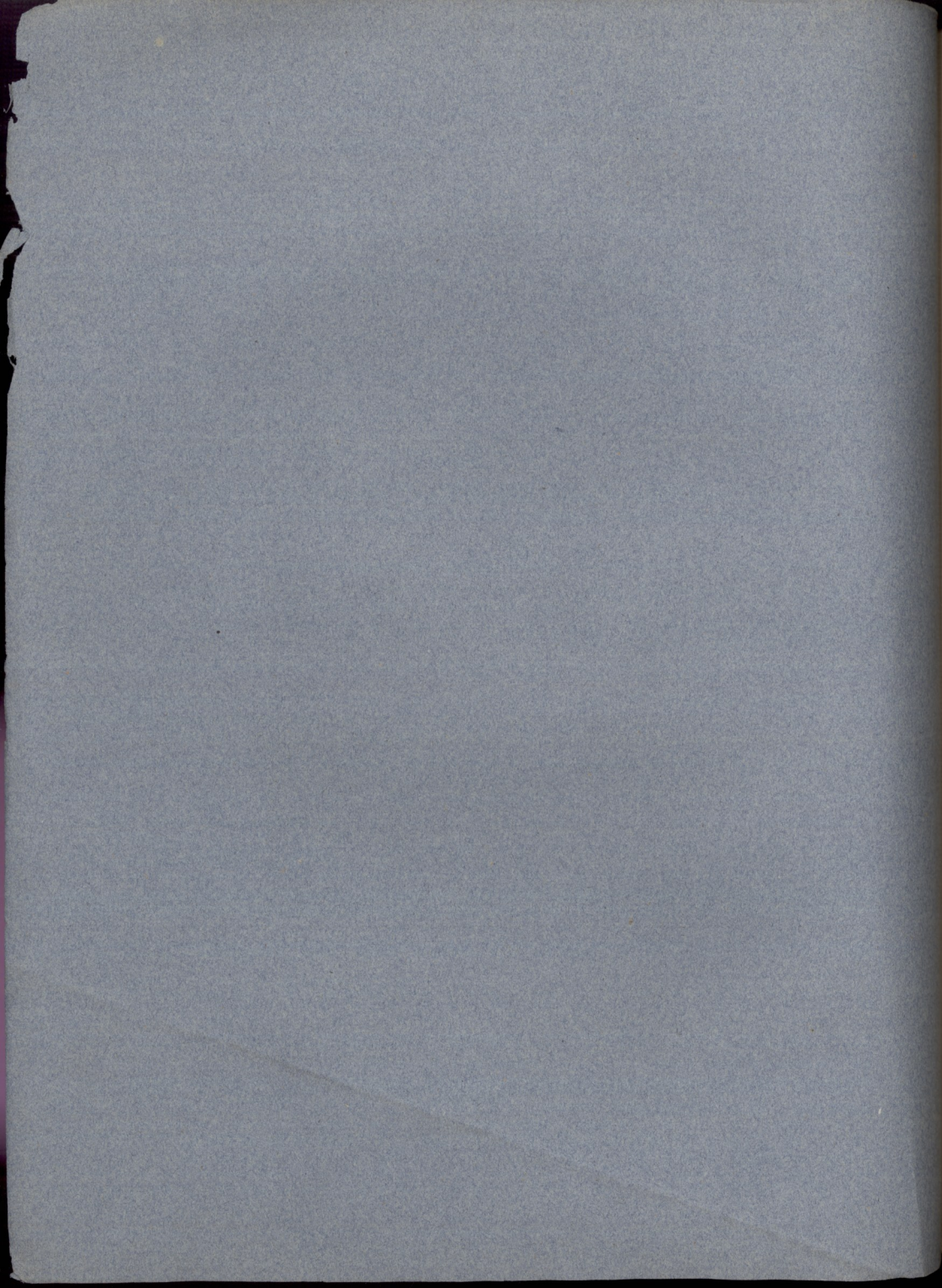


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XLII.—*On the Connexion of certain Volcanic Phenomena in South America ; and on the Formation of Mountain Chains and Volcanos, as the Effect of the same Power by which Continents are elevated.*

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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. Caldeugh. 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.

* *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.

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.

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. $1^{\circ} 15' N.$ (near Pasto), dreadful earthquake; eighty persons perished; town of Santiago swallowed up.
 — May 22nd. Santa Martha, lat. $11^{\circ} 30' N.$; 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. $40^{\circ} 31' S.$ in eruption.
 Before day-light Aconcagua, lat. $32^{\circ} 30' S.$ in eruption.
 in the morning. Coseguina, lat. $13^{\circ} N.$ 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. $33^{\circ} 30' S.$, submarine eruption.
 11½ A.M. Concepcion, (lat. $36^{\circ} 40' S.$), 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. Dyerbache, 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.

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 Guatemala, 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.*†

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

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

same manner as they do that of Peru and Chile. Thus, at Valparaiso in 1833, 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 1877, 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 scorix 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.

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 engulfed, 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.

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

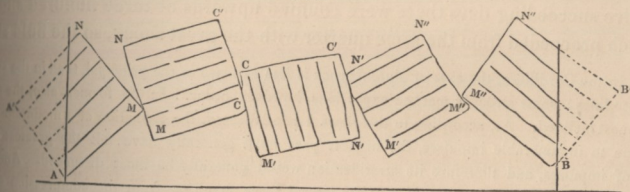
* According to M. Boussingault (Bulletin de la Soc. Geol., Tom. vi. p. 55), this is not the case in the Cordillera of the Equatorial regions. He states that trachyte there forms the base of the mountains, and that it has been protruded in a consolidated form. But can the *deep-scated* axis of a gigantic 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.

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.

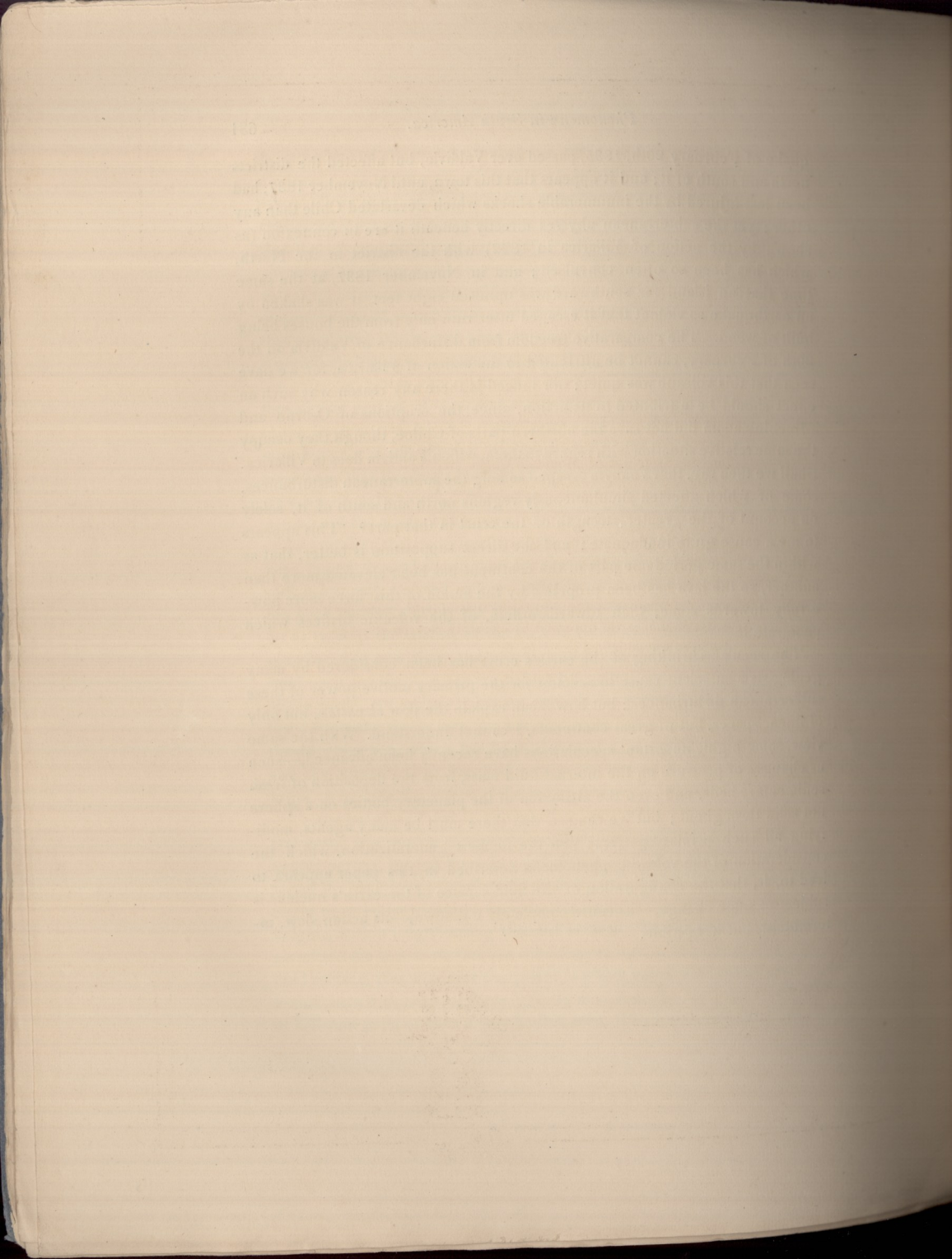




PLATE XLIX.

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.

Scale of Geographical Miles.

 A horizontal scale bar with markings at 0, 50, 100, 150, and 200 miles.

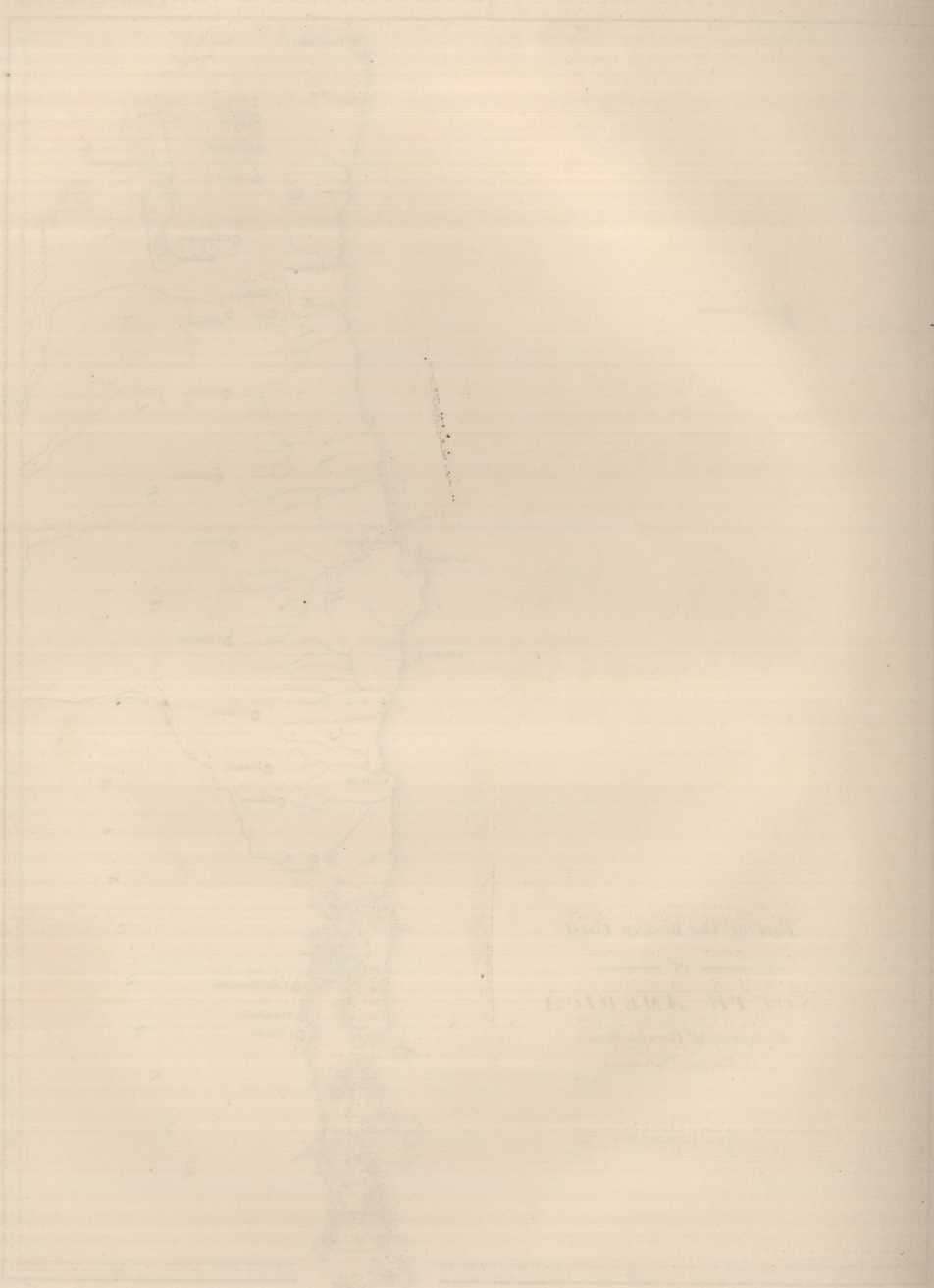

The first of the two views of the eastern coast of South America is that of the
 region of the mountains of the Andes, showing the high peaks and
 the deep valleys. The second view is that of the coast of the
 Pacific Ocean, showing the lowlands and the bay of Valparaiso.
 The first view is taken from the summit of the mountain of
 Parí, and the second view is taken from the summit of the
 mountain of San Pedro de Atacama. The first view is
 taken from the summit of the mountain of Parí, and the
 second view is taken from the summit of the mountain of
 San Pedro de Atacama. The first view is taken from the
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 mountain of Parí, and the second view is taken from the
 summit of the mountain of San Pedro de Atacama.



Part of the Western Coast
 of
SOUTH AMERICA

To illustrate Mr Darwin's Memoir
 on Volcanic Phenomena.

Scale of Geographical Miles
 0 50 100 150 200



Map of the Eastern Coast
of the State of New York
from the Hudson River
to the Long Neck
of the Eastern Head
of Long Island
by the late
Major-General
John B. Heintzelman
1847

