taken his parting glimpse of his palace of the Alhambra, the rich Vega, and 'Grenada the marvellous.' It is appropriately named 'Suspiro del Moro' ('the Moor's sigh').

A very few men can safely hold the entrances to the Alpujarras; and they long remained the last stronghold of the Arab power in Spain, which has passed, leaving as its memorial little more than the names of a few villages, and the wonderful system of irrigating-works.

There can hardly be a doubt that the series of calamities, hardly closed, which has laid so many villages in ruins since last Christmas, is a continuation of the processes by which portions of the earth's crust are raised in mountain ranges above the rest. A few words on the geological structure of the sierra may indicate the possibilities of the locality. The structure of the sierra and its neighbors is quite simple. They rise like islands or domes of ancient mica schists out of a sea of later formations, which break like waves upon their flanks. These schists are of a silvery white, appearing like snow when distant and illuminated by the sun. They are absolutely sterile, but dip, in a general way, outward from the central axis of elevation in all directions. A belt of radiately dipping Silurian schists encircles the central part of the sierra, which, like the exposed part of the core, assumes rounded outlines, but is succeeded by another belt, rugged, precipitous, and craggy, of Permian limestones, which extends to the base on the eastward, but is nearly as irregular in height as in extent. The Alpujarra basins are excavated in these limestones, and protected by escarped cliffs. Against the base of the sierra, raised slightly near the mountains, but elsewhere horizontal, lie tertiary grits, clayey sands and clays, deposits of fine gypsum, etc., covered with two alluvial series of beds, — the lower composed of decomposition products of the Silurian schists, brought down by water and mingled with material derived from the subjacent tertiary; the upper and later, from the denudation of the fundamental mica schists now forming the crests of the sierras. Moule observes that the elevation of the sierras has, in part at least, taken place since the tertiary epoch, and even since the alluvial period, and that it may not yet have ceased. This observation, written before the recent disturbances, has found in them renewed support.

The people of the country, finding in the elevated blocks of argillaceous alluvium left isolated by the torrential rains of part of the year a soft but compact and resisting material, have carved in them whole villages of cave-houses, with doors and windows, and often with one story above another. These abrupt elevations, though of moderate height, are extremely numerous, entirely without vegetation, and of an ashy hue. The cave villages are numerous, and, as in the case of Purullana, contain sometimes several hundred inhabitants. One may imagine the devastation among these gnomes which an earthquake shock must produce, and which would go far to explain the great loss of life in these small places.

The shocks felt have been chiefly to the westward of the Sierra Nevada, and have been most severe along the junction of the tertiary rocks with the schists. Here towns have been almost or quite destroyed, and the ruin wrought has been largely proportional to the proximity of the town or village to the unconformability of the rocks, though the motion has been propagated over a much wider area.

THE WORK OF THE SWISS EARTHQUAKE COMMISSION.

THE Swiss earthquake commission was appointed by the Swiss society of natural sciences, in 1879, to secure more uniform and accurate observation and study of the seismic disturbances in and around the Alps. It included such men as Forel, Forster, Hagenbach-Bischof, Heim, Soret, and others of mark as physical-geographers and geologists; and they at once began an active campaign. Professor Heim of Zurich wrote several general articles[1] to call attention to the undertaking, and to outline the method by which intelligent persons could give effective assistance; and since then, he and Forel, both admirably qualified, have prepared a number of monographic reports on the results thus far reached. The official journal of publication is the *Jahrbuch des tellurisches observatorium* of Bern; but, so far as I can learn, none of our libraries possess a copy of it. Fortunately, the reports have mostly been reprinted in periodicals of more general circulation, and from these the notes here presented are derived.

Forel's entertaining papers[2] give the results of the

[1] Ueber die untersuchungen der erdbeben und die bisherige resultate. *Zurich vierteljahresschr.*, 1879.

Die erdbeben und deren beobachtung. Zurich, 1880. This appeared also in French, translated by Forel, in the *Arch. des sciences*, iii. 1880, 261.

Die schweizerischen erdbeben von November 1879 bis ende 1880. *Jahrb. tellur. observ.*, 1881; with an appendix giving important corrections.

[2] Les tremblements de terre étudiés par la commission sismologique suisse de novembre 1879 à fin de 1880. *Arch. des sciences*, vi. 1881, 461.

Id. . . . pendant l'année 1881. *Arch. des sc.*, xi. 1884, 147.

Les tremblements de terre orogéniques étudiés en Suisse. *L'Astronomie*, ii. 1883, 449; iii. 1884, 13.

commission's work in attractive form. It is sometimes even a little amusing to notice the purely scientific treatment that these distressing calamities receive; for, just as an old surgeon will describe a terrible operation as a 'beautiful case,' so Forel writes of a violent shock as 'ce beau tremblement de terre.' Spain must advance far beyond its present superstitions before it can have so calm and judicial a commissioner. The classification that was early adopted is an important matter, and, in the present stage of the study in this country, deserves quotation in full; for, in any statistical comparisons, it is important that the facts on which they rest should be recorded on similar scales. The first principle is the grouping of the fainter antecedent and subsequent tremors with the more violent shocks, as making parts of a single disturbance; and, although this is generally well advised, it sometimes leads to including shocks (*secousses*, *stossen*) that occurred during ten or more days as parts of a single earthquake (*tremblement*, *beben*). Thus, in 1880, there were sixty-two tremors or shocks in twenty-one earthquakes; and in 1881 the numbers were one hundred and sixty-three, and thirty-seven for Switzerland alone. The intensity of shocks is measured on the Rossi-Forel scale, as follows: —

1. Very faint; recorded by a single seismometer; noticed only by practised observers.
2. Registered on several seismometers of different construction; noticed by a few persons at rest.
3. Duration or direction noted; felt by a number of persons at rest.
4. Felt by persons while moving; shaking of movable objects, doors, windows; cracking of ceilings.
5. Felt by every one; furniture shaken, and some bells rung.
6. Sleepers awakened; general bell-ringing, clocks stopped, visible swaying of trees; some persons run out of buildings.
7. Overturning of loose objects; plaster falling, general fright; buildings not seriously injured.
8. Chimneys falling; walls cracked.
9. Partial or total destruction of buildings.
10. Great disasters; overturning rocks, forming fissures and mountain-slides.

In order to obtain a measure of the 'value' of the earthquake in which all its elements are included, the area affected and the number of accessory shocks must also be considered. For Switzerland, the areas are grouped by diameters of five, fifty, one hundred and fifty, and five hundred kilometres; and the weak, medium, and strong accessory tremors are counted separately (n, n', n''). Then the total value of a disturbance is $V =$ (Intensity scale $\times$ area scale) $+ n + 2n' + 3n''$. This is evidently a useful method of combining and giving weight to the various peculiarities of an earthquake, but it has a manifest inaccuracy coming from the inequality of the divisions in the scale of intensity. Great earthquakes would not be given their deserved superiority over small ones in such a measurement. It would be improved by squaring the intensity number of the principal shock.

The numerical results thus far announced may be briefly summarized: they give a moderate winter maximum, thus agreeing with Volger's studies of some years ago; a strongly marked preference for the night hours, with a maximum between two and four in the morning, while the minimum is from noon to two o'clock in the day; no sufficient connection is made out between the attitude of the moon and the occurrence of shocks; and the south-western corner of the country has had twice as many earthquakes as any other, but no general map showing distribution has yet been published.

There seems to be no dissent from the opinion that these shocks are in no way of volcanic origin: they are by all regarded as evidence of continued structural disturbance and growth of the Alps. There is no appearance of volcanic action, but evidence of lateral crowding is afforded by every valley that exposes sections of distorted rocks on its sides. The distortion may be slow and uniform, and evenly distributed through the rocks, especially when far below the surface, under the heavy weight of overlying strata; and then it is probable that no disturbance would be felt above. But it may also be irregular by fits and starts, as the crushing stress accumulates to the limit of the rocks' strength, which snap asunder as the limit is passed; and the tremor thus produced is known on the surface as an earthquake. The migration of shocks gives valuable confirmation of this view. Some earthquakes, composed of a number of accessory shocks having a common centre, are properly referred to a single origin: examples of such are found in 1879, vii., and 1880, i., ix., xiii., and xx., of Forel's lists. But in a few other cases the successive shocks must be referred to different centres, which travel or 'migrate' along a line that is naturally supposed to mark a yielding fissure. 1879, v., and 1880, viii., belong to this interesting class. Still more peculiar is the interpretation given by Heim to number xlvii. of his list (June 28, 1880). The observations of this earthquake showed only a moderate velocity of propagation (112 to 204 metres a second) in the direction of the longer diameter of the region affected, and this is regarded as too small for the advance of an elastic earth-wave. Moreover, the local directions of the shock, agreeing fairly well among themselves on either side of the longer diameter, did not agree with the direction of the extension of the disturbed area in time. It was therefore supposed that the disturbance resulted from the successive breaking or slipping of a long fissure, from which earth-waves spread out laterally with normal velocity; thus showing the migration of the focus quickly accomplished in a simple earthquake, much as it had been implied by the more deliberate shifting of the successive shocks in complex disturbances. The explanation is a tempting one, and, if confirmed by similar results in the future, will be an important contribution to seismology.

The statistical results that will, after a few decades, be gathered from these uniformly recorded observations, will be of especial value; and the further development of the connection that has been surmised

between the disturbed areas and the structural features of the Alps will be looked for with interest.

W. M. DAVIS.

THE CAUSES OF EARTHQUAKES.[1]

I HAVE followed with much interest the details upon the recent earthquakes, which the newspapers have published; but this question is so intricate, so difficult, that I assure you I should not have undertaken its investigation had I thought any other person would have been willing to do so. Meanwhile, at the academy, the question is growing in importance, geologists, geodesists, and others having taken it up with considerable enthusiasm. Under these conditions, I have thought that I ought not to draw back. Nevertheless, I am not without a certain apprehension. Indeed, the question of earthquakes is one of the vaguest. Data are hitherto wanting, but there is no lack of theories; for as in medicine, when there are many remedies for one disease, it is frequently the case that neither is really good, so in geology, in terrestrial physics, when many theories are put forward to explain a phenomenon, it is necessary to cast aside each, and say that none is absolutely sufficient. I start, then, with a certain hesitation; and yet, when one accepts an appointment to study facts of this sort, it seems to me necessary to have in mind some theory, true or false, and to adopt it more or less boldly, free to abandon it after contradiction.

I start, then, with a certain idea which I expect to verify or invalidate. I do not propose to tell you what it is: I will simply ask your permission, before giving my plan of studies, to point out in a few words the current theories to account for earthquakes.

There are four principal ones. They are very old. We find them in the Greek authors, and perhaps, if one were to search carefully, they would be found among East-Indian traditions. The first is based upon the supposition, that, under the solid crust of the earth, the sudden generation of gases and vapors causes subterranean explosions; and it is the effect of these shocks that we feel on the surface. This would be in a way comparable to an explosion of dynamite taking place at a great depth. I need not discuss these theories, yet I may say that perhaps this one is true when applied to earthquakes in the neighborhood of volcanoes. It is certain, indeed, that as soon as the earth opens, great quantities of gas are liberated from beneath the surface, where in some way they have been generated and furnished with extraordinary power.

But even if this theory is probable with regard to volcanic earthquakes, I think that it would be difficult to apply it to those in Spain.

A second theory has been proposed by a learned physicist, Alexis Perrey. It is based upon the supposition that the combined influence of the sun and moon, acting upon the liquid parts beneath the surface, produces tides analogous to those on the surface of the earth. These vast tides of liquid fire at certain favorable movements, striking upon the solid external crust, cause the earthquake shocks. I also abandon this theory, for I do not think it can apply to Spain.

There remain two others, one that of Scheuchzer, a distinguished *savant*, at once paleontologist, geologist, and physicist. Having studied the earthquakes in Switzerland, he has attributed them, not without reason, in certain particular cases, to the falling-in of subterranean caverns caused by the dissolving-out of such substances as salt or gypsum by water which has penetrated beneath the surface. Such a collapse would, without doubt, cause a very appreciable shock at the surface of the earth. This theory may apply to certain special cases; but it remains to be seen if it applies to the Spanish earthquakes.

There is a fourth which is at present in favor in Germany among nearly all geologists of that country, and it has also been accepted by some in other countries. In France it has not been so well received: nevertheless, there are eminent men who entertain it. It is based upon geological observations. There are no geologists, indeed, who, observing the walls of the cracks in the metamorphic rocks, for instance, have not been struck by the fact that these beds, originally deposited in a horizontal position, have been raised and broken. There have evidently been movements of extreme importance, since rocks that were originally connected and regular are now in the greatest disorder. Now, it is certain that these movements could not have been produced without superficial shocks at the moment when the fissures were made. Therefore there must have been earthquakes in all geological epochs, even the most ancient, which are exactly comparable with those of to-day. But reciprocally, if these ancient foldings have produced earthquakes, why are not the present earthquakes the result of analogous phenomena?

You see that the theory is perfectly regular up to this point. It is only necessary to know (the difficulty is merely thrown back in time) what is the origin of these foldings, of these fractures. Why these out-throws, these subsidences, these convolutions? We then arrive at a very old explanation, given by geologists, and still admitted by many *savants*. It is that the earth is continually cooling, and so contracting. The superficial crust has reached a nearly constant temperature; but this is not true of the liquid portions adjacent to it, where the temperature must be very high, though constantly cooling. In cooling, its volume becomes less, and its contractions cause foldings and fractures in the solid crust. This theory is rather old, it is true, but there is no better theory at present.

As to the Spanish earthquakes, it seems to me, that, of these four theories, only two should receive any attention.

The question is, therefore, whether there are fissures, bendings, and faults beneath the surface, or whether the water is dissolving out caverns. In a

[1] A communication to the French geographical society, on Jan. 23, by Mr. FOUQUÉ, professor of geology in the Collége de France, and chief of the commission appointed by the Academy of sciences to study the Spanish earthquakes.