A paper, on the connexion of certain volcanic phænomena, and on the formation of mountain-chains and volcanos, as the effects of continental elevations, by Charles Darwin, Esq., Sec. G. S., was then read.

The author first gave a detailed account of the volcanic phænomena, which accompanied the earthquake that destroyed Concepcion on the morning of the 20th of February, 1835; and then deduced from volcanic phænomena, certain inferences with respect to the formation of mountain-chains, and continental elevations.

In describing the phænomena of the earthquake of 1835, Mr. Darwin quotes the published accounts by Captain Fitzroy* and Mr.

* Journal of the Royal Geographical Society, vol. vi., p. 319, 1836.

Caldcleugh*; likewise communications received by him from Mr. Douglas, a resident on the island of Chiloe.

A few days after the earthquake, several volcanos within the Cordilleras, to the north of Concepcion, though previously quiescent, were in great activity. It is doubtful, however, if the volcano of Antujo, in nearly the latitude of Concepcion, was affected, while the island of Juan Fernandez, 360 miles to the north-east of the city, was apparently more violently shaken than the opposite shore of the main land. Near Bacalao Head, a submarine volcano burst forth in sixty-nine fathoms water, and continued in action during the day as well as part of the following night. That island was also affected in a remarkable manner, by the earthquake which overthrew Concepcion in 1751.

In Concepcion, the undulations of the surface appeared, to the inhabitants, to proceed from the south-west; and this direction was likewise inferred, from the effects observed in the buildings; for those walls, which had their extremities towards the point of disturbance, remained erect, though much fractured; whilst those (and the streets cross each other at right angles) which extended parallel to the line of the vibration, were hurled to the ground. This was strikingly exemplified in the cathedral, where the great buttresses of solid brick-work were cut off, as if by a chisel, and thrown down; while the wall, for the support of which they had been built, though much shattered, remained standing.

In Chiloe, south of Concepcion, the shocks were very severe, but they entirely ceased in about eight minutes. The motion, as described by Mr. Douglas, was horizontal, and similar to that of a ship going before a high, regular swell; from three to five shocks being felt in a minute; and the direction being from N.E. to S.W. Forest-trees nearly touched the soil in these directions; and a pocket compass placed level on the ground vibrated, during the violent shocks, two points to westward, but only half a point to eastward; and during the minor shocks the needle pointed north. At Calbuco, a village on the mainland opposite the northern extremity of Chiloe, as well as at Valdivia, between Chiloe and Concepcion, the earthquake was much less severely felt; and near Mellipulli, in the Cordilleras (not far from Calbuco), not at all. The volcano of Villareca, near Valdivia, which is said to be more frequently in irruption than almost any other in the chain, was not the least affected; though the volcanos of central Chili are stated by Mr. Caldcleugh to have been seen, some days afterwards, in great activity. Several of the culminating points of the Cordillera in front of the island of Chiloe, exhibited increased energy during the earthquake, and immediately after it. During the shocks, Osorno, which had been in activity for at least forty-eight hours previously, threw up a thick column of dark blue smoke; and directly it had passed away, a large crater was seen forming in the S.S.E. side of the mountain; Minchinmadiva also, which had been in its usual state of moderate activity, commenced a fresh period of

* Phil. Trans., 1836; Part I. p. 21. [An abstract of Mr. Caldcleugh's paper appeared in Lond. and Edinb. Phil. Mag. vol. viii. p. 148.]

violence. At the time of the principal shock, the Corcovado was quiet; but when the summit of the mountain was visible a week afterwards, the snow had disappeared from the north-west crater. On Yntales, to the south of the Corcovado, three black patches, resembling craters, were observed above the snow-line after the earthquake, though they had not been noticed previously to it. During the remainder of the year, the whole of the volcanic chain, from Osorno to Yntales, a range of 150 miles, exhibited, at times, unusual activity. On the night of the 11th of November, Osorno and Corcovado threw up stones to a great height; and on the same day, Talcahuano, the port of Concepcion, 400 miles distant, was shaken by a very severe earthquake; and on the 5th of December the whole summit of Osorno fell in.

After these details of more particular phænomena, Mr. Darwin alluded to the great areas over which earthquakes have been simultaneously felt; but he added, it is impossible even to guess through how wide an extent, in the subterranean regions, actual changes may have taken place. In order to enable the reader, who may be more familiar with European than South American geography, to comprehend the vast surface which was affected by the earthquake of February 1835, he stated, that it had a north and south range, equal in extent to the distance between the North Sea and the Mediterranean: that we must imagine the eastern coast of England to be permanently raised; and a train of volcanos to become active in the southern extremity of Norway; also that a submarine volcano burst forth near the northern extremity of Ireland; and that the long dormant volcanos of the Cantal and Auvergne, each sent up a column of smoke.

The contemplation of volcanic phænomena in South America, has induced the author to infer, that the crust of the globe in Chili rests on a lake of molten stone, undergoing some slow but great change; for if this inference be denied, he says, the only alternative is, that channels from the various points of eruption must unite in some very deeply-seated focus. This conclusion, however, he doubts, on account of the union of the different trains of volcanos on the one line of the Cordillera, and more especially as many hundred square miles of surface in Chili have been elevated during the same earthquake. Moreover, these elevations have acted within a period geologically recent, throughout the whole, or at least the greater part, of Chili and Peru, and have upraised the land several hundred feet. He is further of opinion, that the shocks coming from a given point of the compass, and the overthrow of the walls, according to their position with respect to this point, prove that the vibrations do not travel from a profound depth, but are due to the rending of the strata not far below the surface of the earth.

In a geological point of view, the author conceives, the three classes of phænomena exhibited during this earthquake of February 1835, viz. a submarine outburst—renewed volcanic activity, simultaneously at distant localities—and a permanent elevation of the land, to be of the greatest importance, as forming parts of one great action, and

being the effects of one great cause, modified only by local circumstances. Mr. Darwin further observed, that, as the volcanos near Chiloe commenced, at the moment of the shock, a period of renewed activity, which lasted throughout the following year, the motive power of these volcanos (as well as of the submarine outburst near Juan Fernandez) must be of a similar nature with that, which, at the same instant, permanently raised another part of the coast; and he therefore concluded, that no theory of the cause of volcanos, which is not applicable to continental elevations, can be considered as well-grounded.

Mr. Darwin then offered some remarks on the two tables published by Humboldt, of the great earthquakes which affected, in 1797 and 1811, so large portions of America; and he is of opinion, that a repetition of the coincidences can alone determine how far the increased activity of the subterranean powers, at such remote points, was the effect of some general law, or of accident. He likewise disbelieves, that periodical eruptions, as those of Coseguina, in 1709 and 1809, or of earthquakes, as the shocks felt at Lima on the 17th of June 1578, and the 17th of June 1678, are more than accidental agreements. He also gave a table of the volcanic phænomena in South America in 1835; and concluded, that it is probable that the subterranean forces manifest, for a period, their action, beneath a large portion of the South American continent, in the same intermittent manner as they do beneath isolated volcanos. In the latter table, Mr. Darwin pointed out the case of Osorno, Aconcagua, and Coseguina, (the first and last being 2700 miles apart,) which burst into sudden activity early on the morning of June 20th, 1835; but he hesitated to assent to there being any necessary connexion between them. He further remarked, that if such simultaneous outbursts had been observed in Hecla and Ætna, points unconnected by any uniformity of physical structure, it would be doubtful how far they would have been worthy of consideration; but in South America, where the volcanic orifices fall on one line of uniform physical structure, and where the whole country presents proofs of the action of subterranean forces, he conceives it ceases to be improbable, to any excessive degree, that the action of the volcanos should sometimes be absolutely simultaneous.

The author then briefly described the groups into which the volcanic vents of the Cordilleras have been divided. The most southern extends from Yntales to the volcanos of central Chili, a distance of nearly 800 geographical miles; the second, from Arequipa to Patas, rather more than 600 miles; the third, from Riobamba to Popayan, a distance of about 300 miles; and to the northward, there are in Guatimala, Mexico, and California, three groups of volcanos separated from each other a few hundred miles. That the vents in each of these groups are connected, the author has little doubt; but that the groups are united in one system, there are less satisfactory means of proving.

Mr. Darwin next considered the nature of the earthquakes which occur at irregular intervals on the South American coast. He is

perfectly convinced, from the numerous points of analogy which exist between these phænomena and simple eruptions, that they belong to the same class of events; but he makes this distinction, that earthquakes, unaccompanied by eruptions at the chief point of disturbance, are followed by a vast number of minor shocks. These, he believes, indicate a repeated rending of the strata beneath the surface; whereas, in an ordinary eruption, a channel is formed during the first outburst.

Among other phænomena belonging to earthquakes, Mr. Darwin alluded to their affecting elongated areas. Thus the shock in Syria, in 1837, was felt on a line 500 miles in length by 90 in breadth; and those in South America are felt along 800 and 1000 miles of coast, but are on no occasion transmitted across the Cordillera to a nearly equal distance; and, as a consequence, the inland towns are much less affected than those near the coast. He does not conceive, however, that the disturbances proceed from one point, but many ranged in a band, otherwise the linear extension of earthquakes would be unintelligible. For instance, in 1835, the island of Chiloe, the neighbourhood of Concepcion and Juan Fernandez were all violently affected at the same time.

The last consideration which Mr. Darwin entered upon indicating the cause of earthquakes, is, that in South America they have been generally accompanied by elevation of the land; though it is not a necessary concomitant, at least to a perceptible amount. But he especially observed, that, as at Concepcion, during the few days succeeding the great shock, several hundred earthquakes, of no inconsiderable violence, were experienced, whilst the level of the ground in that part of the coast certainly was not raised by them (but after the interval of a few weeks, it stood lower,), there is a clear indication of some cause of disturbance, independent of the uplifting of the land in mass.

In summing up the evidence of phænomena accompanying earthquakes, the author is of opinion that the following conclusions may be drawn:—

1st. That the primary shock of an earthquake is caused by a violent rending of the strata, which, on the coast of Chili and Peru, seems generally to occur at the bottom of the neighbouring sea.

2ndly. That this is followed by many minor fractures, which, though extending upwards, do not, except in submarine volcanos, actually reach the surface.

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

Lastly. That the earthquake relieves the subterranean force, precisely in the same manner as an eruption through an ordinary volcano*.

* [Those who have perused Sir John F. W. Herschel's views on the theory of volcanic action (Babbage's Ninth Bridgewater Treatise, sec. edit. pp. 230–240,) will not fail to recognise the close accordance with them, of

The author afterwards discussed the nature and phænomena of mountain chains; and stated his belief, that the injection, when in a fluid state, of the great mass of crystalline matter, of which the axis is generally composed, would relieve the subterranean pressure in the same manner as an ejection of lava or scoria; and that the dislocation of the strata would produce horizontal vibrations through the surrounding country. In drawing this parallel, he also stated his belief, that the earthquake of Concepcion marked one step in the elevation of a mountain chain; and he adduced, in support of this opinion, the fact observed by Capt. Fitzroy, that the island of Santa Maria, situated 35 miles to the south-west of that city, was elevated to three times the height of the upraised coast near Concepcion; or at the southern extremity of the island, eight feet; in the middle, nine feet; and at the northern extremity, upwards of ten feet; and that at Tubal, to the south-east of Santa Maria, the land was raised six feet*; this unequal change of level indicating, in his opinion, an axis of elevation in the bottom of the sea, off the northern end of Santa Maria.

Mr. Darwin then alluded to Mr. Hopkins's Researches in Physical Geology,† where it is demonstrated, that if an elongated area were elevated uniformly, it would crack or yield parallel to its longer axis; and that if the force acted unequally, transverse cracks or fissures would be produced, and that the masses, thus unequally disturbed, would represent the irregular outline of a mountain-chain. He further added, that if the force should act unequally beneath the area simultaneously affected, various fissures would be formed in different parts, having different directions, and thus give rise, at the same moment, to as many local earthquakes. The author believes, that this view will more readily explain intermediate districts being little disturbed (as Valdivia in 1835, and in cases alluded to by Humboldt,) than the supposed inertness of intermediary rock in conveying the vibrations from a deeply-seated focus.

If the preceding theory of the cause of earthquakes be true, Mr. Darwin said, we might expect to find, that the many parallel ridges of which the Cordillera is composed, were of successive ages. In Central Chili, the only portion examined by him, this is the case, even with regard to the two main ridges; and some of the exterior lines of mountains appear, likewise, to be of subsequent dates to the central ones. The contemplation of these phænomena led him, while in South America, to infer, that mountain-chains are only subsidiary, and attendant operations on continental elevations.

The conclusion, that mountain-chains are formed by a long succession of small movements, the author conceived may be arrived at by theoretical reasoning. The first effect of disturbing agents, Mr. Hopkins has shown, is to arch the crust of the earth, and to traverse

the phænomena above described and the conclusions above drawn by Mr. Darwin.—Edit.]

* Journal of the Royal Geographical Society, vol. vi. p. 327.

† [See Lond. and Edinb. Phil. Mag. vol. viii. p. 227, *et seq.*]

it by a system of parallel but vertical fissures; and that subsequent elevations and subsidences of the disjointed masses would produce anticlinal and synclinal lines. In the Cordillera, the strata in the central parts, are inclined at an angle commonly exceeding 45°, and are very often absolutely vertical, the axis being composed of granitic masses, which, from the number of dikes branching from them, must have been fluid when propelled against the lower beds. How then, he asked, could the strata have been placed in a highly inclined and often vertical position, by the action of the fluid rock beneath, without the very bowels of the earth gushing out? If, on the other hand, it be supposed that mountain-chains were formed by a succession of shocks similar to those which elevated Concepcion, and after long intervals, time would be allowed for the injected rock to become solid, as well as the upper part of the great central mass. Thus, by a succession of movements, the strata might be placed in any position; and the crystalline nucleus gradually thickening, would prevent the surface of the surrounding country being inundated with molten matter.

In crossing the Andes, Mr. Darwin was surprised at finding, not one great anticlinal line, but eight, or more; and that the rocks composing the axes were seldom visible, except in denuded patches in the vallies. This circumstance, he conceives, must be due to the thickness of the upheaved strata being equal, or nearly so, to the average distance of the anticlinal from the synclinal lines. For in that case, the masses of strata, when placed vertically, would occupy, or rest on, as great an horizontal extent, as they did before they were disturbed.

In the central ridges of the Cordillera, there are masses of compact, unstratified rocks, half again as lofty as Ætna; and these, he believes, for the reasons before stated, were formed by the gradual cooling of the subjacent fluid mass; afterwards slowly elevated to the present position, by the injection of molten matter at nearly as slow a rate, as we must suppose the innumerable layers of volcanic products, of which the Sicilian mountain is formed, have been ejected.

In conclusion, Mr. Darwin repeated the argument, that mountain-chains and volcanos are due to the same cause, and may be considered as mere subsidiary phænomena, attendant on continental elevations;—that continental elevations, and the action of volcanos, are phænomena now in progress, caused by some slow but great change in the interior of the earth; and, therefore, that it might be anticipated, that the formation of mountain-chains is likewise in progress; and at a rate which may be judged of, by either actions, but most clearly by the growth of volcanos.