruz.
6. Bellerophon; like *B. Urii*, Fleming. Isthmus of Copacabana.
7. Orthis, sp. Oruro.
8. Phacops latifrons, *Bronn.* Oruro.
9. Ph. Pentlandii, *Salter.* Aygatchi.
10. Favosites (?), sp. Oruro.
11. Tentaculites supremus, *Salter.*
12. T. Saienzii, *Salter.*
13 *a*. Tentaculites, sp., and Beyrichia Forbesii, *Jones.* } Illampu.
13 *b* & 13 *c*. Beyrichia Forbesii, *Jones.*
14. Orthis Aymara, *Salter.* } Valley of Millepaya.
15, 16. Orthis, sp.
17. Cucullella, sp. Illampu.
18. Ctenodonta (Nucula), sp. Valley of Millepaya.
19. Arca (?) Brownii, *Salter.* Fig. 20. Young specimen. Illampu.

PLATE V.

Fig. 1 & 2. Homalonotus Linares, *Salter.* } Illampu.
3. Homalonotus, sp.
4, 5, & 6. Cruziana Cucurbita, *Salter.*
7 & 8. C. Unduavi, *Salter.*
9. Boliviana Melocactus, *Salter.* } Valleys of Aceromarka and Unduavi.
10. B. proboscidea, *Salter.*
11. B. bipennis, *Salter.*

On a NEW SPECIES *of* MACRAUCHENIA (M. Boliviensis). By THOMAS H. HUXLEY, F.R.S., Sec. G.S., Professor of Natural History, Government School of Mines.

[PLATE VI.]

THE vertebrate remains obtained by David Forbes, Esq., F.R.S., F.G.S., from the mines at Corocoro, under the circumstances detailed in his paper "On the Geology of Bolivia and Southern Peru," consist of the following parts of the skeleton of apparently one and the same Mammal:—1. A portion of the right maxilla and palate, with fragments of grinding teeth. 2. Rather more than the right half of the occipital portion of the skull. 3. A middle cervical vertebra, nearly entire. 4. A fragment of a posterior lumbar vertebra. 5. A small portion of a right scapula. 6. A crushed fragment of the proximal end of an ulna. 7. Part of the proximal end of the left tibia. 8. The entire left astragalus, and part of the right astragalus.

The bones are all in the same, and that a very peculiar, mineral condition—the Haversian canals being for the most part filled up with threads of native copper; so that the fossils are not only exceedingly dense, but, in consequence of their internal flexible metallic support, their thinner and more delicate parts bend, rather than break, when force is applied to them.

The characters of the cervical vertebra and of the astragalus, which are fortunately the best-preserved of all the fossils, at once demonstrated the remains to belong to the genus *Macrauchenia* (Owen), while the entire absence of epiphysial sutures in the vertebræ and the long bones, and of similar indications of immaturity in the fragment of the skull, proved the animal to have attained its adult condition. The vertebra and the astragalus, however, have not more than half the size of the corresponding bones of the species, *M. Patachonica*, discovered by Mr. Darwin, and described by Professor Owen in the 'Appendix to the Voyage of the Beagle'; and as, in addition, these and the other bones present different proportions from those of the Patagonian species, I have no hesitation in regarding the fossils collected by Mr. Forbes as the remains of a distinct species, for which I propose the name of *Macrauchenia Boliviensis*. It will be convenient to commence the description of these fossils with those parts upon which the diagnosis of the species may be most safely rested, viz. the cervical vertebra and the astragalus.

The cervical vertebra (Plate VI. fig. 1).—The great length of the centrum of this vertebra, the peculiar form of its transverse processes, and the absence of perforations for the vertebral arteries in them are characters which, in the present state of knowledge, oblige the anatomist at once to refer it either to one of the existing *Camelidæ* or to the genus *Macrauchenia*; while the two strong, converging ridges which mark the posterior half of the under surface of the vertebra, and meet to form a single ridge, which dies away anteriorly in the middle of that surface, together with the slight concavity of both the posterior and the anterior articular faces of the centrum, are decisive in favour of the latter alternative. In fact, the excellent description of the cervical vertebræ of *Macrauchenia Patachonica* which has been given by Professor Owen applies so well to that of *M. Boliviensis*, that, referring to the paper in the 'Appendix to the Voyage of the Beagle,' already cited, for a general account of the characters of Macrauchenian vertebræ, I shall content myself with pointing out the resemblances and differences of the Bolivian from the Patagonian *Macrauchenia*, and from the existing *Auchenieæ*. The dimensions of the centrum of the cervical vertebræ of the two *Macrauchenieæ*, and of the fourth cervical of a Guanaco and of a Vicugna in the College of Surgeons' Museum are as follows:—

	M. Boliviensis.	*M. Patachonica.*	*Guanaco.*	*Vicugna.*
	in.	in.	in.	in.
Length.....	3·8	6·6	4·6	4·0
Width of anterior face	1·1	3·2	1·1	·8
Width of posterior face	1·25	3·4	1·3	1·0

Thus it appears that the centrum of the cervical vertebra of *Macrauchenia Boliviensis* is far more slender than that of *M. Patachonica*; for, while the length of the former is to that of the latter as 1 : $1\frac{7}{8}$, the transverse diameters of the anterior faces of the centra of the two species are, nearly, as 1:3. The cervical vertebra of the new species is, absolutely, rather shorter than the fourth cervical of tho Vicugna; but, relatively to its width, it is much shorter and stouter than this bone in either the Guanaco or the Vicugna. There are no longitudinal ridges on the surface of the vertebra below the prezygapophyses, in which respect *M. Boliviensis* differs from *M. Patachonica*, and approaches the *Auchenieæ*. The anterior articular facet of the centrum is concave from above downwards, in consequence of the projection of the thickened and convex lower third of that face; the posterior facet is not only concave from above downwards from a similar cause, but is also concave from side to side. The concavity of both articular facets is greater than in *M. Patachonica*, and the present species departs, in these respects, more widely than the latter does from the *Auchenieæ*.

The astragalus (Plate VI. fig. 2).—This bone is, again, quite that of the Patagonian species in miniature, differing chiefly in the proportions of its dimensions, as shown by the subjoined table:—

	Macrauchenia Boliviensis.	*M. Patachonica.*	*Guanaco.*	*Vicugna.*
	in.	in.	in.	in.
Length	1·45	3·3	1·6	1·3
Greatest width ..	1·2	2·7	1·2	·85
Greatest depth ..	·85	2·15	·95	·8

If we take the lengths of the astragali, it will be observed that their proportions in the Bolivian and Patagonian *Macraucheniæ* are not the same as those of the cervical vertebræ. The astragali bear the ratio of 1 : $2\frac{1}{3}$, while the cervical vertebræ gave 1 : $1\frac{7}{8}$. Furthermore, the proportions of length, width, and depth in the two astragali are different. Like the cervical vertebra, the astragalus of *M. Boliviensis* is a, relatively, stouter bone than that of the Vicugna; though instead of being shorter it is a little longer, occupying a position, in point of absolute length, between the astragalus of the Vicugna and that of the Guanaco. As the astragalus thus yields results agreeing very well with those given by the cervical vertebra, we may safely assume that not only the absolute size, but the proportions of the body of *Macrauchenia Boliviensis* were nearly those of the existing Llamas, and differed widely from those of the heavy and huge *Macrauchenia Patachonica*.

The tibia.—What remains of the bones of the hind leg confirms this view of the proportions of *Macrauchenia Boliviensis*. I have the proximal end of the left tibia, minus the fibula, and with the outer articular condyle broken away. Below this point, the outer edge and surface of the fragment are uninjured, and the posterior face is in good preservation, but the internal face is somewhat crushed. The muscular ridges on the posterior face are as well marked as in the skeleton of the Guanaco, and far more distinct than in that of

the Vicugna, yielding additional evidence of the adult condition of the animal, to that afforded by the absence of epiphyses.

The antero-posterior diameter of the tibia, measured from the posterior edge of the internal articular facet to the anterior edge of the crest of the tibia, is, in—

M. Boliviensis.	*M. Patachonica.*	*Guanaco.*	*Vicugna.*
in.	in.	in.	in.
2·4	5·4	2·3	2·1,

so that the depths of the proximal ends of the tibiæ of the two *Macraucheniæ* have the ratio of 1 $2\frac{1}{4}$, which corresponds very well with the proportions of the astragali, and confirms the conclusions already arrived at, as to the relative lightness of the limbs of this species in comparison with those of *M. Patachonica*, and as to the similarity of the proportions of the Bolivian species to those of the Llamas.

What remains of the outer edge of the tibia is sufficient to prove that the fibula must have remained unanchylosed to the tibia for a much greater distance than in the Patagonian species. From the manner in which the outer tuberosity of the proximal end of the tibia is broken off, I am inclined to suspect that the fibula was anchylosed to it at this point; and perhaps, as in the *Auchenia*, its proximal end was represented only by a bony style.

The scapula is represented merely by a mutilated fragment, comprising the glenoid cavity and the adjacent parts. The spine of the scapula is broken off, and the glenoid cavity is somewhat distorted by the bending of one of its edges; but enough remains to show that the bone must have agreed with the scapula of *Macrauchenia Patachonica* in all essential respects, and that it therefore differed very widely from that of the *Auchenia*. In size, however, it nearly corresponded with the corresponding bone in the latter animal; for the greatest diameter of the glenoid cavity is 1·2 in., the same measurement in the Vicugna being 1·0, and in the Guanaco 1·6.

The ulna.—The fragment of the ulna, consisting of part of the olecranon process and of the sigmoid cavity, is so crushed, that I can only affirm its general agreement in form with that of *Macrauchenia Patachonica*, and in size with the same bone in the Llamas.

The lumbar vertebra.—Of bones referable to this region of the body, again, there is but a single fragment, of value only so far as it confirms the conclusions arrived at by the examination of the more perfect fossils. It corresponds very well with the posterior half of the centrum of the penultimate lumbar vertebra of *M. Patachonica* in form, and with the corresponding vertebra of *Auchenia* in size; but the crest into which the middle of its under surface is raised, and which is still sharper than that in the Patagonian species, diagnosticates it at once from any of the lumbar vertebræ of the Llamas.

The transverse diameter of the articular face is 1·1 in., its vertical diameter 0·9. The corresponding measurements of the antepenultimate lumbar vertebra of *M. Patachonica* are 3·0 in. and 2·1; so

that, as in other bones, the proportions of diverse diameters of the same bone are not the same in the two species. But as the transverse diameters of the cervical vertebræ of the two species are nearly as 1 : 3, and the transverse diameters of the lumbar vertebræ are, also, nearly in the ratio of 1 : 3, it would seem as if the different regions of the vertebral column of the two species exhibited the same proportional correspondence to one another.

The skull.—As no part of the skull of *Macrauchenia Patachonica* has yet been discovered (with perhaps the exception of part of the lower jaw), a great interest attaches to every fragment which promises to throw light upon this part of its organization; and I therefore make no apology for dwelling at some length upon the characters of the two very imperfect and mutilated portions of the cranium which turned up among the specimens submitted to me by Mr. Forbes.

The one of these (Plate VI. fig. 3) consists of rather more than half of the occipital segment of the skull, and exhibits the whole of the supra-occipital bone, with its strong occipital crest, a part of the parietal with the sagittal crest, the greater part of the right paramastoid process, and the entire right occipital condyle.

As I have already remarked, the sutures are obliterated: and this is true, not only of those which ordinarily exist between the elements of the occipital bone in young mammals, but of the lambdoidal suture, which usually persists for a longer period. The occipital foramen must, when entire, have had a depressed-oval form, the short, vertical axis of the oval being about 0·6 of an inch long. The face of the bone above it inclines upwards and forwards, at an angle of about 50° with the base of the skull, and presents a sharp ridge in the middle line, on either side of which the surface of the supra-occipital element slopes with a slight convexity outwards and forwards, at the sides and below; while, above, it becomes concave by passing almost vertically upwards in the middle line, and laterally, bending upwards and backwards at a right angle with its previous inclination into the occipital crest.

This crest is nearly 0·2 inch thick at the sides, and becomes still thicker in the middle line, where it joins the sagittal crest. It is 1·1 inch in diameter at its widest part, and about half an inch high. Its contour is that of a parallelogram, with its angles rounded off, and the middle of its upper side rather truncated. The lateral portions project backwards rather more than its centre; so that, while, supposing the basi-occipital to be horizontal, a vertical line drawn through the posterior edge of that bone would nearly coincide with the contour of its central part, it would pass a little anterior to the plane of the lateral extremities of the crest. Inferiorly, the thick lateral portions of the crest divide into two ridges; the posterior of which turns slightly inwards and comes to an end, while the anterior, much sharper at its edge, passes forwards and outwards, and becomes continuous with the sharp ridge in which the paramastoid process terminates externally.

Behind this ridge, between the paramastoid process, the occipital condyle, and the lateral convexity of that part of the occipital bone which lies above the foramen magnum, there is a deep fossa, which is

divided into two portions by a transverse ridge, extending from the outer and upper part of the condyle to the posterior and inner face of the paramastoid process. The large precondyloid foramen (probably somewhat enlarged accidentally) opens into the lower and anterior division of the fossa, beside the condyle, and about $\frac{1}{6}$th of an inch behind its anterior inferior boundary. The upper boundary of the foramen magnum is almost straight, and its summit is below the level of the superior edge of the condyle (when the base of the skull is horizontal). The condyle is divisible into an upper, smaller, obliquely ascending, and a lower, more nearly horizontal facet. The line of junction between the two, forming the posterior limit of the condyle, is rounded off and is directed obliquely outwards and upwards. The moderately convex upper facet looks upwards, backwards, and but very slightly outwards. It is broad above, where its transverse diameter amounts to nearly half an inch, and tapers off gradually to a point below and internally.

The inferior facet, less curved than the other, is 0·6 of an inch wide behind, hardly more than half that in front, and fully 0·8 of an inch long. It is slightly convex from side to side, and from behind forwards, posteriorly, where it looks downwards and outwards; convex from side to side, and slightly concave from behind forwards, in front, where it is directed more horizontally downwards. Its anterior narrow end has a sharply defined rounded margin, which can be traced to the anterior boundary of the occipital foramen; so that the occipital condyles certainly did not coalesce in the middle line.

The paramastoid process is broken off rather above the level of the lower boundary of the occipital condyle; but, from the thinness of the fractured edge, I imagine it did not extend much further. It is broad and flattened, the direction of its greatest diameter being from behind and without, inwards and forwards. Its posterior face is directed as much inwards as backwards, and its outer margin is sharp, except towards the lower end, where it becomes rounded. Internally, it thickens before rejoining the exoccipital, in front of, and external to, the precondyloid foramen. The upper part of its anterior and external face is evidently rough and has united with the mastoid, now completely broken away; but it is difficult to say how far downwards the sutural face extended. The posterior boundary of the jugular foramen is preserved on the inner side, and in front of, the thick inner edge of the paramastoid.

The sagittal crest is continued forwards from the triangular prominence common to it and the occipital crest, and at once becomes very thin and sharp. It is broken off at a very short distance from its commencement, and at this point it is a quarter of an inch high. Its superior margin is not parallel with the contour of the middle line of the parietal region, but has a more marked upward inclination, so as to lead one to suppose that the crest rose to a considerable height in the middle of the synciput,—a conclusion which is strengthened by the great thickness of the parietals (of whose median suture no trace is visible) in the middle line. The transverse section presented by the anterior broken edges of these bones is, in fact, triangular,

and the height of the triangle from its apex, which corresponds with the base of the crest, to its base (the concave inner wall of the cranium) is nearly 0·4 of an inch.

In viewing the fragment of the occiput from within, one is surprised by the great thickness of the supra-occipital region, the bone immediately above the middle of the occipital foramen being half an inch thick. A well-marked ridge, defining the interior boundary of the cerebellar fossa, is continued downwards, forwards, and outwards, from the anterior boundary of the thick roof of the occipital foramen. There is no venous canal traceable above the inner aperture of the precondyloid foramen.

If the occiput of *Macrauchenia Boliviensis* be restored by reversing the outlines of the right half (as in Pl. VI. fig. 3), thus supplying the wanting left moiety, the following measurements may be obtained. Side by side with them I give the corresponding measurements of the skull of the Vicugna:—

	M. Boliviensis.	*Vicugna.*
	in.	in.
Transverse diameter of the occiput from the outer edge of one paramastoid to that of the other	1·9	2·25
Ditto from the outer edge of one occipital condyle to that of the other.	1·5	1·5
The transverse diameter of the occipital foramen.....	·7	·7

It will be observed that the two series of dimensions correspond very closely, the two latter being identical, while the *Macrauchenia* appears to have had even a narrower skull than the Vicugna. In form, the occiput of *Macrauchenia* agrees better with that of the Llamas than with that of any other ungulate animal with which I have compared it.

Thus, in an old Guanaco I find an equally well-marked ridge in the middle line of the supra-occipital element; the occipital crest is equally prominent, though not so stout; the sagittal crest is as well marked, thin and sharp, and, as in *Macrauchenia*, its superior edge ascends. There is a fossa between the occipital condyle and the paramastoid, similar in form to that in *Macrauchenia*, though much shallower. The occipital condyles are very much alike; and their relation to the precondyloid foramina is the same in both cases. The paramastoid has the same proportional breadth; and its greatest diameter is, in both cases, directed from without and behind, inwards and forwards: in both cases its inner edge is peculiarly thickened. Again, the paramastoid of the *Auchenia*, like that of the fossil, is very short, its apex hardly extending below the level of the occipital condyle.

The occiput of *Macrauchenia*, on the other hand, differs from that of *Auchenia* in the much greater thickness of the supra-occipital, which in the *Macrauchenia* has fully double the thickness of the same region in an old Guanaco, whose skull is much larger—in this respect approaching the Sheep and some other Ruminants, which have this bone very thick. The supra-occipital, also, is much higher, in proportion to its width, in *Macrauchenia* than in *Auchenia*; its lateral

contours are parallel, and not divergent outwards and upwards. There is nothing in the *Macrauchenia* resembling the deep notch between the supra-occipital and the base of the paramastoid, into which a part of the mastoid fits in *Auchenia*. In contour, in fact, the occiput of the *Macrauchenia* resembles that of the *Palæotherium* more nearly than that of any other Mammal. But, on the whole, I think it must be admitted that the resemblance of the back of the skull of the *Macrauchenia* to that of *Auchenia* is sufficiently close to justify the conclusion, that the predominance of the Cameline type, so marked in the neck, was maintained in the head of the extinct Mammifer.

The fossil which remains for description (Plate VI. fig. 4) consists of two fragments of the matrix (*a* and *b*), which fit together, and to which adhere certain portions of the upper jaw and palate, together with the fractured remains of three grinding-teeth and part of the alveolus of a fourth, all of the right side, and in a continuous series. The alveoli and part of the crowns of these teeth are contained in the larger fragment of matrix,—the smaller fragment fitting against the larger and the teeth which it contains, and exhibiting the impressions of the grinding surfaces of three teeth and of their inner faces, a portion of dental substance adhering to the latter, in the case of the two anterior teeth. Of the hindermost tooth nothing is left but the impression of one fang.

The impression of the grinding surface of the first tooth is nearly four-tenths of an inch long, convex from before backwards, concave internally: the outer boundary of the impression is broken away, a fragment of dental substance adhering to the posterior part of its inner face. The part of the larger portion of the matrix (*a*) which should contain the alveolus of this tooth is absent. The antero-posterior extent of the coronal impression of the second tooth is a little more than 0·4 of an inch; it is concave from before backwards externally, nearly flat internally, and shelves with a slight convexity upwards and inwards. The inner boundary of the impression is, as in the preceding case, markedly concave; and a much larger fragment of tooth-substance adheres to it. The outer boundary of the impression is broken away, but much more in front than behind, where its width is fully 0·4 of an inch. The impressed line which separates this impression from the next is convex forwards. Corresponding with this impression there are, in the larger fragment of matrix, an almost entire conical posterior fang, about 0·4 of an inch long, lodged in a complete bony alveolus, whose outer wall is broken away, and the posterior half of a similar alveolus for an anterior fang: there is no trace of a third alveolus or fang; and, indeed, there seems to be no room for one. The fang which exists is connected below with a portion of the crown; but this is so broken, that all that can be remarked of it is its marked internal convexity.

The coronal impression of the third tooth is half an inch long; like the preceding, its face shelves upwards and inwards. The posterior part of its outer margin is broken away; but it is clear that this crown was quite as wide as that which preceded it, if not wider;

the surface appears, however, to have been more evenly flat. The inner perpendicular face of the impression presents two concavities, separated by a slight ridge.

More of this tooth is preserved than of any other; the outer wall of the maxilla is, for the most part, preserved over it, and encloses the alveoli of two external fangs. There is evidently at least one, and perhaps two, internal fangs. The whole thickness of the inner and posterior part of the crown is preserved, and the posterior and inner half of its worn face; the rest of the tooth is broken away. The posterior and outer fang, partially exposed, is 0·3 of an inch long, conical, and slightly inclined backwards, as well as upwards and inwards. The crown, where it joins the fang, is 0·4 of an inch long; so that it must have widened a little below. The vertical height of the crown of the tooth posteriorly and internally is hardly more than 0·15; anteriorly and internally it is broken; but, when entire, it had a height of at least 0·2. The inner surface of the tooth is divided into two tolerably well-marked subcylindrical faces, which correspond with the impressions on the inner wall of the coronal impressions.

The outer moiety of the crown is altogether broken away; the inner moiety, broken anteriorly, exhibits in its posterior half a smoothly worn facet, concave from before backwards, and inclined not only downwards but slightly backwards. A narrow fringe of enamel appears to surround the worn dentine of this face, which is wider in the middle than at the two ends. The true outer face of the enamel can be traced from the inner face of the tooth, continuously, round the posterior boundary of this worn facet, and as far as its most dilated portion on the inner side. It is concave outwards, and presents a slight inflexion midway between the posterior end of the facet and its middle dilatation. Beyond the dilated middle of the facet, its enamel-wall seems to have been united with that of the opposite half of the tooth; but it is traceable forwards, becoming concave externally, past the anterior end of the worn facet, to the anterior margin of the tooth, where it bends round and again becomes continuous with the enamel of the inner face.

This tooth, therefore, appears to have possessed an internal division, elongated from before backwards, surrounded by a narrow band of enamel,—having its inner contour produced into two convexities, separated by a slight vertical depression, while its outer wall presents two concavities, separated by a slight ridge which lies rather behind the level of the depression on the inner face. By use, the posterior part of this division wore down into a facet, concave from before backwards, and separated, by a transverse ridge, from the facet in front of it. A longitudinal fossa separated the posterior moiety, at least, of this division of the tooth from the outer division.

Imperfect as is this fragmentary grinder, certain important conclusions may, I conceive, be very safely drawn from its structure. The predominance of the longitudinal, to the exclusion of transverse valleys and ridges in the crown of the tooth, the distinct, though not strongly marked, crescentic form of the internal division of the tooth, and its short crown, remove it from the teeth of any known

Perissodactyle Mammal, and lead one, at once, to seek its analogue among the *Artiodactyla*; and of these the Ruminants alone, so far as I know, offer anything like it. The inner grinding-surface of any true molar of a Ruminant, however, exhibits two ridges and three depressions; while that of the *Macrauchenia* has only one ridge, with a concave shelving depression behind, and doubtless, in the perfect condition, another in front; in other words, it has the contour exhibited by one of the hinder premolars of a Ruminant. The inner division of a posterior premolar of *Auchenia* has its convex inner surface undivided by any vertical depression; and its outer, posterior margin exhibits no marked inflexion: but such an inflexion exists in the corresponding teeth of the Giraffe and of many Deer, in some of which latter a vertical groove, dividing the inner face into two convexities, may also be noted.

I am of opinion, therefore, that the tooth in question is a posterior premolar, and that it was constructed upon the Ruminant type. In this case, however, the dentition of *Macrauchenia* must have departed widely from that of the *Camelidæ*; for there were certainly two teeth with flat grinding crowns in front of that just described, which would give, at least, three premolars in all, or as many as are found in ordinary Ruminants.

I am strengthened in the conviction that there were as many as three premolars, by the rest of the structure of this interesting fragment. Within the series of teeth just described, in fact, it presents a considerable portion of the roof of the palate, some of whose bony matter remains. At a distance of half an inch from the inner wall of the posterior premolar, a longitudinal sutural line traverses the whole length of the palatine surface, and ends abruptly (in consequence of the fracture of the matrix) as well behind as in front. Its posterior end is 1·2 of an inch behind a transverse line drawn at the level of the posterior margin of the last premolar. Opposite and behind this tooth, the right half of the palate is marked by what might hastily be taken for a suture, but which is nothing but a fracture. Behind it, and 0·9 of an inch in front of the posterior end of the longitudinal suture, two curved transverse lines, convex forwards, which I believe to be the maxillo-palatine sutures, pass into the longitudinal suture.

Thus, it is clear that the palate must have extended back for 1·2 of an inch behind the third grinding-tooth.

Supposing this tooth to have been succeeded by three others whose length, if they were molars, would be probably between 0·6 and 0·7 of an inch, it follows that the posterior margin of the palate must have extended, at least, as far back as the posterior margin of the second molar. This is further than it extends in the *Auchenia* (the very forward extension of whose palatine aperture is exceptional among the *Artiodactyla*), but it is not so far as in the Camel, where the posterior boundary of the palate is opposite the middle of the last molar*.

* The attempt to differentiate the *Artiodactyla* and *Perissodactyla* absolutely by the position of the posterior margin of the bony palate is fallacious. On an

This backward extension of the palate is, so far as it goes, in favour of the view to which the consideration of the dentition and the structure of the occiput leads, viz. that the cranium of the *Macrauchenia* was constructed upon an essentially Artiodactyle type.

The following are the dimensions of the palate and teeth of *Macrauchenia Boliviensis*, and those of the corresponding parts in the Vicugna:—

		Macrauchenia.	*Vicugna.*
Width of palate inside the grinding teeth*	about	1·0	1·25 (at widest).
Antero-posterior length of four grinders....	more than	2·0	2·2
	less than	2·5	

The narrower palate of the *Macrauchenia* agrees with its narrower occiput, while it exhibits the same general correspondence with the Vicugna as has been met with in the limbs and vertebræ.

Thus I conceive that an attentive examination of these scanty remains is sufficient to prove that, when they were imbedded, there lived in the highlands of Bolivia a species of *Macrauchenia* not half as large as the Patagonian form, and having proportions nearly as slender as those of the Vicugna, with even a lighter head; and it is very interesting to observe that, during that probably post-pleistocene epoch, a small and a large species of more or less Auchenoid Mammal ranged the mountains and the plains of South America respectively, just as at present the small Vicugna is found in the highlands, and the large Guanaco in the plains of the same continent†.

The structure and geological date of the genus *Macrauchenia* may serve, if taken together, to point an important palæontological moral. Professor Owen, in the able memoir cited above, has clearly pointed out the remarkable combination of Artiodactyle and Perissodactyle characters exhibited by *Macrauchenia*, which unites the eminently characteristic cervical vertebræ of the Artiodactyle *Camelidæ* with the three-toed fore foot and the triply trochantered femur of the

average it is doubtless true that the bony palate extends further back in the former than in the latter; but the bony palate extends to a line joining the anterior edges of the last molars in *Hyrax*; while in the full-grown Guanaco, a similar line is 0·4 of an inch behind the posterior boundary of the palate.

* The six grinding-teeth of the lower jaw, which Professor Owen has provisionally referred to *Macrauchenia* (British Association Reports, 1846), are said to form a series 9 inches long. A series of six such teeth of the lower jaw of *Macrauchenia Boliviensis* could not have exceeded 4 inches in length, and was probably shorter. Under these circumstances, the heads (as measured by the teeth) of the two species would be in nearly the same proportion as their astragali, and in very different proportions from their cervical vertebræ. This is not improbable; for the Vicugna has a much lighter head than the Guanaco, if the cervical vertebræ be taken as the standard. The length of the fourth cervical of the Vicugna is to that of the same bone in the Guanaco as 1 : 1⅓, while the length of the head in the two is as 1 : 1½.

† As the Guanaco ranges into the highlands, it may not be a too sanguine expectation to hope for the future discovery of remains of the great *Macrauchenia*, also, in Bolivia.

Perissodactyla; and with an astragalus which, in the apparent entire absence of any facet for the cuboid, is, I may affirm, more Perissodactyle than that of any member of the order, except *Hyrax*.

None of the older Tertiary mammalia can produce such strong claims to be considered an example of what has been termed "a generalized type" as *Macrauchenia*; and yet there seems little doubt that the latter is the South American equivalent, in point of age, of our Irish Elk!

Again. *Macrauchenia*, alone, affords a sufficient refutation of the doctrine, that an extinct animal can be safely and certainly restored if we know a single important bone or tooth. If, up to this time, the cervical vertebræ of *Macrauchenia* only had been known, palæontologists would have been justified by all the canons of comparative anatomy in concluding that the rest of its organization was Camelidan. With our present knowledge (leaving *Macrauchenia* aside), a cervical vertebra with elongated centrum, flattened articular ends, an internal vertebral canal, and imperforate transverse processes, as definitely characterizes one of the Camel tribe as the marsupial bones do a Marsupial,—and, indeed, better; for we know of recent non-marsupial animals with marsupial bones. Had, therefore, a block containing an entire skeleton of *Macrauchenia*, but showing only these portions of one of the cervical vertebræ, been placed before an anatomist, he would have been as fully justified in predicting cannon-bones, bi-trochanterian femora, and astragali with two, subequal, scapho-cuboidal facets, as Cuvier was in reasoning from the inflected angle of the jaw to the marsupial bones of his famous Opossum. But, for all that, our hypothetical anatomist would have been wrong; and, instead of finding what he sought, he would have learned a lesson of caution, of great service to his future progress.

EXPLANATION OF PLATE VI.

Fig. 1. Cervical vertebra of *Macrauchenia Boliviensis*, Huxley; restored from the opposite side, posteriorly.

1 *a*. The same vertebra, viewed from in front.

1 *b*. The same vertebra, viewed from behind.

2. Astragalus (left), from above.

2 *a*. ,, from below.

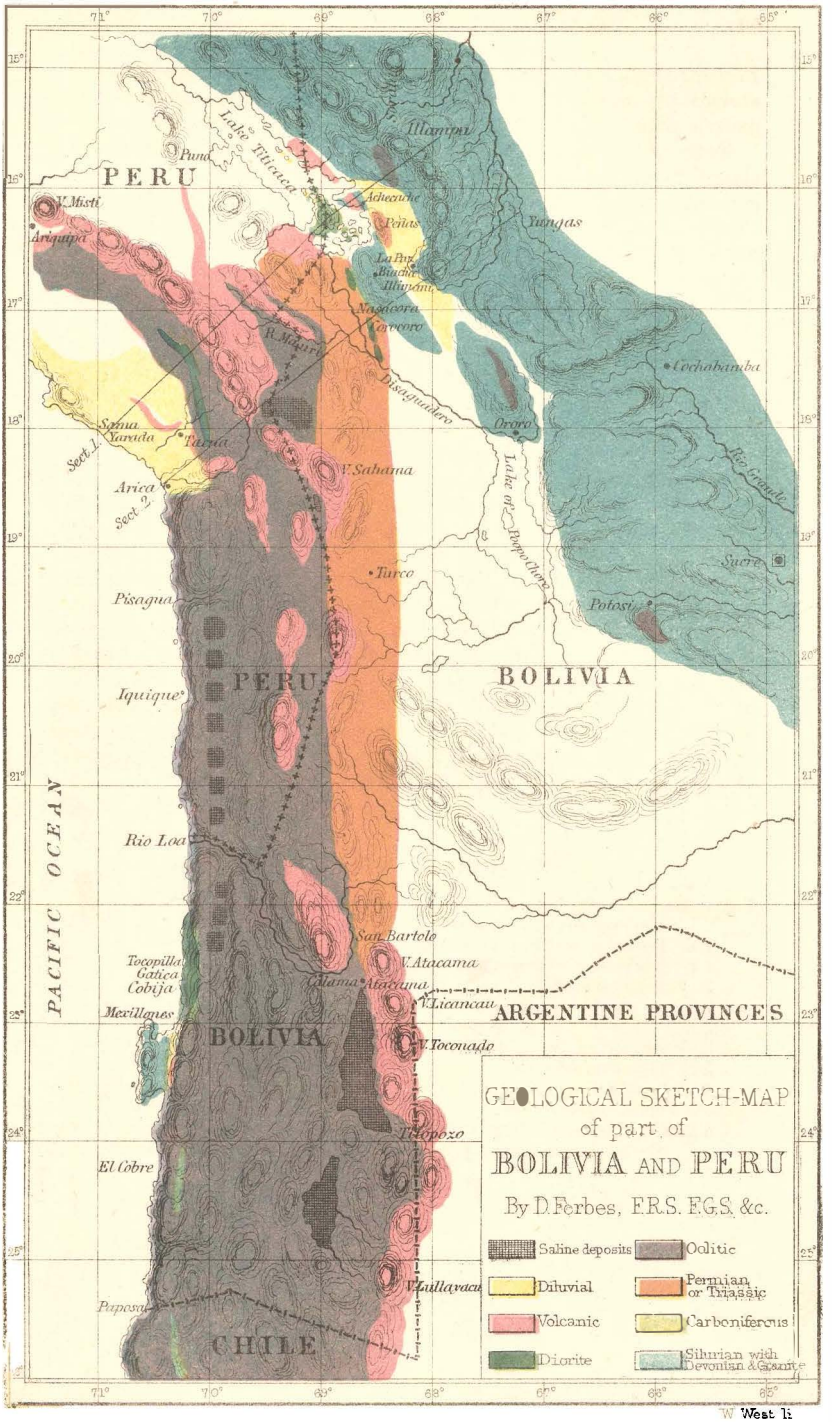
2 *b*. ,, ,, from the outer side.

3. Fragment of the occipital portion of the cranium, restored in outline.

3 *a*. The same fragment, viewed from without and laterally.

4. Part of the upper jaw and palate, and lateral view (*a*) of the crown of the most perfect tooth.

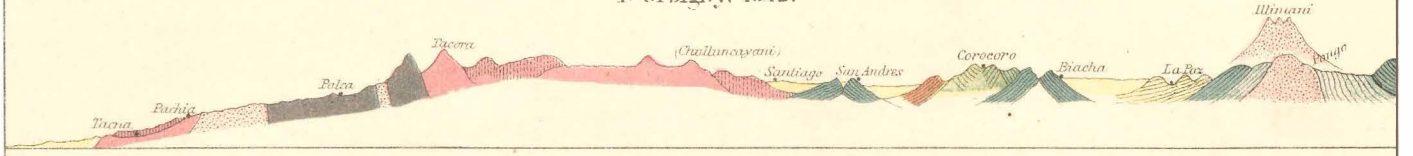
4 *a*. Side-view of the large fragment of the matrix containing the teeth, with the smaller fragment, exhibiting the coronal impressions, adapted to it.


PERU
Lake Titicaca
Illampu
Puno
V. Misti
Arequipa
Achacache
Peñas
Yungas
La Paz
Illimani
Mashcorra
Corocoro
R. Mauri
Cochabamba
Pisagua
Oruro
Sama
Tarapaca
Tacna
Sect. 1
Sect. 2
Arica
V. Sahama
Lake of Pampa Aullagas
Rio Grande
Sucre
Turco
Pisagua
Potosi
PERU
BOLIVIA
Iquique
PACIFIC OCEAN
Rio Loa
San Bartolo
Tocopilla
Cobija
V. Atacama
Calama
Atacama
Mexillones
V. Licancaur
ARGENTINE PROVINCES
BOLIVIA
V. Toconado
Tuyopozo
El Cobre
V. Cullavaca
Paposo
CHILE
GEOLOGICAL SKETCH-MAP
of part of
BOLIVIA AND PERU
By D. Forbes, F.R.S. F.G.S. &c.
Saline deposits
Oolitic
Diluvial
Permian or Triassic
Volcanic
Carboniferous
Diorite
Silurian with Devonian & Granite

W. West li

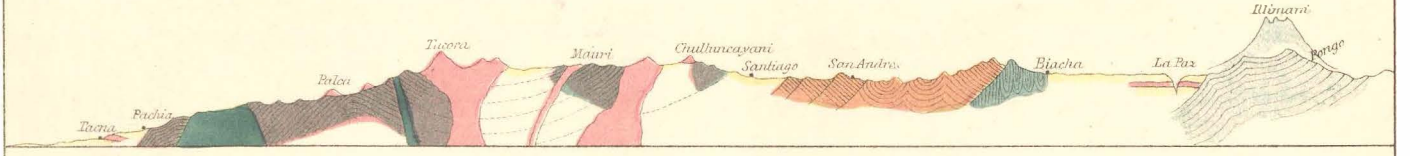
General Section across the Andes of Peru and Bolivia, from the Pacific Ocean N. of Arica to Illimani, as represented by the following authors:–

D'Orbigny, 1842.

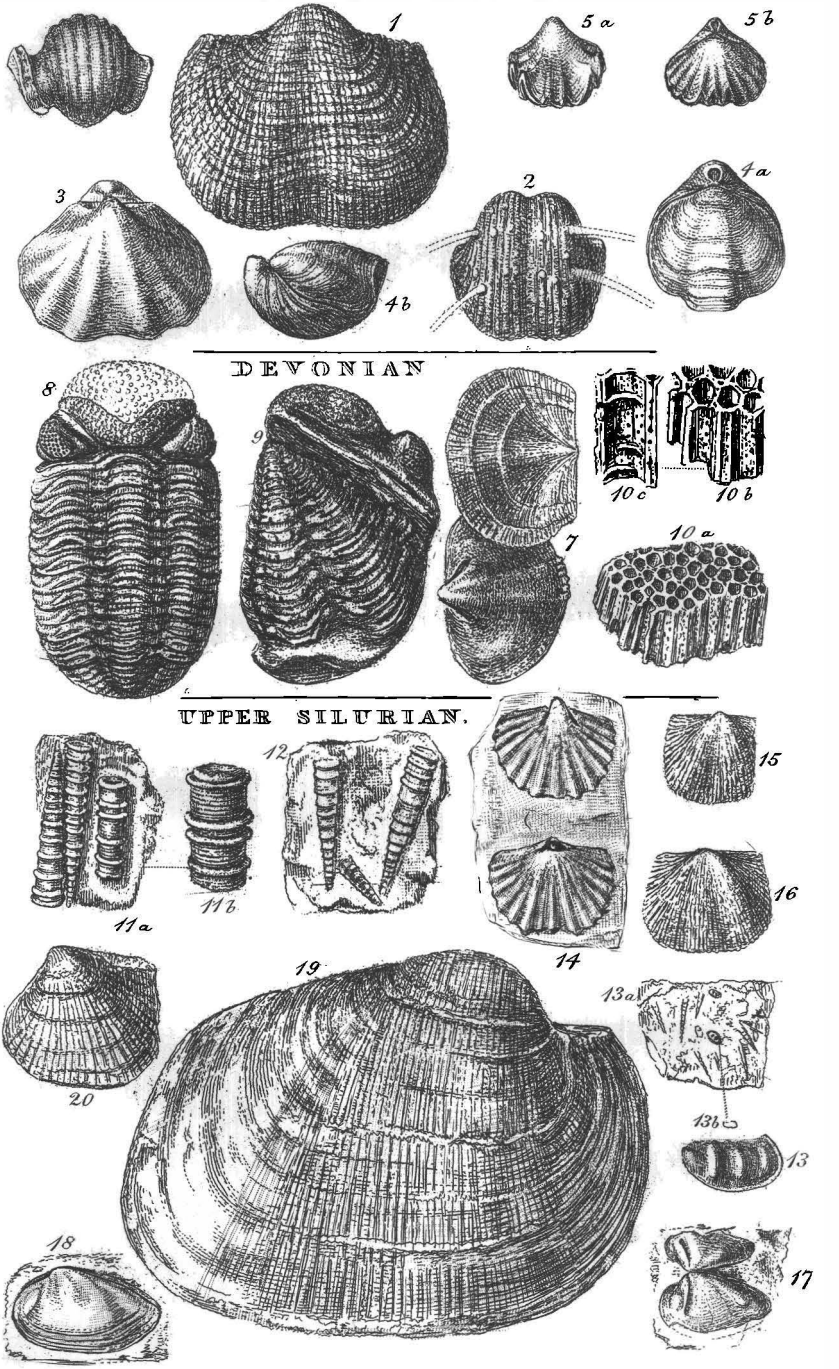


Pissis, 1856.

D. Forbes, 1860.



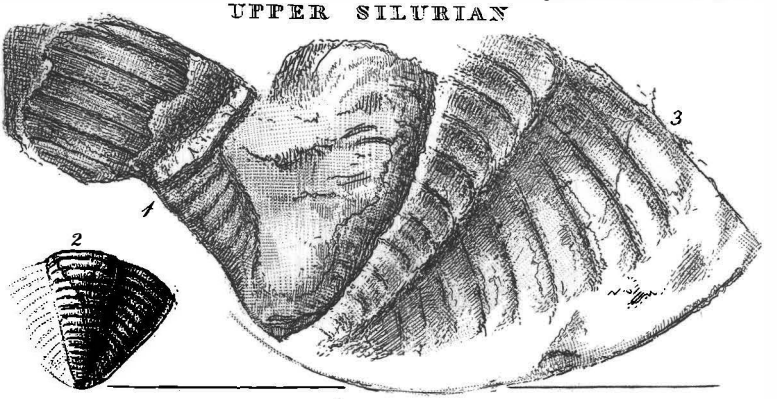
W.West lith.



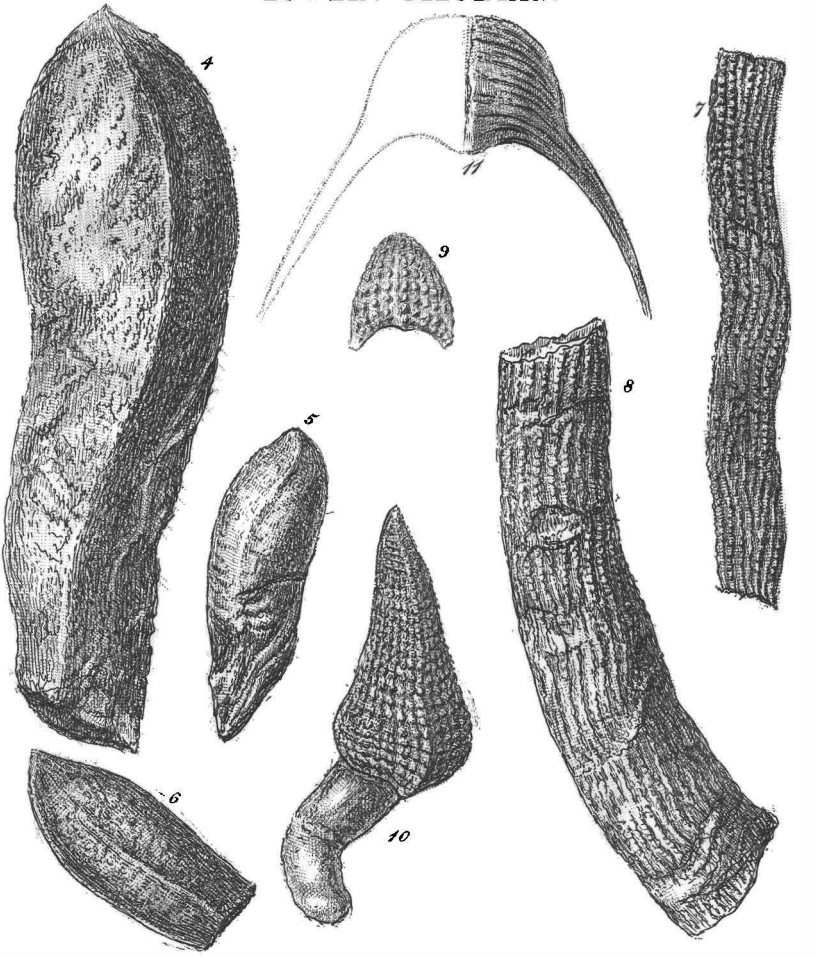
FOSSILS *from the* ANDES.

G. B. Sowerby

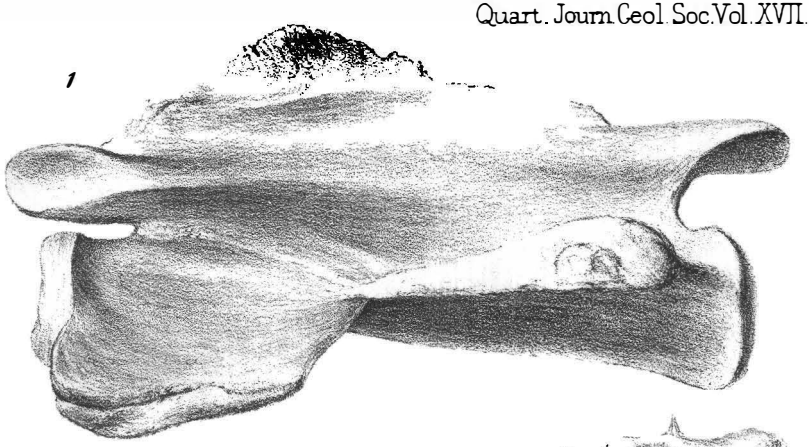
UPPER SILURIAN

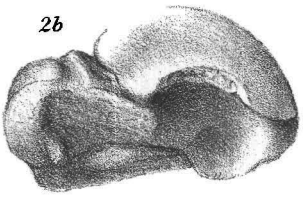


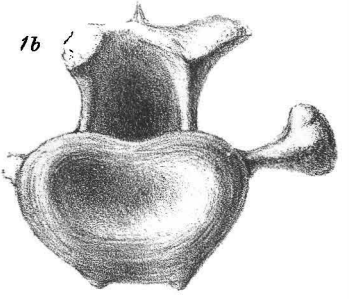
LOWER? SILURIAN.

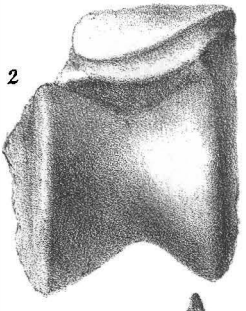


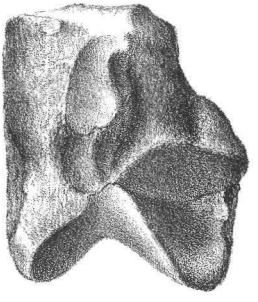
FOSSILS *from the* ANDES.

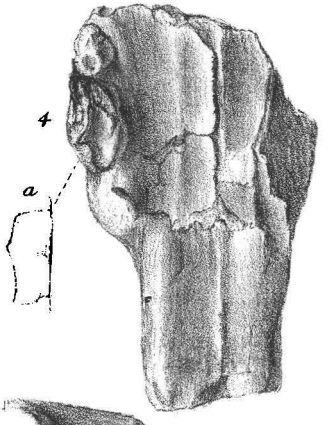


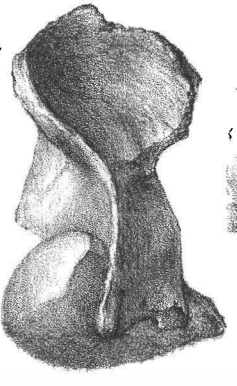


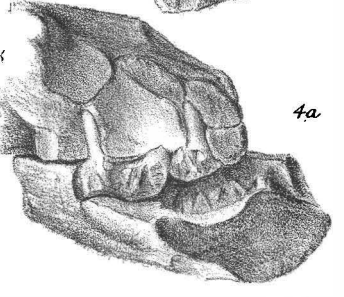












G.West del. & lith.

W.West imp.