XLII.—*On the Connexion of certain Volcanic Phenomena in South America; and on the Formation of Mountain Chains and Volcanos, as the Effect of the same Power by which Continents are elevated.*

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[Read March 7th, 1838.]

Plate XLIX.

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INTRODUCTION.

THE object of the present memoir is to describe the principal phenomena generally accompanying the earthquakes on the west coast of South America; and more especially those which attended the shock that overthrew the city of Concepcion on the morning of the 20th of February, 1835. These phenomena evince, in a remarkable manner, the intimate connexion between the volcanic and elevatory forces; and it will be attempted to deduce from this connexion, certain inferences regarding the slow formation of mountain chains.

Observations on the Earthquake in Chile of Feb. 20th, 1835.

This earthquake has been the subject of several published memoirs: the sixth volume of the Geographical Journal* contains an admirable account of it by Capt. Fitz Roy, R.N., in which many interesting facts are detailed, and the elevation of a large extent of coast is incontestably proved. The Philosophical

* "Sketch of the Surveying Voyage of His Majesty's ships Adventure and Beagle." Vol. vi. Part II. p. 311.

Transactions for 1836, also, contains a memoir on this subject by Mr. Caldcleugh. I must, therefore, refer to these authors, whose statements, as far as I had an opportunity of observing, I can fully corroborate, for a particular description of the earthquake itself, and of the changes of level which accompanied it in the neighbourhood of Concepcion. I will add only a few details, and will then proceed to describe the manner in which the southern volcanos of Chile were affected during the shock.

The island of Juan Fernandez, situated 360 geographical miles N.E. of Concepcion, seems to have been more violently shaken than the opposite shore of the mainland, and at the same time a submarine volcano, which continued in action during the day and part of the following night, burst forth near Bacalao Head, where the depth was afterwards ascertained to be sixty-nine fathoms. This fact possesses a peculiar interest, inasmuch as during the earthquake of 1751, which utterly overthrew Concepcion, this island was likewise affected in a remarkable manner, considering its great distance from the chief seat of disturbance. If any exact record had been kept of that event, many other points of resemblance would probably have been discovered. There is a tradition, that the land was then permanently elevated, and the area affected appears to have been very much the same with that disturbed in Feb. 1835. Molina* also states, that the undulation travelled from the southward; and in this second catastrophe the inhabitants agreed in thinking that it came from S.W., or even more southerly. After an interval of only eighty-four years, it is not at all improbable that the subterranean forces should be directed towards the same identical points.

Being anxious to trace the effects of the earthquake to the south, I wrote, shortly after visiting Concepcion, to Mr. Douglas, a very intelligent man, with whom I had become acquainted in the island of Chiloe; and the answer, which I have received since my return to England, is full of curious information.

He describes the earthquake, which appears to have been felt over the whole area at almost the same minute, (as far as the clocks of the country can be relied on,) as being very violent. He says, that twenty minutes before the great shock a trifling one was felt, a circumstance which I did not hear of in any other part. He was at the time on the island of Caucahue, (one of the many islets on the inland shore of Chiloe) and at the time wrote down the following remarks in his pocket-book: "Felt an earthquake at half-past eleven o'clock, motion horizontal and slow, similar to that of a ship at sea going before a high regular swell, with three to five shocks in a minute, somewhat stronger than the continued motion; direction from N.E. to S.W. Forest trees nearly touched the ground in these directions, but none fell in our vicinity;—pocket compass placed level on the ground, N. point set to lubbers' point; remarked that it vibrated during the violent

* Compendio de la Historia del Reyno de Chile, vol. i. p. 33.

shocks two points to westward and only half a point to eastward; stood at N. when the motion was less violent. Four minutes afterwards, a shock more violent than any of the preceding ones, affecting the compass as before: another violent shock, and then the movements became gradually less distinct, and eight minutes after the first commencement, they entirely ceased."

I have quoted Mr. Douglas's statement with regard to the compass, although it is not clear how any movement could have forced it to oscillate towards one side more than to another. I presume, however, if the needle with its card had not been acted on by the magnetic force, it would have been thrown in the trough (if such an expression may be used,) of the undulation, that is, in a N.W. and S.E. line, and, therefore, that the *recurrence* of this tendency, acting against the polar attraction, caused the unequal oscillations, as described. In my Journal of Researches*, I have endeavoured to show, that the vorticose movement, which in several earthquakes appears to have affected the stones in buildings, possibly may be explained on the same principle, namely, that the stones are so shaken that they arrange themselves according to their forms, in the line of vibration, as the compass would have done, had it not been acted on by the magnetic force. That the movement of the surface was undulatory, is shown by the fact, that at Concepcion the walls which had their extremities directed towards the chief point of disturbance generally remained erect, although much fractured; whilst those extending at right angles to these first lines, were hurled to the ground; for in the latter case we must suppose, that the whole wall was thrown at the same moment out of its perpendicular by coinciding with an undulation.

The fact mentioned by Mr. Douglas of the trees almost touching the ground from the effects of the movement, though very extraordinary, has been noticed by eye-witnesses of earthquakes in other parts of the world†. The circumstance (even supposing it somewhat exaggerated) is the more remarkable, since at Valdivia, which is situated on the coast between this island and the centre of the disturbance at Concepcion, the shock produced no such effects. I was seated in a thick wood there, during the earthquake, and the trees were only slightly shaken.

The range of the Cordillera opposite Chiloe, a narrow island ninety miles in length, is not nearly so lofty as in Central Chile, and a few only of the culminant peaks, which are all active volcanos, exceed 7000 feet in height. Mr. Douglas has given me a detailed account of the effect produced on them by the shock.

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* Journal of Researches during the Voyage of the Beagle, p. 376.

† This is mentioned by Dolomeu as a well-known fact during the Calabrian earthquake of 1783. Lyell's Principles of Geology (5th edition), vol. ii. p. 217.

The volcano of Osorno had been in a state of moderate activity for at least forty-eight hours previously; Minchinmadom in much the same gentle action as for the last thirty years; and the Corcovado had been quiet during the whole previous twelve months. "At the moment of the shock, Osorno threw up a thick column of dark blue smoke, and directly that passed, a large crater was seen forming on the S.S.E. side of the mountain; it boiled up lava, and threw up burning stones to some height, but the smoke soon hid the mountain. When seen again a few days afterwards, it showed very little smoke by day, but by night, the new crater, as well as the old one on its truncated summit, shone with a steady light. This volcano appears to have remained in activity throughout the year. The action of Minchinmadom was similar to that of Osorno: two curling pillars of white smoke had been observed all the morning; but during the shock, numerous small chimneys seemed to be smoking within the great crater, and lava was thrown out of a small one just above the lower verge of the snow. Eight days afterwards this little crater was extinct; but at night five small red flames were seen in a line, equidistant from each other, like those in the streets of a village. By the 1st of March its activity was much diminished; but on the 26th there was a smart earthquake, and at night the five fires were again seen. A fortnight afterwards the tops of fifteen conical hills could be seen within the wall of the great crater, and at night nine steady fires, of which seven were in a line, and two straggling."

At the time of the great shock, the Corcovado showed no signs of activity, nor was it heard in action after the Cordillera were hidden in the clouds. Mr. Douglas, however, states, that when that volcano was visible a week afterwards, the snow was seen to have been melted around the N.W. crater. On Yantales, a lofty mountain south of the Corcovado, three black patches having the appearance of craters were observed above the snow-line; and Mr. Douglas did not recollect having seen them before the earthquake. Bearing in mind, that on many occasions, the melting of the snow on a volcano has been the first indication of a fresh period of activity, and that, as I shall presently show, the eruptions of the Corcovado and Orsono are sometimes co-instantaneous, I think there can be little doubt that these appearances prove the effects of the great convulsion of the 20th of February to have been felt by these, the most southern volcanos in America.

Mr. Douglas states, that on the night of November 11th (ten months after the overthrow of Concepcion), Osorno and Corcovado both burst out in violent action, throwing up stones to a great height, and making much noise. He subsequently heard, that on the same day, Talcahuano, the port of Concepcion, little less than 400 miles distant, was shaken by a severe earthquake. This latter statement has since been confirmed to me by a gentleman, who was at the time resident in Chile. Here, then, we have a repetition of the same connected action, which was displayed in so remarkable a manner on the 20th of February. Mr. Douglas in conclusion adds, that on December the 5th his "attention was arrested by the grandest volcanic spectacle he had ever beheld; the S.S.E. side of Osorno had fallen in, thus uniting the two craters, which appeared like one great river of fire. Enormous quantities of ashes and smoke were erupted during the succeeding fortnight."

It is therefore evident, that the volcanic chain from Osorno to Yantales (a length of nearly 150 miles) was affected not only at the moment of the great shock of February 20, 1835, but remained in very unusual activity during many subsequent months.

Again, on November 7, 1837, two years and three quarters after the overthrow of Concepcion, both Valdivia and San Carlos, the capital of Chiloe, were violently convulsed, even more so, according to M. Gay*, than in 1835, or on any former recorded period; this shock was sufficiently

* Comptes Rendus, 1838. Séance Juin 11.

strong (*bastante recio**) at Talcahuano; and it appears from the evidence of Captain Coste, published in the Comptes Rendus†, that the island of Lemus in the Chonos Archipelago, 200 miles south of San Carlos, was, by this same earthquake, upraised more than eight feet: describing the present state of the island, M. Coste says, "des roches jadis toujours couvertes par la mer, restant aujourd'hui constamment découvertes."

We see, therefore, that, in 1835,—the earthquake of Chiloe,—the activity of the train of neighbouring volcanos,—the elevation of the land around Concepcion,—and the submarine eruption at Juan Fernandez, took place simultaneously, and were parts of *one and the same* great phenomenon. Again in 1837 a large part of the same area was violently affected, whilst a district, 200 miles southward of San Carlos in Chiloe, instead, as in 1835, of 300 northward of it, was permanently upraised. We must therefore believe, that these two elevations of the land, although not simultaneous, were effects of the same motive power intimately connected together.

Although the earthquake of February 1835 was so severe in Chiloe, yet at Calbuco, a village situated on the mainland opposite the northern extremity of the island, it was felt with much diminished violence, and on the neighbouring Cordillera (near Mellipulli) not at all. Some men who had been employed in the mountains splitting fir-planks, when they returned in the evening to Calbuco and were told of the shock, said, that "about the time mentioned, they recollected that they had not been able to strike fair with the axe, and that they had spoilt a board or two, by cutting too deep." This probably is not so fanciful as it at first appears; at least it shows that, if there were any motion, it was of an exceedingly gentle kind. It is a most interesting circumstance thus to find, that the great columns of smoke shot forth from the tall chimneys of the Andes, relieved the trembling ground, which at that moment was convulsed over the whole surrounding country.

Mr. Caldcleugh‡, has stated in his Memoir, that several volcanos in the Cordillera northward of Concepcion were in a state of great activity after the earthquake. It is therefore remarkable that Villarica (near Valdivia), a volcano which is more frequently in eruption than almost any other in the range, although situated in an intermediate position, between those of central Chile and those in front of Chiloe, was not in the least affected. The day was very clear, and although not at the moment of the shock, yet within two hours after it, I attentively watched its truncated summit, but did not perceive the least signs of action. This circumstance probably has an intimate relation with the less force of the earthquake in the same intermediate district. In 1837, however, it suffered similarly with Chiloe. Although Villarica was passed over in 1835, yet in the account of the earthquake of 1822 at Valparaiso, it is said, "at the moment the shock was felt, two volcanos in the neighbourhood of Valdivia (where the earthquake was pretty sharp) burst out suddenly with great noise, illuminated the heavens and the surrounding country for a few seconds, and as sud-

* Voyages of the Adventure and Beagle, vol. ii. p. 418.

† Comptes Rendus, October, 1838, p. 706.

‡ Phil. Transact. for 1836. I likewise was informed by an intelligent person, that he had seen, from the plain near Talca, a volcano in the Cordillera in great activity on the night subsequent to the earthquake.

denly subsided into their quiescent state*." The vents in Central Chile, nearer the chief focus of disturbance, were not at the time of that earthquake affected; but according to the information received by Dr. Gillies† in 1836, from a miner who had resided many years in sight of the volcano of Maypu, its eruptions were very frequent during the four years immediately subsequent to it. Many other instances are on record of earthquakes having passed over certain districts, in the same manner as we see the eruptive force acted with respect to Villarica. Humboldt‡ remarks, that the inhabitants of the Andes, speaking of an intermediary ground, which is not affected by the general motion, say with simplicity, "that it forms a bridge" (*que hace puente*); and he adds, "as if they meant to indicate by this expression, that the undulations were propagated at an immense depth under an inert rock §."

On the identity of the force which elevates Continents with that which causes volcanic outbursts.

It has frequently happened, that during the same convulsion large areas of the globe have been agitated, and strange noises propagated to countries many hundred miles apart‖; but in these cases, it is not possible to form any conjecture over how wide an extent, any actual change has taken place in the subterranean regions. It is different, when we hear from Humboldt, that at the moment when the volcano of Pasto ceased to eject a column of smoke, the city of Riobamba, sixty leagues to the southward, was overwhelmed by an earthquake; for the effect here produced certainly cannot be explained by the mere transmission of a vibration¶. During the Concepcion earthquake,

* Journal of Science, Vol. xvii.

† The Edinburgh Journal of Natural and Geographical Science, August 1830, p. 317.

‡ Humboldt's Personal Narrative, Vol. iv. p. 21. English Translation.

§ Another instance of earthquakes, violently affecting distant regions and passing over the intermediate country, is mentioned in the "True relation of the Earthquake of Lima, 1746." It is there said (p. 192) that the shock was most violent at Lima and Callao, becoming gradually less along the coast, but that at Guancavelica excessive shocks were felt and noises heard. The editor believes, there is no other place called Guancavelica except the famous quicksilver mines of that name, situated 155 miles to the S.E. of Lima. MacClelland (*Report on the Coal Mines of India*, p. 43,) mentions some cases of intermediate places being little shaken during great earthquakes.

‖ As examples of the first case, may be adduced the trembling of the ground on the coast of Chile along a space of more than one thousand miles; and during the Lisbon earthquake in 1755, countries about 3000 miles apart were affected (see Michell on Earthquakes: Phil. Trans. 1760.). With respect to the second case, Humboldt states, that during the eruption at St. Vincent's, subterranean noises were heard on the banks of the Apure, a distance of two hundred and ten leagues. (Person. Narr. Vol. iv. p. 27.) During the eruption of Coseguina in 1835, it is said, that noises were heard at Jamaica, 660 miles distant.

¶ As other instances of the same kind, I may mention the outburst in 1822, of the volcanos near Valdivia at the same moment that Valparaiso, nearly 400 miles distant, was levelled to the ground. Again, in 1746, when Lima was overthrown, three volcanos near Patas and one near Lucanas, the two places being 480 miles apart from each other, burst forth during the same night. (Ulloa's

at one extremity of the area affected, the snow was melted on Yantales and the neighbouring vents renewed their activity; whilst at Juan Fernandez, at the distance of no less than 720 geographical miles from Yantales, an eruption took place beneath the sea; and soon afterwards the volcanos in the Cordillera, 400 miles to the eastward of that island, burst forth in action,—a large extent also of country, intermediate between these extreme points, being permanently upraised. To form a just idea of the scale of this phenomenon, we must suppose, during the same hour, Europe to be shaken from the North Sea to the Mediterranean,—a large tract of the eastern coast of England to be permanently elevated,—a train of volcanos on the northern coast of Holland to burst forth in action,—an eruption to take place at the bottom of the sea, near the northern extremity of Ireland,—and the ancient vents of Auvergne, Cantal, Mont d'Or, and others, so long extinct, each to send up to the sky a dark column of smoke. Moreover, as, in Chile, a large part of the same area was two years afterwards most violently shaken, at the same time that Lemus was upraised, so must we imagine that, subsequently also, in Europe, whilst France, from the English Channel to the central provinces, where the volcanos had been excited into long and fierce action, was desolated by an earthquake, an island in the Mediterranean was permanently elevated;—then should we have the subterranean movements which shook South America on the 20th of February, 1835, and on the 7th of November, 1837, acted in countries with which we are familiar.

When first considering these phenomena, which prove that an actual movement in the subterranean volcanic matter occurred almost at the same instant of time at very distant places, the idea of water splashing up through holes in the ice of a frozen pool, when a person stamps on the surface, came irresistibly before my mind. The inference from it was obvious, namely, that the land in Chile floated on a lake of molten stone, of which the area, as known from the various points in eruption on the day of the earthquake, would be nearly double that of the Black Sea. If this inference be denied, the only alternative is, that channels from the various points of eruption unite in some deep-seated focus, like the arteries of the body in the heart, whence

Voyage, Vol. ii. p. 84.) I allude to these cases more particularly, because that distinguished philosopher, M. Boussingault (*Bulletin de la Soc. Géolog.* Vol. vi. p. 54.), having been much struck with the fact, that the earthquakes which have been most destructive to human life have been unaccompanied by volcanic outbursts, has, I think, generalized the remark too far. The earthquake of Concepcion in 1835 undoubtedly was one of extreme violence, although, from happening in the day, and from *commencing gradually*, it caused but few deaths (probably in the whole province not more than 70); nevertheless we have seen, that it was accompanied by co-instantaneous eruptions from several and very distant points.

an impulse can be transmitted to distant parts of the surface, with nearly equal force. But according to this view, if two separate trains of volcanos in the Andes have any connexion whatever, which seems highly probable from the symmetry of the Cordillera, (and possibly an intimate one, as will presently be discussed,) then the common focus, from which the two main branches are sent off, must be seated at an enormous depth. But all the calculations regarding the depth at which molten rocks must necessarily be met with, if they can be at all trusted *, tend to prove, that the earth's crust is not much more, and perhaps less, than twenty miles in thickness; and if this be so, the crust may, indeed, be well compared with a thin sheet of ice over a frozen pool.

These considerations are, perhaps, of little weight, but we must bear in mind, that the elevation of many hundred square miles of territory near Concepcion is part of the same phenomenon, with that splashing up, if I may so call it, of volcanic matter through the orifices in the Cordillera at the moment of the shock; and as this elevation is only one of a long series, by which the whole coast of Chile and Peru, even for more than a thousand miles, has been upraised several hundred feet within the recent period, (as I endeavoured to show in a paper formerly read to the Society†, and I hope hereafter to prove more fully,) the body of matter added below must have been enormous. When we reflect on this, it is obvious, that the term *channel* cannot be applied to a means of communication extending beneath a large portion of a continent, and from the interior of the globe to the superficial crust ‡. The facts appear to me clearly to indicate some slow, but in its effects great, change in the form of the surface of the fluid on which the land rests.

* M. Parrot, however, (Mémoires de l'Acad. Imp. des Sciences de St. Pétersbourg, Tom. i. 1831. Science. Math. Phys. et Naturelles) altogether denies that the data are sufficient to form any judgment on this subject.

† Proceedings Geol. Soc., Vol. ii. p. 446, Jan. 1837.

‡ Professor Bischoff (Edinburgh New Philosophical Journal, Vol. xxvi. p. 59, 1838.) has even argued that "the immense masses of lava ejected from a single volcano, and the enormous extent in which volcanic actions are felt at the same time, scarcely leave room to doubt that every active volcano is in immediate communication with the whole melted matter in the interior." How incomparably stronger this argument is, if applied to the plutonic as well as volcanic rocks, composing the great masses of the Cordillera! but now that we know, that continental elevations are caused by the very same impulses with those which eject lava and scoriæ through the mouths of volcanos, the argument from the bulk of matter observable in ejected or interjected masses of rock, may be passed over, since the matter added below, when a whole kingdom is permanently elevated, must far exceed that composing either a volcanic hill or the axis of a mountain-chain; and therefore we are so much the more strongly urged to look for its source in "the whole melted matter of the interior," and not in any local receptacle.

In a geological point of view, it is of the highest importance thus to find three great phenomena,—a submarine outburst, a period of renewed activity through many habitual vents, and a permanent elevation of the land,—forming parts of one action, and being the effects of one great cause, modified only by local circumstances. When we consider, that the southern volcanos were in eruption some days before the earthquake, and that one of them, Minchinmadom, has seldom been dormant for the last thirty years, and that they all remained active for many months afterwards, we must conclude that the impulse given to them at that moment, was of the same nature with the force which has kept up their activity during the many ages necessary to accumulate the volcanic matter into great snow-clad cones, and which force still continues to add to their height. If the earthquake or trembling of the ground (which, however, we have seen was less near these volcanos than elsewhere) had acted in no other way, than in merely breaking the crust over the lava within the craters, a few jets of smoke might have been emitted, but it could not have given rise to a prolonged and vigorous period of activity.

But the power which manifested itself in this renewed action, and to which same power, acting at former periods, the entire formation of these several volcanos has evidently been due, was likewise the cause of the permanent elevation of the land;—a power, I may remark, which acts in paroxysmal upheavals like that of Concepcion, and in great volcanic eruptions, in precisely the same manner, for both these phenomena occur only after long intervals of rest, during which the volcano merely casts out, perhaps, a few showers of scoriæ, and the land rises with so slow a movement that it is called insensible;—therefore no theory of the cause of volcanos which is not applicable to continental elevations can be considered as well-grounded. Those who believe that volcanos are caused by the percolation of water to the metallic bases of the earth, or simply to intensely heated rock, must be prepared either to give up this view, or to extend it* to the elevation of such vast continents as that of South America.

* The arguments in favour of the theory, that steam, produced by the percolation of water to the interior of the cooling planet, is the motive power in volcanic action, has been lately strongly put by Prof. Bischoff in his paper in the Edinburgh Journal (Vol. xxvi. p. 25.). That it must be a modifying cause of great importance seems highly probable; but that it is the primary one of continental elevations, I cannot admit. The phenomenon, as it appears to me, is on far too grand a scale to harmonize with such an explanation. Can the *rising* of the whole west coast of South America, and of the whole width, at least of the southern portion of it, be explained by the lateral force exerted during the general shrinking of the earth's crust, modified only by the formation of steam under high pressure, in those parts where water has percolated to the heated interior? Such an explanation surely is inadmissible.

On periods of increased Volcanic Action affecting large Areas.

Humboldt, when describing certain volcanic phenomena in that part of South America which borders the West-Indian sea, seems to consider, that periods of increased activity affect large portions of the surface of the earth. He has drawn up the two following tables*, to which I have added a third, containing the remarkable events that happened during the years 1834 and 1835 :

1st. TABLE OF VOLCANIC PHENOMENA.

1796.	November.	.....The volcano of Pasto began to emit smoke.
1797.	February 4th.	....Destruction of Riobamba.
——	September 27th.	..Eruption in the West-Indian Islands. Volcano of Guadaloupe.
——	December 14th.	..Destruction of Cumana.

2nd TABLE.

1811.	May.	.....Beginning of the earthquakes in the Island of St. Vincent, which lasted till May 12th.
——	December 16th.	..Beginning of the commotions in the Valley of the Mississippi and the Ohio, which lasted till 1813.
——	December.	.....Earthquake of Caraccas.
1812.	March 26th.	....Destruction of Caraccas, earthquakes, which continued till 1813.
——	April 30th.	.....Eruption of the volcano in St. Vincent's, and on the same day, subterranean noises at Caraccas and on the bank of the Apure.

3rd TABLE.

1834.	January 20th.	....Sabiondoy, lat. 1° 15′ N. (near Pasto), dreadful earthquake; eighty persons perished; town of Santiago swallowed up.
——	May 22nd.	.....Santa Martha, lat. 11° 30′ N.; two-thirds of the town thrown down; in course of a few days, sixty bad shocks.
——	September 7th.	..Jamaica,—violent earthquake, town not much damaged.
1835.	January 20th.	....Osorno, lat. 40° 31′ S. in eruption.
	Before day-light in the morning.	Aconcagua, lat. 32° 30′ S. in eruption. Coseguina, lat. 13° N. in terrific eruption, continuing in activity during the two ensuing months.
——	February 12th.	..Earthquake at sea, very strong off the coast of Guyana.
——	February 20th.	..Juan Fernandez, lat. 33° 30′ S., submarine eruption.
	11½ A.M.	Concepcion, (lat. 36° 40′ S.), and all the neighbouring towns destroyed by an earthquake; the coast permanently elevated. Volcanos along the whole length of the Cordillera of Chile in eruption. N.B. These volcanos remained in activity for some months subsequently, and many earthquakes were felt.
——	November 11th.	..Concepcion, severe earthquake; Osorno and Corcovado in violent action.
——	December 5th.	..Osorno fell in with a grand explosion.

* Personal Narrative, Vol. iv. p. 36. I have altered some of the dates in these tables, as they did not agree with the text or with the well-known period of the events.

With respect to these tables, it must be observed, that we can never feel sure that the connexion of volcanic phenomena at very distant points is real, until some strongly marked event takes place during the same moment at those points, the intermediate country being likewise affected to a certain degree. In the first two tables, the connexion of the West-Indian vents and the coast of Venezuela may be admitted as almost certain *, nor is the distance very great, being at most only 400 miles. But when, on the one hand, we include Quito, distant from the above area more than 1200 miles, and, on the other, the Valley of the Mississippi, the case is very much more doubtful. The coincidence certainly is very remarkable, both in regard to the commencement and the cessation of the long series of earthquakes which affected South Carolina, the basin of the Mississippi, the Leeward Islands, and Venezuela: yet New Madrid is more than 2000 miles from the latter. A repetition alone of such coincidences can determine how far the increased activity of the subterranean powers, at points so remote, is the effect of some general law, or of accident.

We now come to the third table, with which we are more particularly concerned. I have already described in detail the remarkable volcanic phenomena which happened, in connexion with each other, on the morning of February 20th, 1835, and likewise during the subsequent year.

On January 20th, one month previously, three eruptions, as stated in the table, occurred almost at the same hour in very distant points of the Cordillera. Near midnight on the 19th, the summit of Osorno shone like a great star in the horizon; and this appearance soon increased into a magnificent glare of light, in the midst of which, by the aid of a telescope, great dark bodies were seen to shoot upward and to fall down in endless succession. When I was at Valparaiso some time afterwards, Mr. Byerbache, a resident merchant, informed me, that sailing out of the harbour one night very late, he was awakened by the captain to see the volcano of Aconcagua in activity. As this is a most rare event I recorded the date. Some time afterwards papers arrived from Central America giving an account of one of the most fearful eruptions of modern times †. "On the 19th of January, after twenty-six years' repose, a slight noise, attended with smoke, proceeded from the mountain of Coseguina. On the following morning (the 20th) about half-past six o'clock, a cloud of very unusual size and shape was observed by the inhabitants to rise in the direction of this volcano." Enormous quantities of ashes and pumice were then ejected, and the air was darkened, and the ground convulsed, during the three succeeding days. Nearly two months afterwards the volcano was in action. Mr. Caldcleugh observes, that perhaps the only parallel case on record is the well-known explosion of Sumbawa in 1815.

When I compared the dates of these three events, I was astonished to find that they agreed within less than six hours of each other. Aconcagua is only 480 miles north of Osorno, but Coseguina is about 2700 north of

* Humboldt's Personal Narrative, vol. ii. p. 226., and vol. iv. p. 36.

† Caldcleugh on the volcanic eruption of Coseguina. Philosophical Transactions, 1836, p. 27.

Aconcagua. It may be asked, were these three eruptions, which burst through the same chain of mountains, in any respect connected, or was the coincidence accidental? We cannot be too cautious in guarding against the assumption that phenomena are connected, because they happen at periods bearing some determined relation to each other. If we wished to show that the subterranean forces acted after periods of a century, as has sometimes been believed, we might adduce the case of Lima, violently shaken by an earthquake on the 17th of June, 1578, and again on the very same day in 1678; or the eruptions of Coseguina in the years 1709 and 1809, which are the only two on record previous to that of 1835. Again, we might urge, on such grounds, that the Guatimala convulsions follow, at the interval of one year, those near Pasto; for a district in the neighbourhood of the latter place was overthrown by a violent shock precisely one year before the explosion of Coseguina; both having occurred on the 20th of January. Cosme Bueno imagined that this relation actually did exist between the subterranean movements in Guatimala and Peru, and this case makes one more to the list which I have subjoined* as extracted from Humboldt. With respect to the simultaneous eruptions of Aconcagua and Osorno, there is little difficulty in admitting that they may have been connected, because in this same region, and only a month subsequently, volcanos further apart were affected by the same impulse. There is nevertheless this remarkable difference in the two cases;—the last, or that of February the 20th, was a period of commotion throughout the kingdom of Chile, while the simultaneous eruption of Aconcagua and Osorno appears to have been unaccompanied by any *general* movement in the subterranean regions. This eruption, probably, was the first indication of those great volcanic disturbances which ensued exactly one month afterwards; for it seems to be a very general occurrence in earthquakes, that weak spasms precede the worst convulsions. Thus, in 1822, on the 4th of November, Copiapó (lat. 27° 10′) was visited by a severe shock, which damaged many houses; and was followed the next day by a much more violent earthquake, which nearly destroyed the town, and did considerable

* *Mexico.*	*Peru.*	*Difference of time.*
(Lat. 13° 32′ North.	(Lat. 12° 2′ South.)	
30th of November, 1577.	17th of June, 1578.	Six and a half months subsequent.
4th of March, 1679.	17th of June, 1678.	Eight months in advance.
12th of February, 1689.	10th of October, 1688.	Four months in advance.
27th of September, 1717.	8th of February, 1716.	Seven and a half months in advance.

Humboldt's Personal Narrative, Vol. ii. p. 227. These facts perhaps tend to show that periods of increased volcanic energy are common to remote parts of the continent; but as the order of priority is not constant, I cannot believe any other law is indicated.

injury to that of Coquimbo, in lat. 29° 50′*. On the 19th of the same month Valparaiso was almost destroyed. Other instances† might be brought forward to show that most earthquakes, though appearing sudden, are in truth parts of a prolonged action, as evinced both by the events which precede and those which follow it.

Although, possibly, we may allow that the eruptions of Aconcagua and Osorno, occurring in the middle of the same night, were connected together, and formed a part of the great subsequent disturbances,—yet what must we conclude respecting their coincidence with Coseguina, so immensely remote? The case is rendered far more extraordinary by two of the three volcanos being generally quiescent. Coseguina, according to Mr. Caldcleugh, burst forth after twenty-six years of repose; and Aconcagua so seldom manifests any signs of activity, that it had even been doubted whether any part of this gigantic mass, with an altitude of more than 23,000 feet, is of volcanic origin. To illustrate the case: if we suppose Stromboli and Vesuvius to be in violent eruption on the same hour of the night, little would be thought of the coincidence; but it would be otherwise if this should happen with Vesuvius and Etna; and our surprise would be greatly increased if we afterwards heard that Hekla, after twenty-six years' repose, had burst forth at the same time with tremendous explosions. Nevertheless, if such a coincidence had occurred in Europe, a country possessing no unity of character, and the two points not being more than 2000 miles apart, it is very doubtful how far the phenomenon would have been worthy of consideration. But the case is different in America, where the volcanic orifices all fall on one great wall or fissure, (for the Andes may be indifferently so called,) and where the immensity of the level area on the eastern side, proves with what wonderful equability the subterranean forces have acted on this portion of the globe. Moreover, when a line of coast more than two thousand geographical miles in length has been elevated (as I hope hereafter to prove) within a period so recent, that, as compared to the countless past ages of which we possess records in the *works* of nature, it may be

* Journal of Science, Vol. xvii.

† Several distinct cases are known in which springs and wells have been affected, their water rendered turbid, and altered in quantity, previously to bad earthquakes. This was observed at Lisbon in 1755; and in New England during two or three days before a shock, "the waters of some wells were rendered muddy and stank intolerably." (Michell, Philosophical Transactions, 1760, p. 44.) Humboldt and others have noticed, that the wells in the neighbourhood of Vesuvius are affected previously to its bad eruptions. These facts appear explicable, on the idea of a slight stretching or movement taking place in the crust, before its tension is overcome, a fissure formed, and, as a consequence, an earthquake or eruption caused. Courrejolles, also, has remarked in his memoir on earthquakes (Journal de Phys., Tom. lxiv. p. 106.), that great earthquakes are almost always preceded by lesser ones.

reckoned as unity; on such a coast it ceases to be improbable, in any excessive degree, that the many impulses which together have produced the one grand effect, should sometimes have been absolutely simultaneous.

It has long been remarked, that the vents throughout the Cordillera may be grouped into several systems. Thus we have already shown, that the extreme southern volcanos are connected with those of Central Chile; and I was informed by an intelligent resident that he had seen Aconcagua and two volcanos northward of it, in great activity together:—we thus have a portion of the Andes 780 geographical miles in length (about the distance from the south of England to Vesuvius) forming one connected system. Ulloa * states, that when Lima was overthrown in 1746, three volcanos near Patas and one near Lucanas burst forth; these places being 480 miles apart from each other. Moreover, Arequipa, to the south, has twice (1582 and 1687) been affected by severe earthquakes simultaneously with Lima. The distance between Arequipa (where there is an active volcano) and Patas is rather more than 600 miles; and this perhaps may form a second system.

Humboldt† says, "it appears probable that the higher part of the kingdom of Quito, and the neighbouring Cordillera, far from being a group of distinct volcanos, constitute a single swollen mass, an enormous volcanic wall stretching from north to south, and the crest of which exhibits a surface of more than six hundred square leagues. Cotapaxi, Tunguragua, Antisana, and Pichincha, are placed in this same vault, on this raised ground." He afterwards shows, from the phenomenon already alluded to, of the cessation of the column of smoke at the moment when Riobamba was overthrown, the connexion of these volcanos with those of Pasto and Popayan. This joint system is rather less than 300 miles in length. Again, to the north at Guatimala, Mexico, and California, we have three groups of volcanos, each system being a few hundred miles apart.

The connexion between the vents in each separate system has been, in some places, plainly shown, and is extremely probable in all; but what relation the different systems bear to each other is more doubtful. I am not aware of any fact on record, similar to the contemporaneous eruption of Osorno and Aconcagua with Coseguina. It must not, however, be overlooked, that such events may have happened every year since the Spanish conquest, without the coincidence having once been detected. Excepting from the concurrence of two accidents, I should never have known of this case. On that same night every vent in the Cordillera might have shown transient signs of activity, and six months afterwards it would have been as impossible to have discovered

* Ulloa's Voyage, English Translation, Vol. ii. p. 84.

† Personal Narrative, Vol. iv. p. 29.

that such had happened, as to have ascertained whether the next day were bright or clouded. There are some active and some nearly extinct craters, in the interval between the Chilian and Peruvian systems, (which is the longest of any, being 900 miles,) but they are situated in countries very thinly peopled, and in some parts entirely desert; and who is there in such cases to record phenomena, which, even if beheld, are thought of little consequence?

Returning to the third table, I feel no doubt that the volcanic phenomena which occurred in S. America sometime previously as well as subsequently to the months of January and February 1835, were far more numerous than the average proportion during an equal length of time. This remark applies to the two tables copied from Humboldt. In looking at the dates of these events, it must be remembered that each date represents only the moment when the crust of the earth has given way beneath the force, which in some cases has already shown its action, and invariably continues to do so during a period, often of considerable length. Under this point of view, the earthquakes of Caraccas and New Madrid, of Coseguina and Concepcion, may be considered as actually contemporaneous.

From these various circumstances, I am strongly inclined to believe, that the subterranean forces manifest their action beneath a large portion of the South American continent, in the same intermittent manner as, in accordance with all observation, they do beneath isolated volcanos,—that is, remaining for a period dormant, and then bursting forth throughout considerable districts with renewed vigour.

Nature of the Earthquakes on the Coasts of South America.

I will now more particularly consider the nature of the earthquakes which occur at irregular intervals on the coast of South America. It cannot be otherwise than difficult to trace their precise origin, but the following considerations, as it appears to me, lead to one conclusion alone—namely, that they are caused by the interjection of liquefied rock between masses of strata. Ulloa, in his travels*, says,

"Experience has sufficiently shown, especially in this country (South America), by the many volcanos in the Cordillera which pass through it, that the bursting of a new burning mountain causes a violent earthquake, so as totally to destroy all the towns within its reach, as happened at the opening of the volcano in the desert of Carguagoazo. This tremulous motion, which we may properly call an earthquake, does not so usually happen in case of a second eruption, when an aperture has been before made, or, at least, the motion it causes in the earth is comparatively but small." †

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* Ulloa's Voyage, Vol. ii. p. 85.

† Michell, in his remarkable paper on Earthquakes in the Philosophical Transactions for 1760,

Although the bursting forth of a *new* vent may invariably be accompanied by an earthquake, the converse is not true; for if it were, at Valparaiso, Concepcion, Lima, Caraccas, and other places, in the *immediate neighbourhood* of the part most violently shaken, an eruption must always have taken place, which, even if we suppose it to have occurred beneath the sea, is improbable in the highest degree. But we may suppose that these earthquakes are owing to some phenomenon analogous to volcanic eruptions. This opinion is much strengthened by the fact, that great earthquakes, like great eruptions, generally recur only after long intervals of repose, and they thus lead us to believe, that the subterranean force is relieved by either in the same manner. This, indeed, is the direct opinion of the inhabitants of the whole west coast of South America, who are firmly convinced of an intimate relation between the suppressed activity of the volcanos in the Andes and the tremblings of the ground. We have, also, seen that, when the island of Chiloe was strongly shaken, some men at work on the flanks of the Cordillera, between the volcanos of Osorno and Minchinmadom, (which both sent up dark columns of smoke, like signals to mark the new period of violence,) were quite unaware of the great convulsion, which then caused the shores of the Pacific to vibrate throughout a space of more than a thousand miles.

There is, however, one difference, although more apparent than real, between earthquakes like that of Concepcion, and those alluded to by Ulloa. In the former, it has almost invariably happened, at least in those on the South American coast, that a vast number of shocks have followed the first great convulsion*, and these, as well as the accompanying subterranean noises, having proceeded from the same quarter with the first shock, are therefore undoubtedly due to the very same cause, only acting with somewhat less intensity. Thus, even in the first twenty-four hours after the earthquake of

(p. 580,) has quoted this same passage in confirmation of his view, that "the eruptions of volcanos which happen at the same time with earthquakes may, with more probability, be ascribed to those earthquakes, than the earthquakes to the eruptions, whenever at least the earthquakes are of considerable extent." The term earthquake is here used to express the cause of the trembling of the ground. Sir James Hall, in his celebrated memoir on "Heat modified by compression," (Edin. Phil. Trans., Vol. vi. p. 166,) distinctly states "that the earthquakes which desolate countries not externally volcanic, indicate the protrusion from below of matter in liquid fusion, penetrating the mass of rocks;" but he does not extend this view, which is the same which I hold, to any comprehensive generalization, or restrict it to any particular class of earthquakes.

* Courrejolles, in his Memoir on Earthquakes, (Journal de Physique, Tom. liv. p. 106,) says, "Les grands tremblemens de terre sont presque toujours précédés et suivis quelque temps avant et après par de petites secousses." Michell (Philosophical Transactions, 1760, p. 10) has given some instances of successive minor shocks, which appeared to travel from the same point, whence the previous more violent ones had come.

1746 at Lima, no less than 200 horrible (I use the language of its historian) shocks were counted. Now in the other case, Ulloa says, that when the orifice of eruption is once formed, the earth becomes nearly tranquil; yet we well know, that the volcano itself almost invariably continues in great activity for many weeks afterwards. Had Ulloa, however, stood near the crater itself, he would undoubtedly have felt those small tremors, which accompany each fresh explosion, as described by others who have been so circumstanced. The tremors, therefore, seem analogous to the secondary shocks; and, this being so, the phenomena in the two cases are in every respect closely similar. In a primary volcanic outburst, we know the cause to be the explosion of liquid and aeriform matter, first through solid strata, and afterwards through a nearly open passage; hence we are led to conclude, that the cause of the simple earthquake, with its secondary shocks, are explosions of a similar nature, which, however, do not open a passage, but rend successively portions of the superincumbent masses.

At Concepcion, where the streets run in two series, at right angles to each other, the walls were affected, as already observed, according to their direction. This was strikingly exemplified in the cathedral, where the great buttresses, built of solid brickwork, were cut off as if by a chisel, and hurled to the ground; whilst the wall, to support which they had been vainly built, though much shattered, stood erect,—for the latter had its extremity directed towards the point whence the vibration travelled, but the buttresses were in lines parallel to the undulation. Nearly similar circumstances were observed* in 1822 at Valparaiso. At the great earthquake of Caraccas the direction of the vibration was E.N.E. and W.S.W., and some definite direction appears to have been observed in almost every violent earthquake. Now, it may be asked, could a vibration, which had travelled upwards through the earth from a profound depth, be felt on the surface, as if it had come from a given point of the compass, and could it likewise determine the overthrow of walls according to their direction with respect to any such point? It appears to me clearly not; but that a vibration to produce such effects must be transmitted from the rending of strata, at a point not very deep below the surface of the earth.

Earthquakes generally affect elongated areas. In the shock of 1837, in Syria, the vibration was felt "on a line 500 miles in length by 90 in breadth†." Humboldt‡ remarks, that earthquakes follow the coast of New Andalusia in the

* See Miers's Travels in Chile, Vol. i. p. 392.

† Proceedings of Geological Society, p. 540. April 5th, 1837.

‡ Personal Narrative, Vol. ii., p. 224.

same manner as they do that of Peru and Chile. Thus, at Valparaiso in 1822, the movement was felt along 880 miles of the shore of the Pacific; and at Concepcion, in 1835, for the greater length of more than 1000 miles; but on no occasion has the shock been transmitted across the Cordillera to a nearly equal distance. In 1835 the rocking of the ground was so gentle at Mendoza, that an old man, one of the inhabitants, (and every one in these countries is possessed with an almost instinctive power of perceiving the slightest tremor,) told me, that for some time he mistook the movement of the ground for a giddiness in his head, and that he called out to his friends that he was going to die. At Concepcion, Valparaiso, Lima, and Acapulco*, the residents believe that the disturbance generally proceeds from the bottom of the neighbouring sea; and thus they explain the unquestionable fact†, that the inland towns are generally much less injured than those near the coast. It does not appear, that the disturbance proceeds from any one point, but from many ranged in a band; otherwise the fact of the linear and unequal extension of earthquakes would be unintelligible. Thus, in 1835, the island of Chiloe, the neighbourhood of Concepcion, and Juan Fernandez, were all violently affected at the same time, and more so than the intermediate districts. In mountainous countries, such as New Andalusia, Peru, and Chile, when earthquakes follow coast lines, they may be said to extend parallel to the littoral chain of mountains.

The last consideration I shall enter on, as indicating the cause of earthquakes, is, that in South America they have sometimes (if not, as I believe, generally‡) been accompanied by elevations of the land; but this, judging from the Lima shock of 1746, does not appear to be a necessary concomitant, at least to a *perceptible* amount. It might at first be thought that, at Concepcion, the uplifting of the ground, which accompanied the first and great shock, would by itself have accounted for the whole phenomenon of the earthquake. The great shock, however, during the few succeeding days, was followed by some hundred minor ones (though of no inconsiderable violence), which seemed to come from the same quarter from which the first had proceeded;

* At Acapulco, Humboldt says, the shocks come from three different quarters, the west, north-west, and south. (Polit. Essay on the Kingdom of New Spain; English Translation, Vol. iv. p. 58.)

† Almost every author, from the time of Molina, makes this observation. See Molina's *Compendio de la Hist. del Reyno de Chile*, Vol. i. p. 32.

‡ My belief is grounded on the fact that, on the same coasts, and within the same period, in which a vast number of earthquakes are recorded, there exist proofs of an elevation of the land; although the rise is not known to have been connected with any particular earthquake.

whilst, on the other hand, the level of the ground certainly was not raised by them; but on the contrary, after an interval of some weeks, it stood rather lower than it did immediately after the great convulsion,—a consequence, perhaps, of the settling down of the shaken ground. In the same manner, in 1822, at Valparaiso, the permanent change of level in the rocks on the coast was observed the morning next after the great shock; though the earth continued to tremble at intervals for many days. In these instances of change of level we have, then, a clear indication of some cause of disturbance, superadded to that which produced the vibrations, and which, it is highly probable, would accompany the simple elevation of the coast in mass.

From these considerations, we may, I think, fairly conclude, with regard to the earthquakes on the west coast of South America,

1st. That the primary shock is caused by a violent rending of the strata, which seems generally to occur at the bottom of the neighbouring sea.

2nd. That this is followed by many minor fractures, which, though extending upwards nearly to the surface, do not (excepting in the comparatively rare case of a submarine eruption) actually reach it.

3rd. That the area thus fissured extends parallel, or approximately so, to the neighbouring coast mountains.

4th. That when the earthquake is accompanied by an elevation of the land in mass, there is some additional cause of disturbance.

And lastly, That an earthquake, or rather the action indicated by it, relieves the subterranean force, in the same manner as an eruption through an ordinary volcano.

Now, what constitutes the axis, where visible, of most great mountain-chains? Is it not a wedge-formed linear mass of rock, which scarcely any geologist disputes was once fluid, and has since cooled under pressure? Must not the interjection of such matter between masses of strata have relieved the subterranean pressure in the same manner, as an ejection of lava and scoriæ through a volcanic orifice? The dislocation having been effected in that portion of the upper crust of the earth, now forming a mountain, must not superficial vibrations, proceeding from a focus not deeply seated, have been propagated over the surrounding country? And, whatever direction these dislocations took, would not an area, elongated in the same line, have been affected by the vibration?

In drawing this parallel, I state my belief, that those earthquakes, with their secondary shocks, which are attended by such phenomena as accompanied the earthquake of Concepcion in 1835, are caused by the rending of great masses of strata, and their interjection by fluid rock;—a process which must have formed one step in a line of elevation.

The inhabitants of Concepcion believed, that the vibrations proceeded from the south-west, in which quarter subterranean noises were likewise frequently heard. It is, therefore, a most interesting circumstance, that the island of Santa Maria, situated 35 miles distant in this direction, was found by Captain Fitz-Roy to have been elevated to nearly three times the height that the coast near Concepcion was upraised. At Tubul, S. by E. of Santa Maria, the land was raised 6 feet; at the southern extremity of the latter island, 8 feet; in its middle, 9 feet; and at its northern extremity, upwards of 10 feet*. These measurements, which were made with extreme care by Captain Fitz-Roy, seem to point out an axis of elevation in the sea off the northern end of Santa Maria.

There is one remark, which I must introduce here. The motion of the earth, on February 20th, 1835, at Valdivia, appeared to me like that of a crust, spread over an undulating fluid; and in my Journal, I have compared the motion to the bending of thin ice, beneath a moving weight. Afterwards, when I became convinced that the crust there does rest upon a sea of molten rock, my first impression regarding the movement was strongly confirmed. Michell long since observed, (Phil. Trans., 1760, p. 8) that "the motion of the earth in earthquakes is partly tremulous and partly propagated by waves, which succeed one another, sometimes at larger and sometimes at smaller distances; and this latter motion is generally propagated much further than the former." This distinction, I believe, is strictly true. Professor Phillips† argues that rocks, although elastic in their parts, are "very imperfectly so in their mass, owing to the numerous divisions which intersect them. Composed of such materials," he says, "the crust of the earth does not, and in fact hardly can, *vibrate*, in the ordinary sense of this term; the motion observed is more similar to the undulation of a flexible lamina over an agitated liquid." The result arrived at by this reasoning thus coincides with mine, drawn from the impression on my senses; and it, at first, appears to explain, in a very satisfactory manner, the propagation to greater distances of the long and gentle undulations than of the vibrations, by the transmission of the former in the subterranean fluid, and of the latter in the crust of the earth. With respect, however, to the supposed want of elasticity in the crust of the earth, taken in mass, I cannot agree with Professor Phillips. Michell, (Phil. Trans., 1760, p. 35,) when he adduces the fact of the great vibration, or rather oscillation, during gales of wind, of steeples, and even towers†, which may be said to be composed of a vast number of strata of different densities, and which are frequently traversed by fissures or faults, leaves

* Geographical Journal, Vol. vi. p. 327.

† Lardner's Encyclopædia, Geol., Vol. ii. p. 209.

scarcely any doubt on the mind that a similar and much greater vibration might be transmitted from the depths of the earth, where the parts must be pressed together with incomparably greater force than in any building. Plausible as is the foregoing explanation of the two kinds of movements, I do not believe it to be the correct one; for if an undulation be ever produced in the subterranean fluid expanse, we can hardly conceive a more powerful cause of it, than the upward rush of a great body of molten rock and aëriform matter from the lowest abyss of a volcano: but we know that eruptions on an enormous scale have happened through old vents, even in areas subject to far-extended and undulating earthquakes, without such movements having been produced. From this consideration, and from the fact that the force of earthquakes appears to have a definite relation to the thickness of crust ruptured, as we may conclude from the great difference in the effects caused by an eruption through an old, and one through a new orifice, I do not conceive we are justified in admitting the hypothesis of an undulating fluid. The two kinds of movements may, possibly, be explained, by considering that when the crust yields to the tension, caused by its gradual elevation, there is a jar at the moment of rupture, and a greater movement may be produced by the tilting up of the edges of the strata and by the passage of the fluid rock between them. In breaking a long bar of steel, would not a jar be caused by the fracture, as well as a vibration of the two ends when separate?

Mr. Hopkins*, in his Researches on Physical Geology, has demonstrated, that when an elongated area is elevated by a force acting equally beneath all parts, if the strata yield, fissures must be formed parallel to its longer axis, and other minor ones transverse to it. Knowing then with certainty, that the coast of Chile, near Concepcion, was elevated on the 20th of February, and likewise that the area affected by the earthquake was elongated;—bearing also in mind, that several of these elevations have occurred, as attested both historically and by the extensive beds of recent species of shells, at the altitude of some hundred feet, we are absolutely compelled to believe, that the area (without we assume that the strata possessed extraordinary powers of extension) was at that time fissured in lines, the principal of which were parallel to its longer axis. If, however, the elevatory force acted unequally in different parts, as was the case in Chile, we can understand, from the admirable generalization of the same author, that separate fissures might be formed, which would produce at the same instant, in distant places, separate shocks, perhaps of different intensities. Hence we need not suppose, that the shocks felt more strongly at Juan Fernandez, Concepcion, and Chiloe, than at intermediate points, pro-

* Transactions of the Cambridge Philosophical Society, Vol. vi. Part I.

ceeded from any one focus, but that they were generated in each separate district,—the vibrations probably having, in each case, different directions *. This explanation is, I think, far more satisfactory than that offered by Humboldt, of the supposed inertness of an intermediary mass of rock, in transmitting to the surface vibrations from a deeply-seated focus.

On different kinds of Earthquakes; and conclusions regarding those which accompany Elevatory Movements.

I confine the foregoing observations to the earthquakes on the coast of South America, or to similar ones, which seem generally to have been accompanied by elevation of the land. But, as we know that subsidence has gone on in other quarters of the world, fissures must there have been formed, and therefore earthquakes. I think, it would be highly advantageous to geology, if the author who has followed out the effects of an elevatory force, would consider those produced by the failure of support in the arched surface of the globe. The earthquakes of Calabria, and perhaps of Syria, and of some other countries, have a very different character from those on the American coast. When Molina, the historian of Chile was in Italy, he was much struck with this difference; he says†, in Chile even the smaller shocks extend over the whole kingdom, and are propagated horizontally, whilst those which he felt at Bologna, were of small extension, but instantaneous, and commonly explosive.

I will add, that in the accounts collected by Mr. Lyell‡ of the earthquakes of Calabria, Lisbon, and some other places, portions of the surface are described as having been absolutely engulphed, and seen no more: but this does not appear to have happened in any of the earthquakes on the west coast of South America. If the fluid matter, on which I suppose the crust to rest, should gradually sink instead of rising, there would be a tendency to leave hollows, and therefore a suction exerted downwards; or hollows would be actually left, into which the unsupported masses might be precipitated with the violence of an explosion. Such earthquakes, we may conclude, from what has been shown in the foregoing part of this paper, would seldom be accompanied by eruptions, and never, probably, by *periods* of renewed volcanic

* At Concepcion the line of vibration appears to have been N.W. and S.E., coming from S.W. At Mocha, (an island between Concepcion and Valdivia), from the manner in which water oscillated in the bottom of a boat drawn up on shore, the vibration must have been N. and S. coming from either E. or W. For the facts alluded to, see Capt. FitzRoy's account of the Voyages of the Adventure and Beagle, volume ii. p. 414.

† Compendio de la Historia del Reyno de Chile, Vol. i. p. 36.

‡ Principles of Geology, 5th edit. Vol. ii. Book ii. Chap. xiv.

energy. According to M. Boussingault*, those earthquakes in South America which have been most destructive to human life, that is, which have been most sudden and violent, have not coincided with volcanic eruptions. He adduces several instances, including the shocks felt at Caraccas in 1812; but, according to Humboldt†, the connexion between the subterranean disturbances at that place and the West Indian vents can hardly be doubted. M. Boussingault's remark, indeed, although perhaps generally true, should be taken with some reserve; for had the earthquake of Concepcion happened at night, thousands of persons must inevitably have perished.

In a line of fracture, produced by subsidence, the distortion and overthrow of the strata would probably be even greater than in one of elevation, from the circumstance, that as soon as the weight of the mass overcame its cohesion, and it began to sink, there would be no counterbalancing power, like gravity during elevation, to check the movement, excepting, indeed, the lateral pressure of the masses together, and this would only add to the disturbance. There would be, in this case, no axis of injected plutonic rock, or at least not one protuberant above the general surface; and thus we may explain the extreme disturbance in the strata of countries which are only hilly, like parts of Great Britain; and the occurrence there of such axes of elevation, as they are generally called, but which probably, in most cases, would be more appropriately termed axes of subsidence.

If the theory which I have given of the cause of the earthquakes on the west coast of South America be true, we might naturally expect on the same principle to find proofs of successive formation in the many parallel ridges, of which the Cordillera is composed. In the parts of Central Chile which I examined, this is true, even with regard to the two main lines; of which one is partly formed of inclined beds of conglomerate, consisting of pebbles derived from the rocks of the other. I have also evidence, but of a less satisfactory kind, that some of the exterior lines of mountains are altogether of subsequent date to the more central ridges. Moreover, in all parts of the Cordillera, there are proofs of an equable elevation *in mass* to a very great altitude. I was so much struck with this latter fact, connected with what I imagined must have taken place during the Concepcion earthquake, that I came to nearly the same conclusion, which Mr. Hopkins has demonstrated by his mathematical researches, namely, that mountain-chains are only subsidiary and attendant phenomena on continental elevations. If this be so, and few, after having read Mr. Hopkins's memoir, will dispute it; then, as it is certain continental elevations have ~~certainly~~ taken place on a great scale within the

* Bulletin de la Soc. Geol., Vol. vi. p. 54.

† Personal Narrative, Vol. ii. p. 226, and Vol. iv. p. 6, English Translation.

recent period, so, as certainly, must masses on the lines of fracture have been unequally lifted up and let down,—that is, some steps in the formation of a mountain-chain have been produced.

I may here ask, when Mr. Hopkins* says, he "can in no way conceive the successive formation of parallel fissures, without hypotheses respecting the mode of action of the elevatory force, which are infinitely too arbitrary to be admitted for an instant," has he considered the effects of long intervals of rest, during which the injected rock might become solid? Would not the crust in such case yield more readily on either flank, as I believe it must have done in the Cordillera, than on the line of an axis composed of solidified rocks, such as granite or porphyry? An extremely slow elevation of the land, with long intervals of rest, being the only kind of movement of which we have any knowledge, the slow cooling of that portion of the liquefied rock which is propelled into the upper parts of the crust, cannot be considered an arbitrary assumption.

From the facts stated in this paper, we may safely conclude, that volcanic action, even on a *very grand scale*, as in the Andes, is only one effect of the power which elevates continents, at the slow rate at which the South American coast is now rising. In looking back to the past history of the world, we learn from Mr. Lyell†, that there have been volcanic eruptions during every epoch, from that of the Cambrian formations to the present day. The ancient eruptions seem to have been accompanied by all the circumstances which attend modern ones; nor is there any evidence, as remarked by the same author, that the quantity of matter ejected, in the greater number of ancient cases, was excessive. Therefore, we must conclude that continental elevations, one of the effects of the same motive power which keeps the volcano in action, has ordinarily gone on, since those ancient days, at the same slow rate as at present, and, consequently, as above inferred, the step-like formation of mountain-chains. It may, therefore, be questioned, whether we are justified in admitting the hypothesis of a paroxysmal elevation of any mountain-chain, without distinct proofs in each particular case, that a series of impulses, like those, which now acting frequently on the same lines, rend the earth's crust,

* Abstract of a Memoir on Physical Geology, by W. Hopkins, Esq., M.A., p. 31.

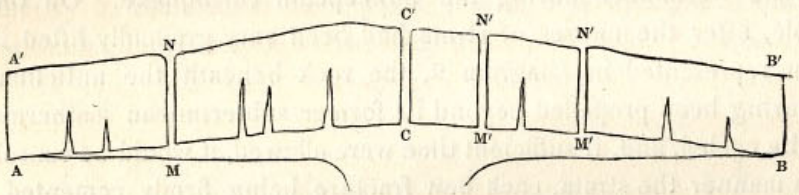
† Elements of Geology. In the 24th chapter, Mr. Lyell has collected instances of volcanic eruptions in each of the great epochs of the geological history of Europe. The argument, which follows in the text, is the same with that advanced by this author in the Principles of Geology, (Book I. Chap. v.) but Mr. Lyell more particularly applies it to the earthquakes and convulsions, "caused by subterranean movements, which seem to be merely another portion of the volcanic phenomena."

and elevate unequally portions of it, could not have effected the observed effects. It is, however, a subordinate question, whether there exist proofs of paroxysmal violence in some mountain-chains; the important fact which appears to me proved, is, that there is a power now in action, and which has been in action with the same average intensity (volcanic eruptions being the index) since the remotest periods, not only sufficient to produce, but which almost inevitably must have produced, unequal elevation on the lines of fracture.

Theoretical Considerations on the slow Elevation of Mountain-Chains.

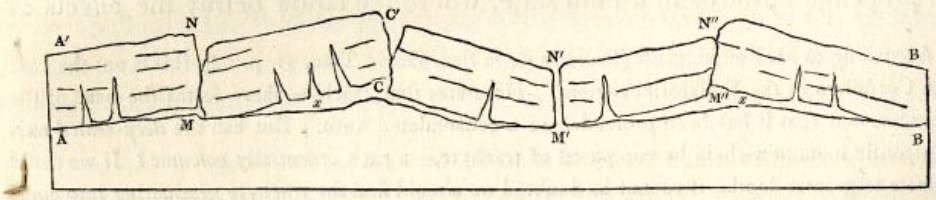
The conclusion that mountain-chains are formed by a long succession of small movements, may, as it appears to me, be rendered also probable by simple theoretical reasoning. Mr. Hopkins has demonstrated, that the first effect of equably elevating a *longitudinal* portion of the crust of the earth, is to form fissures, parallel to the longer axis (with others transverse to them, which may here be neglected) of the kinds represented in the accompanying diagram (No. 1.), copied from that published in the Cambridge Philosophical

No. 1.



Transactions. But he further shows, that the square masses, now disjointed, will,—from the extreme improbability of the force uplifting them, when separate, equably, or from their settling down afterwards,—assume some such position as that given in Diagram No. 2. In the Cordillera, which may be taken

No. 2.



as a good example of the structure of a great mountain-chain, the strata in the central parts are inclined more commonly at an angle above 45°, than beneath it; and very often they are absolutely vertical. The axis of the lines of dislocation is formed of syenitic and porphyritic masses, which, from the

number of dikes branching from them, must have been fluid when propelled against the lower strata*. If then we suppose Diagram 2 to represent the section of the Cordillera before its final elevation, I may ask, how is it possible, that some of the masses of strata should be placed vertical, and others absolutely overturned, by the action of the *fluid* rock, without the very bowels of the earth gushing out? Should we not have one enormous deluge of volcanic matter, instead of wedge-formed, injected masses of solid crystalline rock? On the other hand, if we suppose the loftiest chain of mountains to be formed by a succession of shocks similar to those of Concepcion,—a few stronger and many slighter ones, separated from each other by long intervals of time,—then we may believe, that the formation of a fissure through the whole thickness of the crust would be the effect of many efforts on the same line, and that during the intervals, the rock first injected would become cooled. When, therefore, the tension (which, according to Mr. Hopkins, acts on the lower surface first†) caused the upper part to crack, the fissures, if on the same line, would meet the consolidated extremity of a dike, instead of the fluid mass below. In those cases, however, where the fissure happened to traverse at once the entire crust, a volcano would be formed, such as that near Juan Fernandez during the Concepcion earthquake. On the same principle, after the masses of strata had been very gradually lifted into the position represented in Diagram 2, the rock beneath the anticlinal axes, from having been propelled beyond its former subterranean isothermal line, would be cooled, and, if sufficient time were allowed, it would be consolidated. In this manner the strata, each new fracture being firmly cemented by the cooling of the injected rock, might be overturned into any possible position, and yet, from a gradually thickening crust being formed over the fluid mass, on which the whole is believed to rest, the earth would be protected from a deluge of lava. If this reasoning be sound, we may deduce this remarkable conclusion, that in a mountain-chain, having an axis of plutonic rock, which was propelled upwards in a fluid state, where the strata betray the effects of

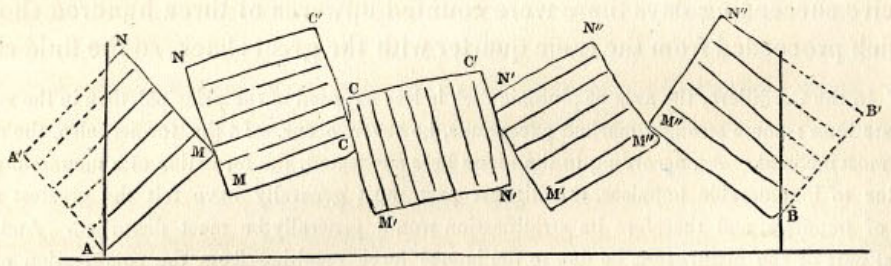
* According to M. Boussingault (Bulletin de la Soc. Geol., Tom. vi. p. 55), this is not the case in the Cordillera of the Equatorial regions. He states that trachyte there forms the base of the mountains, and that it has been protruded in a consolidated form. But can the *deep-seated* axis of a gigantic mountain-chain be composed of trachyte,—a rock essentially *volcanic*? If we could penetrate to greater depths, it cannot be doubted we should find the trachyte graduating into some plutonic rock; and one may be allowed to suspect that its junction with the superincumbent strata would present very different appearances from that of the trachyte;—the trachyte, indeed, we may well imagine to be the crust of such plutonic rocks cooled under little pressure, and forced upwards on the surface of the molten mass, in a solid form.

† Cambridge Philosophical Transactions, Vol. vi. pp. 43–45.

the most violent action, although it be on a gigantic scale, there we have the best evidence of an almost infinite series of small movements*.

I will enter on only one other consideration connected with this subject. From having in my mind the proportional thickness of the strata, usually given in sections in geological works, I felt much surprise, when I crossed the Cordillera, and found highly-tilted anticlinal lines succeeding one another at short distances, that the rock composing the axis was not to be met with, except in patches in the valleys. If we suppose parts of the strata in Diagram 2 to be placed vertically, the rock of the axis would necessarily be exposed in wide spaces; but here, I believe, is the source of error,—geologists have not always sufficiently considered the thickness of the mass upturned, in relation to the distance of the parallel anticlinal lines one from another. In the Cordillera, in a width of about sixty miles, there are eight or more anticlinal lines; and thus the centres of the troughs and of the ridges are about four miles apart. Now, if we suppose the upturned crust to be only four miles thick, (which is somewhat more than can actually be seen,) the strata, when placed vertically, will occupy as great an horizontal extension as they did before they were disturbed. In Diagram 3, which I beg it may be understood is given merely to illustrate this *one* point, I have taken portions of strata of the same exact length as those in Diagram 2; but I have increased their

No. 3.



thickness, so that it equals the distance of the anticlinal lines from each other; —we shall now see that not only the whole axis is covered, but that the masses cannot be forced into their former horizontal limits. I have not, however, allowed for the immense abrasion which, under such circumstances, the lower

* Humboldt has insisted on the fact, that in double chains of mountains, such as form large portions of the Andes, the lofty parts of one line correspond with the lower parts of the other. Such symmetry of structure is hardly conceivable on the idea of mountains having been formed by paroxysmal violence; but if we consider the whole range as the effect of a widely-extended elevation, prolonged during many ages, it is easy to understand, that if one line be weak, and consequently be subjected, for a long time, to disturbance from the subterranean force, it is probable that during so much the less time will the parallel and approximate one be affected.

angles would suffer, nor for the denudation and rounding of the upper ones. This supposed crushing together of such gigantic fragments will, perhaps, explain the utter confusion, which must be familiar to every geologist who has examined any great mountain-chain*. I must here add, that according to these views, which I believe are correct, the theoretical part of the foregoing argument, namely the difficulty of confining during any paroxysmal movement the fluid matter within the crust, is weakened; yet I believe the principle holds good, for, in order to break up and throw over portions of *very thick* crust, as in Diagram 3, there must have been great horizontal extension, and this, if sudden, would have caused as many continuous outbursts of volcanic matter, as there now are axes of solid rock. Moreover, when we consider, first, that the fragments must have stood for one instant separate from each other, and, secondly, that the force necessary to turn over and crush together at one effort these immense masses, must have been in proportion enormously great to that required merely to lift them,—it cannot, I think, be doubted for a moment, that if the force had acted *suddenly*, these portions of the earth's crust would have been absolutely blown off, like fragments of rock by gunpowder; but this has not happened, and, therefore, the force did not act suddenly†.

If we grant that the earthquake of Concepcion on the 20th of February marked one step in the elevation of a mountain-chain; then, as during the twelve succeeding days there were counted upwards of three hundred shocks, which proceeded from the same quarter with the great shock, so the fluid stone

* In the Cordillera, the axis of plutonic rock is less exposed in the principal, than in the subordinate lines; some strongly marked exceptions, however, occur. In the former, also, the strata are most inclined. As, according to the views here advocated, the formation of a mountain-chain is due to innumerable impulses, the highest part must generally have felt the greatest number of impulses, and therefore its stratification would generally be most disturbed. And if a great part of the disturbance be due to the lateral force resulting from the compression of the great *thick* portions of the earth's crust, then the central lines, or those which have several ridges on both sides of them, would be most crushed together, and consequently the strata would be most closely packed over them. I can understand on no other principle, the circumstance of the rock of the axis being visible not on the loftiest, but on the secondary lines of a mountain-range, which very frequently occurs.

† Mr. Hopkins moreover argues, (Abstract of a Memoir on Physical Geology, p. 15,) that if the elevatory force had the character of an *impulsive* action, it "would produce the most irregular phenomena, and such as would be altogether without the sphere of calculation. I exclude, therefore, the hypothesis of this kind of action, not as involving in itself any manifest improbability, but as inconsistent with the existence of distinct approximations to general laws in the resulting phenomena." In other parts the author shows that such approximations do exist in nature.—See also Phil. Mag. 1836, Vol. viii. p. 234.

must have been pumped into the axis by as many separate strokes; nor did the process cease for many subsequent months*. In the central ridges of the Cordillera, there are masses of compact unstratified rocks, half again as lofty as Etna, and I believe, from the reasoning above given, that they were formed by steps nearly as slow as those indicated by the innumerable layers of volcanic matter accumulated on the flanks of the Sicilian mountain. In the volcano, that is, a mountain which has been ruptured in its incipient state, the fluid stone being brought to the surface is rapidly cooled, and hence successive layers are formed; but in the axis of plutonic formation (or subterranean volcano, if it may be so called), the injected matter, not being rapidly cooled, is blended into one huge conical pile. This whole view is nothing more than an application of Hutton's doctrine of the repetition of small causes to produce great effects; and which Mr. Lyell has already brought distinctly to bear on this particular subject.

The action of the elevatory force, as known by beds of littoral shells, successive lines of aqueous erosion on cliffs of solid rock, and terraces rising one above another, seems everywhere to have been prolonged, although intermittently: in the volcano, the structure of the mountain, as well as all history, bespeaks the same fact with respect to the eruptive force. During the Concepcion earthquake, we have seen that these powers, so analogous in their action, were absolutely parts of one common phenomenon. Bearing in mind Mr. Hopkins's demonstration, if there be considerable elevation, there must be fissures, and, if fissures, almost certainly unequal upheaval, or subsequent sinking down,—the argument may be finally thus put:—mountain-chains are the effects of continental elevations; continental elevations and the eruptive force of volcanos are due to one great motive power, now in progressive action; therefore the formation of mountain-chains is likewise in progress, and at a rate which may be judged of by either phenomenon, but most nearly by the growth of volcanos.

Concluding Remarks.

With these views, if we look at a map of America, and observe the continuity of the great chain of the Andes, and its lesser parallel ones, in which from lat. 55° 40′ South to 60° North, a space of little less than 7000 miles, the volcanic forces either now are, or recently have been, in action,—and likewise the symmetry of the whole,—we shall be deeply impressed with

* In an extract from a letter, dated Concepcion, May 6th, that is seventy-six days after the great earthquake, there is this passage:—"It is only since a few days, that a day has passed without a shock, and even yesterday we had one."

the grandeur of the one motive power, which, causing the elevation of the continent, has produced, as secondary effects, mountain-chains and volcanos. The same reasons which led me to the conviction, that the train of connected volcanos in Chile and the recently uplifted coast, together more than 800 geographical miles in length, rested on a sheet of fluid matter, are applicable with nearly equal force to the areas beneath the other trains. We see that these areas are connected by one uniform chain of mountains, from many distant points of which fluid rock is yearly ejected; and as there are proofs that nearly the whole west coast of South America has been elevated within a period geologically modern, and that this movement, in some parts at least, has extended across the continent,—keeping, also, in mind the probability, that during periods of increased subterranean action, such as those indicated in the foregoing tables, the whole western part of the continent has been almost simultaneously affected, it appears to me, that there is little hazard in assuming, that this large portion of the earth's crust floats in a like manner on a sea of molten rock. Moreover,—when we think of the increasing temperature of the strata, as we penetrate downwards in all parts of the world, and of the certainty that every portion of the surface rests on rocks which have once been liquefied;—when we consider the multitude of points from which fluid rock is annually emitted, and the still greater number of points from which it has been emitted during the few last geological periods inclusive, which, as far as regards the cooling of the rock in the lowest abysses, may probably be considered as one, from the extreme slowness with which heat can escape from such depths;—when we reflect how many and wide areas in all parts of the world are certainly known, some to have been rising and others sinking during the recent æra, even to the present day, and do not forget the intimate connexion which has been shown to exist between these movements and the propulsion of liquified rock to the surface in the volcano;—we are urged to include the entire globe in the foregoing hypothesis.

To the belief in these large seas of molten rock, not to speak of an entire concentric layer so constituted, it has been objected, that if its fluidity be tolerably perfect, (which there is good reason to think is the case from what we see of the junction of the plutonic with the metamorphic formations,) the lava ought to stand (supposing a comparative examination possible) at nearly equal heights, within neighbouring volcanic orifices. To this I may answer, if it be permitted me to assume that the subsiding as well as the rising areas rest on a fluid surface, that whatever the power is which causes one to rise and another to sink, acts with unequal force (greatly modified, also, by unequal resistance) in different parts of even a very limited area. The main strength of the earth-

quake of February 20th, 1835, passed over Valdivia, but affected the districts north and south of it; and it appears that this town, until November 1837, had been less injured by the innumerable shocks which devastated Chile than any other; yet the subterranean abysses directly beneath it are in connexion (as shown by the action of Villarica in 1822) with the district to the North, which has been so often convulsed; and in November 1837, at the same time that an island far southward was upraised eight feet, it was shaken by an earthquake so violent that it escaped utter ruin only from the houses being built of wood. The comparative freedom from disturbance of Valdivia on the 20th of February, cannot be attributed to the action of Villarica, for we have seen that this volcano was quiet; nor indeed is there any reason why such an effect should be attributed to its action, since the eruptions of Osorno and Minchinmadom did not save the northern parts of Chiloe, though they occupy the same relative situation with regard to them, which Valdivia does to Villarica. Shall we then say, that Valdivia escaped so long the subterranean disturbances, some of which affected simultaneously regions north and south of it, solely on account of the greater strength of the crust in that part? This appears to me a cause quite inadequate; and the direct supposition is better, that as within the same period one part of the continent has been elevated more than another, so the lava has been propelled by the action of this force more powerfully towards some, than towards others, of the volcanic orifices which penetrate it.

The secular shrinking of the earth's crust has been considered by many geologists a sufficient cause to account for the primary motive power of these subterranean disturbances; but how it can explain the slow *elevation*, not only of linear spaces, but of great continents, I cannot understand. With the same view, some highly important speculations have recently been advanced,—such as changes of pressure on the internal fluid mass, from the deposition of fresh sedimentary beds, and even the attraction of the planetary bodies on a sphere not solid throughout; but we can see that there must be many agents, modifying all such primary powers; and the furthest generalization, which the consideration of the volcanic phenomena described in this paper appears to lead to, is, that the configuration of the fluid surface of the earth's nucleus is subject to some change,—its cause completely unknown,—its action slow, intermittent, but irresistible.

Fig. 20 to 23. *Paludina Deccanensis.* Short, conical, pointed, rounded at the base; whorls 5 or 6, slightly convex, aperture round. Fig. 21 is in chert from Munnoor; and figs. 20 and 22 in indurated clay from between Munnoor and Hutnoor, the cavity of the shells being filled with calcedony. The young shell has a slight carina shown in fig. 20. Fig. 23 appears to be a crushed specimen; it is in laminated, indurated clay, Munnoor. This shell occurs, with *Physa Prinsepii*, in a beautiful green siliceous mineral at Munnoor; at Chicknee, and at the bottom of the Neermull pass. All the specimens natural size.

WOOD-CUTS.

Section of the Bangnapilly Diamond Mines: p. 541.

Section of the Lonar Lake and surrounding rocks: p. 562.

WOOD-CUT.

Map of part of Mazunderān to illustrate Dr. C. M. Bell's Geological Notes of a Journey from Tehran across the Elboorz Range to the Caspian, and back to Tehran along the course of the Heraz River: pp. 577, 581.

PLATE XLVIII.

Map and Sections to illustrate Mr. W. J. Hamilton's memoir on part of Asia Minor between the Salt Lake of Kodj-hissar and Cæsarea of Cappadocia. The map is constructed from original documents. The descriptions engraved on the plate explain sufficiently the range and nature of the Sections: p. 583 *et seq.*

WOOD-CUT

To illustrate Mr. Strickland's notice of some remarkable Dikes of Calcareous Grit, at Ethie, in Ross-shire: pp. 599, 600.

PLATE XLIX.

Outline Map of part of the western coast of South America to illustrate Mr. Darwin's memoir on the connexion of certain volcanic phenomena in South America; and on the formation of Mountain Chains and Volcanos, as the effect of the same Power by which Continents are elevated: p. 601 *et seq.*

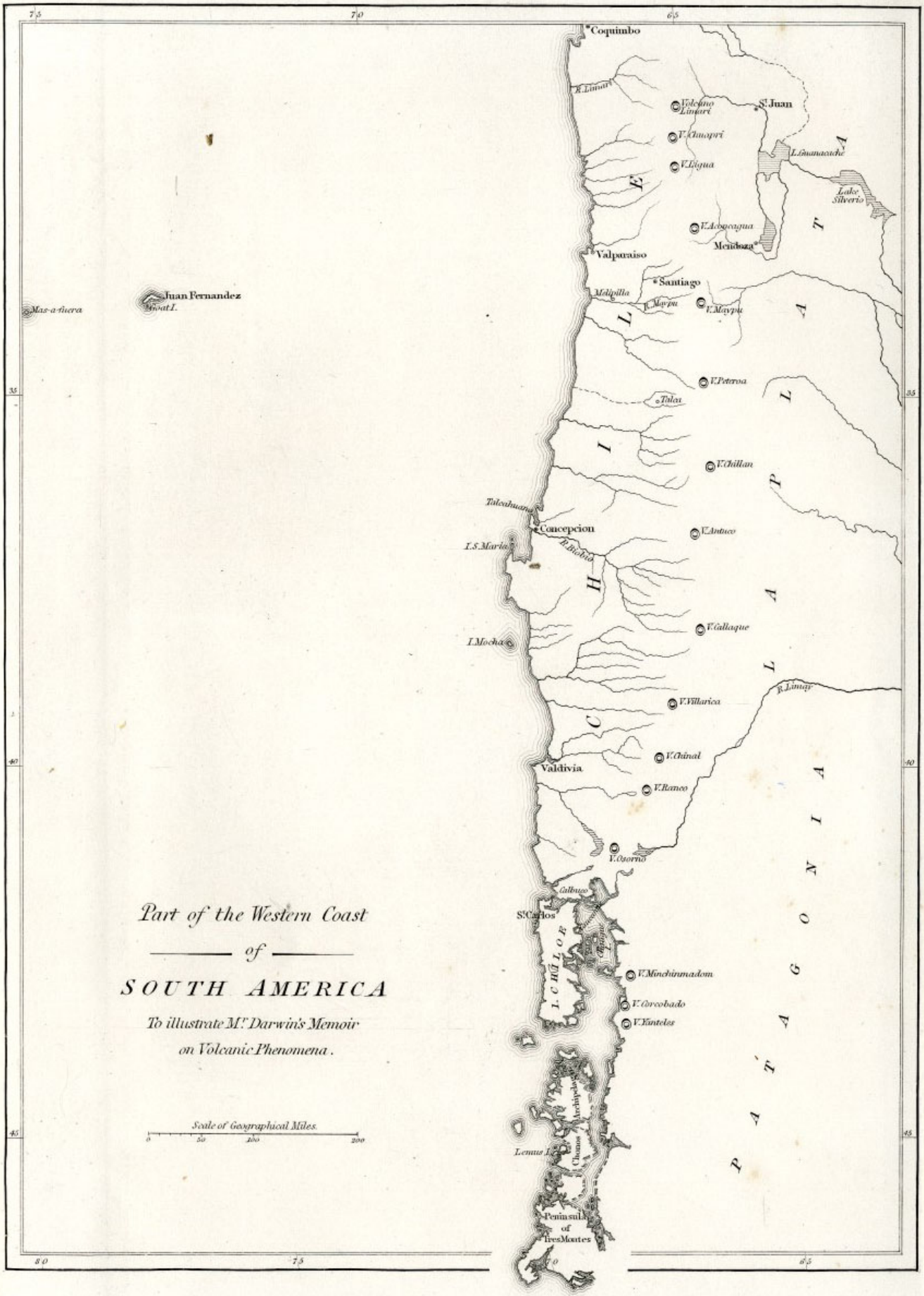
WOOD-CUTS.

Diagrams copied principally from Mr. Hopkin's memoir on Researches in Physical Geology, (Trans. Phil. Soc. Cambridge, vol. vi. pp. 45, 51.) to illustrate slow elevatory movements in the formation of mountain-chains: p. 625.

Diagram explanatory of the effect which would be produced if the thickness of the crust of the earth, upturned by elevatory movements, were equal to the distance between the anticlinal lines: p. 627.

PLATES L. to LVIII.

Illustrate Prof. Sedgwick and Mr. Murchison's memoirs on the Physical Structure of Devonshire, and on the Subdivisions and Geological Relations of its older stratified deposits: p. 633 *et seq.*



Part of the Western Coast

of

SOUTH AMERICA

To illustrate Mr. Darwin's Memoir on Volcanic Phenomena.

Scale of Geographical Miles.

0 50 100 200