dynamic forces in altering the atomic relationships of the chemical constituents of the rocks, *quâ* the development of new minerals, would appear to have been very limited.

3. In the present state of our knowledge the two most interesting questions presented to us by these rocks would seem to consist (*a*) in determining to what extent such dynamic deformation, as we actually observe, has been prior or posterior to the ultimate solidification of the various parts of the original magma; and (*b*) in determining to what extent simple atomic interactions leading to molecular segregation, supplemented by the action of gravity upon minerals of various densities and by forces of a tidal nature acting upon the magma as a whole, may have caused the vein-structure and the stratiform arrangement, which, whether in its original or in its deformed condition, has constituted one of the most puzzling phenomena presented to the minds of investigators of the Malvern crystallines.

4. The phenomena presented by these rocks as a whole seem to lend no support to the doctrine of "regional metamorphism" as usually understood, since, when field-relations are duly considered, it becomes far easier to explain such simulations of "bedding" as are met with, by mechanical deformation of crystalline rocks, to which a diagenetic stratiform structure had been imparted, than by the hypothesis of reconstruction of crystalline minerals out of clastic materials.

5. The writer, having made free use of the published writings of Phillips, Holl, Rutley, and Callaway, and of the valuable results of microscopic work published by the two gentlemen last named, and having approached the subject in the light of the principles advocated by himself in 1888–9, and since, is happy to find himself to a great extent in accord with Dr. Callaway, though unable to follow him to the full extent in the matter of "dynamic metamorphism."

NOTICES OF MEMOIRS.

ABSTRACTS OF PAPERS READ BEFORE THE BRITISH ASSOCIATION, EDINBURGH, AUGUST, 1892.

I.—ON THE "GRAMPIAN SERIES" (PRE-CAMBRIAN ROCKS) OF THE CENTRAL HIGHLANDS. By HENRY HICKS, M.D., F.R.S., Sec. Geol. Soc.

IN his address to the Geologists' Association in the year 1883 (Proceedings of the Geologists' Association, vol. viii. p. 270), the author gave the name of "Grampian Series" to a group of rocks which occupy an extensive area in the Central Highlands. He described them briefly as "tender gneisses, bright siliceous schists, chiastolite schists, quartzites and limestones," also some "chloritic schists." He considered them as of pre-Cambrian age, and all the evidence since obtained tends to confirm this view. It is quite possible, of course, that newer rocks may be in places entangled amongst them, and the author pointed out certain lines running from

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N.E. to S.W. where there are indications of newer rocks in broken folds, but the majority of those which he claimed as being of pre-Cambrian age are now generally admitted to be older than any of the Palæozoic rocks of that area. The further descriptions of these rocks now given have been prepared with the kind assistance of Professor T. G. Bonney, D.Sc., F.R.S., to whom the author some time since submitted specimens, collected at various points in the year 1880.

From near Ballachulish, etc., a finely-banded, fine-grained micaceous schist, containing apparently a considerable amount of felspathic matter.

From Glen Spean, etc. Fine-grained gneisses, not rich in quartz, but with a considerable amount of black mica, not markedly foliated except as the result of subsequent pressure. All are characterized by a peculiar speckled aspect, the spots being about the size of pins' heads. The felspar varies from a warm to a reddish gray.

From Tyndrum, etc. A somewhat varying series of schists, but with a common facies. Some have but little mica, consisting mainly of quartz and felspar, and pale-gray or reddish in colour; others are very micaceous schists of a lead colour, with sheen surfaces and indications of mineral banding. There are also very quartzose gneisses of a white or pinkish-white colour.

Crianlarich and Killin, etc. Calc mica-schists, with sheen surfaces, due to subsequent pressure, but showing mineral banding. Also fine-grained gneisses like some of those near Tyndrum, but as they have a very marked cleavage foliation they may originally have been somewhat coarser grained. A garnetiferous mica-schist from several places.

Blair Athol, etc. Dark mica-schists, with rather a carbonaceous aspect, and a very marked cleavage foliation. Some show on close examination along the edges a speckled aspect, recalling some of the gneisses mentioned above. There is also a fairly coarsely crystalline limestone, with specks and streaks of green serpentinous material and some scattered pyrite; also a calc mica-schist, modified by pressure, and an important series of quartzose schists similar to those found at Tyndrum, etc.

To the south of this line, as mentioned by the author in another paper (Proceedings of the Geologists' Association, vol. vii. p. 84), "schistose and slaty chloritic rocks become more abundant in association with micaceous rocks," and "everywhere strongly recall to mind the pre-Cambrian rocks of Wales, especially those in Anglesea, and in the Lleyn Promontory." The author insisted that the term "Grampian" was the only suitable name for this group of pre-Cambrian rocks. It was suggested and adopted by him at a time when all these rocks were claimed by the Geological Survey as of Silurian age, and these rocks are nowhere in Britain so well exposed as in the Grampian mountains of Scotland.

II.—Earthquake Phenomena in Japan. Twelfth Report. By Prof. John Milne, F.R.S., F.G.S.

1. *The Gray-Milne Seismograph.*

THE seismograph constructed in 1883—the expense of which was partly defrayed by the British Association—has during the last year given diagrams and records of Earthquakes, from number 1106 to number 1241.

2. *Report on Earthquakes felt in Japan in* 1888 *and* 1889.

In 1888 the number of Earthquakes recorded in Japan was 630, and the total land area shaken was 970,800 square miles. In 1889 the number of Earthquakes was 930, and the area shaken 1,048,200 square miles. On February 5th, 1888, an Earthquake shook 57,600 square miles. Some account is given of Earthquakes which preceded the eruption of Bandaisan, when within 10 minutes 28 square miles of a fertile valley were buried from 30 to 100 feet deep beneath a sea of earth and boulders. Everybody in the district perished. The damming up of the valley has formed a lake 8½ miles long.

On July 28th, 1889, an Earthquake took place in the Southern island. Twenty were killed and seventy-four wounded. All these Earthquakes have been classified with regard to hours, days, months, seasons, etc. They are also grouped according to intensity, direction, etc. It is clear that the vast amount of material which comes in yearly from the 700 stations of observation is capable of being analysed by methods other than those given. The Government Staff is insufficient to carry out more than their usual routine work. To carry it out privately requires access to documents and funds. The nature of new researches which might be made is indicated in the Report. At any moment all this valuable material bearing on Seismology accumulated in Japan, and of which there is no copy, may be lost by fire.

3. *Earth Pulsations.*

So far as the writer is aware, no attempt has been made to determine the character of the movements common to all countries usually called Earth Tremors. By using exceedingly light conical pendulums (made from a needle and a silk fibre)—the pointer being replaced by a small mirror reflecting a ray of light—the writer is inclined to the view that the earth-motions producing movements in this form of apparatus are not elastic vibrations such as might be produced by the beating of a steam hammer, but that they are long wave-like undulations like the swell on an ocean. During the time that these pulsations are continuing it is noticed that they have a definite direction. They are most frequent when the place of observation is crossed by a steep barometric gradient, whether there is wind or whether it is fine. The possible relationship of these movements to the escape of Fire Damp, the swinging of pendulums, etc., is discussed. The records of these phenomena have been photographed, and examples of them accompany the Report.

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4. *The Overturning and Fracturing of Columns, Walls, etc.*

By continuing experiments on the overturning of columns when subjected to earthquake-like motion, we can now state with confidence the acceleration required to overturn any given column by its own inertia. In the experiments on fracturing, all the brick columns and walls snapped at their base. The form of column which when moved back and forth by an Earthquake will offer an equal resistance at all horizontal sections to the effects of its own inertia has been determined.

In ordinary engineering practice the cross-section of piers is practically uniform from the base upwards—short piers near a river bank have the same cross-section as long piers in the centre of the river, etc. A large series of piers for bridges now being built in Japan have been designed in accordance with the rules resulting from our experiments on fracturing.

5. *The Great Earthquake of October 28th,* 1891.

9,960 people were killed, 128,750 dwelling houses were totally destroyed, and in a few seconds Japan lost the equivalent of perhaps 30 million dollars. About twelve million dollars have already been poured into the district for repairs and relief. The movement reached Berlin at the rate of 9,800 feet per second. At Tokyo, 150 miles from the origin, the ground moved in long flat waves, which tilted the water in ponds and caused seismographs to act as angle measurers. These waves had a velocity of about eight feet per second. A few chimneys fell.

The origin was the formation of a fault which can be traced for 40 or 50 miles along the surface. Some 3,000 shocks have been recorded since the first great shock. Mountain slopes have been stripped by land slips, valleys are dammed up and lakes have been formed. Valleys have been compressed so that farms have decreased in area. 400 miles of river banks were shaken down or deeply crevassed. Mud volcanoes formed. Railway lines and bridges twisted and distorted. Foundations of bridges in one case were shifted 19 feet.

Some thousands of calculations respecting accelerations to produce fracturing and overturning have been made. Records of seismographs have been examined and the velocity of gravity and of elastic waves have been computed. The origin was in a non-volcanic district but where elevation was in progress. Earthquakes seldom originate from volcanoes, but they occur in volcanic countries where secular movements are in progress or where mountains are in process of formation.

A photographic record taken at each end of a water level several miles in length and if possible at right angles to an axis of elevation might give measurements of slow tilting and throw light on a possible relationship between Earthquakes and these movements, etc. Such an experiment might cost £500.

Earthquake and Volcanic effects will, if possible, be illustrated by some very large photographs kindly *lent* by Prof. W. K. Burton.

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The grant last year was £10, but at least three times this sum has been spent.

Before the end of this year, with the assistance of subscribers, I shall publish a Seismological Journal which will be uniform in character with the Transactions of the Seismological Society.

III.—Fossil Arctic Plants found near Edinburgh. By Clement Reid, F.L.S., F.G.S.

Recent discoveries by Mr. Bennie, of the Geological Survey, have brought to light a series of silted-up tarns or small lochs in the neighbourhood of Edinburgh. These tarns seem to have lain in irregular hollows left on the retreat of the ice, for the lowest deposits usually yield remains of arctic plants. The principal localities for these plants are Corstorphine and Hailes. Trees, except perhaps the alder, are entirely missing in the lower deposits, and the vegetation consists mainly of dwarf willow and birch, with a few herbaceous plants, of species still living within the Arctic Circle. The list now includes the following plants, those marked with an asterisk being arctic species no longer living in the lowlands of Scotland:—

Ranunculus aquatilis, Linn.
,, *repens*, Linn.
Viola (?).
Stellaria media, Cyr.
Rubus sp.
**Dryas octopetala*, Linn.
Potentilla sp.
Poterium sp.
Hippuris vulgaris, Linn.
Myriophyllum spicatum, Linn.
Taraxacum officinale, Web.
Andromeda Polifolia, Linn.
**Loiseleuria procumbens*, Desv.
Menyanthes trifoliata, Linn.
**Oxyria digyna*, Hill.
**Betula nana*, Linn.
Alnus (?).
Salix repens, Linn.
* ,, *herbacea*, Linn.
* ,, *polaris*, Wahlb.
* ,, *reticulata*, Linn.
Empetrum nigrum, Linn.
Potamogeton sp.
Eleocharis palustris, R. Br.
Scirpus pauciflorus, Lightf.
,, *lacustris*, Linn.
Carex, 2 sp.

IV.—Devon and Cornish Granites. By W. A. E. Ussher, F.G.S.

From the relations of the stratified rocks to the granites of Devon and Cornwall there is no obtainable evidence as to the upheaval of the latter.

From evidences of great mechanical disturbance (such as deflections of strike and constrictions of outcrop), of metamorphism in areas bordering the granites, from the shapes, relative positions, and internal structure of the granite masses; from the distribution of the Elvans, and from evidences of the production of cleavage in the area prior to the contact metamorphism of the cleaved rocks, it appears that the sites of the Devon and Cornish granite masses were occupied by the granites or pre-existent and subterraneously connected rocks of pre-Devonian age, which had, in a rigid state, exercised an obstructive influence on the north and south movements, and had thereby produced great mechanical effects on the surrounding strata prior to the alteration of the latter.

The contact alteration of the stratified rocks seems to be coeval

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with the metamorphism of these ancient masses and the consequent genesis of the granites in their present form during the later stages, or at the close of the Carboniferous epoch. The intrusion of granitoid rocks perhaps accompanied, certainly succeeded, the solidification of the granites, and continued at intervals down to the Permian quartz porphyries. These rocks, called Elvan dykes, approximate, with some few exceptions (notably the north and south Elvan of Watergate Bay), to the general strike produced by the north and south movements, and in some cases, as near Camelford, to the main strike deflections produced by the resistance of granite masses to these movements, but in proceeding from granite to killas they ignore the slight uptilt of the latter on the margin of the granites.

The evidences in favour of the subterranean connection of the Devon and Cornish granites are too strong to be ignored, and this connection annihilates the application of the laccolitic hypothesis advanced by me to account for the relations of the Dartmoor granite, and at the same time contradicts the suggestion of the upheaval of the granites in or through their surroundings.

V.—On the Occurrence of *Chonetes Pratti*, Davidson, in the Carboniferous Rocks of Western Australia. By R. Bullen Newton, F.G.S., British Museum (Natural History).

IN this communication the author directed attention to some valves of a *Chonetes* recently discovered by Mr. Harry Page Woodward, F.G.S., in rocks of Carboniferous age situated in the Irwin River District of Western Australia, which he referred to *C. Pratti*, a species described and figured by the late Dr. Thomas Davidson in the "Geologist" for 1859, Plate IV, Figs. 9–12, p. 116. As the original description, contained only in the explanation of the plates, is necessarily somewhat brief and imperfect, the following additional characters were submitted:—

(1) That the external surface of both valves, besides being ornamented with very fine radiating striæ, possess subimbricating concentric lines of growth; (2) that the extent of the cardinal margin represents the minimum width of the shell; (3) that the granular asperites on the interiors of the valves are disposed in lines as they reach the margins, having more or less an elongate appearance resembling short tubular spines; (4) that the external surface of the ventral valve exhibits a number of small orifices placed at irregular distances, which are probably basal attachments of spines, a character known to exist in *Chonetes papilionacea*, *C. Hardrensis*, etc. The author then gave the dimensions of the Davidson type valves, together with those of the Western Australian specimens, the latter being somewhat larger. A minute examination of the Western Australian specimens and their comparison with the originals of *C. Pratti* in the Davidson collection at the British Museum has demonstrated the fact that they are mineralogically as well as structurally the same brachiopod. This fact is of considerable importance, as the Davidson specimens at the time of descrip-

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tion were unlocalised, and the species, as far as can be ascertained, has never been referred to since either by Davidson himself or by any other writer up to the present time. There is very little doubt that the new material from the Irwin River District yielded also the Davidson types. The paper concluded with a small list of Carboniferous fossils collected in the same neighbourhood, which have been described and figured by Messrs. A. H. Foord and G. J. Hinde in the GEOLOGICAL MAGAZINE for 1890.

VI.—THE FULLER'S EARTH MINING CO. AT WOBURN SANDS. By A. C. G. CAMERON, Geological Survey of England and Wales.

SINCE reporting to the British Association in 1884 and 1891 on the progress made in working this mineral, the demand for it has gone on steadily increasing, and mining on systematic principles has been established in Bedfordshire for the first time. The mines now show an extensive industry, with underground galleries that extend many hundreds of feet. The layers of earth as they come to be worked are not found disposed quite evenly, but raised into slight inequalities, ridge-and-furrow-like. Although all one sort of earth, the layers alternate in colour downwards, from yellow, through blue, to yellow again; a difference in colour which Mr. Player, who has analysed the Woburn earth, does not consider is explained by difference in composition.

It has long since been suggested that the name "Woburn Sands" should be applied to the lower portion of the Lower Greensand of the Midlands, and the name may well be retained for Bedfordshire and Bucks. It is at Woburn Sands, in these counties, that the greatest expanse and greatest thickness of Greensand occurs, and where it contains also those valuable deposits of fuller's earth.

VII.—NOTE ON A GREEN SAND IN THE LOWER GREENSAND, AND ON A GREEN SANDSTONE IN BEDFORDSHIRE. By A. C. G. CAMERON, Geological Survey of England and Wales.

THE beds in the section at the "Parish Sandpit" at Apsley Guise are given below in descending order:—

	Ft.	In.
1. Yellow and grey sand with strings of yellow fuller's earth ...	20	0
2. Lenticular seam yellow fuller's earth...	3 to 6	
3. Yellow and grey sand, in parts false-bedded	25	0
4. Yellow fuller's earth, dovetailed amongst green sand	2	0
5. Yellow ochre	0	2
6. Bright green sand 'hearted' darker green	2	6
7. Coarse, buff-coloured irony sand	1	8
Oxford Clay	54	10

The bright green sand (No. 6), with a darker middle portion, consists of irregular-shaped grains of quartz, stained green; besides which, there are brown grains, the precise nature of which remains for the present undetermined. With the hammer this sand gives a brown streak, the brown grains, which are comparatively soft, being the cause of it. The absence of glauconite is a distinct feature in this sand, that being the usual colouring-matter of cretaceous green sands. A darker tint of green pervades the middle portion of the bed, giving it the appearance of being 'hearted,' as the expression goes. Rather over a mile from this place, Mr. Whitaker observed in the tower of Husborne Crawley Church a quantity of green sandstone of a bright colour, and sometimes of a glassy texture, which has been recognized as like some that occurs in the Lower Greensand of Ightham, Kent. It is a serviceable-looking stone, and the brightness of its colour adds beauty to the brown sandstone, of which the edifice is mainly built. The stone seems to be a counterpart of the green sand in the Apsley Section, and similarly colour-hearted. Professor Bonney, on receiving specimens of the Husborne Crawley rock, but speaking from sight only, doubts, however, whether it is the same as the green sand at Apsley. It may be mentioned that pieces of the same rock have been dug up in the roadway half a mile from the church, and a larger boulder-like piece lies by the roadside, on the outskirts of the village green. Adjoining the churchyard is a very old-looking excavation, that suggests the spot at which this stone may have been got. Seeing the difficulty of transporting stones in olden times, it is extremely unlikely that the stone came from a distance. Possibly, therefore, there may be some local equivalent of the Lower Greensand of Kent in the Bedfordshire Greensand, which, if not entirely dug away in supplying the stone for Crawley Church, may yet again be brought to light.

VIII.—British Association for the Advancement of Science, Edinburgh, 1892.

Address to the Geological Section by Professor C. Lapworth, LL.D., F.R.S., F.G.S., President of the Section.

(PART II.)

In the structure of our modern mountain ranges we discover the most beautiful illustrations of the bending and folding of the rocky formations of the earth-crust. The early results of Rogers among the Alleghanies, and of Lory and Favre in the Western Alps, have been greatly extended of late years by the discoveries of Heim and Baltzer in the Central Alps, of Bertrand in Provence, of Margerie in Languedoc, of Dutton and his colleagues in the western ranges of America, and of Peach and Horne and others in the older rocks of Britain. The light these researches throw upon the phenomena of mountain structure will be found admirably summarised and discussed in the works of Leconte, of Dana, of Daubrée, of Reade, of Heim, and finally in the magnificent work of Suess, the 'Antlitz der Erde,' of which only the first two volumes have yet appeared.

Looking first at the mountain fold in its simplest form as that of a bent rock-plate composed of many layers, which has been forced into two similar arc-like forms, the convexities of which are turned, the one upwards and the other downwards, we find in the present mountain ranges of the globe every kind represented. We commence with one in which the arch is represented merely by a gentle swell in the rock sheet, and the trough by an answering shallow depression, the two shading into each other in an area of contrary flexure. From this type we pass insensibly to others in which we see that the sides of the common limb or septum are practically perpendicular. From these we pass to folds in which the twisted common limb or septum overhangs the vertical, and so on to that final extreme, where the arch limb has been pushed completely over on to the trough limb, and all three members, as in our note-book experiment, are practically welded into one conformable solid mass.

Although the movements of these mountain folds are slow and insensible, and only effected in the course of ages, so that little or no evidence of the actual movement of any single one of them has been detected since they were first studied, yet it is perfectly plain that when we regard them collectively, we have here crust folds in every stage of their existence. Each example in itself represents some one single stage in the lifetime of a single fold. They are simply crust folds of different ages. Some are, as it were, just born ; others are in their earliest youth. Some have attained their majority, some are in the prime of life, and some are in the decrepit stages of old age. Finally, those in which all three members—arch limb, trough limb, and septum—are crushed together into a conformable mass, are dead. Their life of individual movement is over. If the earth pressure increases, the material which they have packed together may of course form a passive part of a later fold, but they themselves can move no more.

In many cases, due partly to the action of longitudinal pressures, the septum becomes reduced to a *plane* of contrary motion, namely—the over-fault, or thrust-plane, and the arch limb and the trough limb slide past each other as two solid masses. But here we have no longer a fold, but a fault.

We see that every mountain fold commences first as a gentle alternate elevation and depression of one or more of the component sheets of the geological formations which make up the earth-crust. This movement is due apparently to the tangential thrusts set up by the creeping together, as it were, of those neighbouring and more resistant parts of the earth-crust which lie in front of and behind the moving wave. Yielding slowly to these lateral thrusts, the crest of the fold rises higher and higher, the trough sinks lower and lower, the central common limb or septum grows more and more vertical, and becomes more and more strained, sheared, and twisted. As this middle limb yields, the rising arch part of the fold is forced gradually over on to the sinking trough part, until at last all three members come into conformable contact, and further folding as such is impossible. Movement ceases, the fold is dead. We see also from our note-book experiment that the final result of the completion of the fold is clearly to strengthen up and consolidate that part of the crust plate to the local weakness of which it actually owed its origin and position. The fold has, by its life-action, theoretically trebled the thickness of that part of the earth-plate in which its dead remains now lie. If the lateral pressure goes on increasing and the layers of the earth-crust again begin to fold in the same region, the inert remains of the first fold can only move as a passive part of a newer fold : either as a part of the new arch-limb, the new trough-limb, or the new septum. As each younger and younger fold formed in this way necessarily includes a more resistant, and therefore a thicker, broader, and deeper sheet of the earth-crust, we have here the phylogenetic evolution of a whole family of crust folds, each successive member of which is of a higher grade than its immediate predecessor.

But it very rarely happens that the continuous crust plate in which any fold is imbedded is able to resist the crust creep until the death of the first fold. Usually, long before the first simple fold is completed, a new and a parallel one rises in front of it, normally on the side of the trough limb, and the two grow, as it were, henceforward side by side. But the younger fold, being due to a greater pressure than the older, must of necessity be of a higher specific grade, and the two together form a generic fold in common.

Our present mountain systems are all constituted of several families of folds, formed in this way of different gradations of size, of different dates of origin, and of different stages of life evolution ; and in each family group the members are related to each other by this natural genetic affinity.

Sometimes the new folds are formed in successive order on one side of the first fold, and then we have our unilateral (or so-called unsymmetrical) mountain groups, like those of the Jura and the Bavarian Alps. Sometimes they are formed on both sides of the original fold, and then we have our bilateral (or so-called symmetrical) ranges, like the Central Alps. In both cases the septa of the aged or dead folds of necessity all slope inwards towards the primary fold. If, therefore, they originate only on one side of the primary fold, our mountain group looks unsymmetrical, with a very steep side opposed to a gently sloping side. If they grow on both sides of the original fold, we have the well-known 'fan structure' of mountain ranges. In this latter case the whole complex range is seen at a glance to be a vast compound arch of the upper layers of the earth-crust, keyed up by the material of the dead or dying folds, which by the necessities of the case constitute mighty wedges whose apices are directed inwards towards the centres of the system. But a complete arch of this kind is in reality not a single compound fold, but a double one, with a septum on both sides of it, and it requires two troughs, one on each side of it, as its natural double complement. The so-called unsymmetrical ranges, therefore, which are theoretically constituted merely of arch limb, trough limb, and septum, are locally the more natural and the more common.

It is clear that in the lifetime of any single fold its period of greatest energy and most rapid movement must be that of middle life. In early youth and in old age the lateral pressure is applied at a very small angle, and the tangential forces act therefore under the most disadvantageous circumstances. But in the middle life of the fold the arch limb and the trough limb stand at right angles to the septum, and the work of deformation is then accomplished under the most favourable mechanical conditions and with the greatest rapidity. That is to say, the activity of the fold and the rate of movement of the septum, like the speed of the storm wind, varies directly as the gradient.

In our note-book experiment we observed that little or no change took place in the arch limb and trough limb, while the septum became remarkably sheared and twisted. The same is the case in nature, but here we have to recollect that these moving mountain folds are of enormous size, indeed actual mountains in themselves. These great arches, scores of miles in length, thousands of feet in height and thickness, must of necessity be of enormous weight, capable of crushing to powder the hardest rocks over which they move, while the thrust which drives them forward is practically irresistible. It is plain, therefore, that while the great arch limb and the trough limb of one of these mighty folds move over and under each other from opposite directions, they form in combination an enormous machine, composed of two mighty rollers or millstones, which mangle, roll, tear, squeeze, and twist the rocky material of the middle limb or septum, which lies jammed in between them, into a laminated mass. This deformed material, which is the characteristic product of the mountain-making forces, is, of course, made up of the stuff or the original middle limb of the fold; and whether we call it breccia, mylonite, phyllite, or schist, although it may be composed of sedimentary stuff, it is certainly no longer a *stratified* rock; and though it may have been originally purely igneous material, it is certainly no longer *volcanic*. It is now a manufactured article made in the great earth mill.

These mountain folds, however, are merely the types of folds and wrinkles of all dimensions which affect the rock formations of the earth crust. Within the mountain chains themselves we can follow them in lesser and lesser dimensions, fold within fold, first down to formations, then to strata, then to laminæ, till they disappear at last in microscopic minuteness beyond the limits of ordinary vision. Leaving these, however, for the moment, let us travel rather in the opposite direction, for these mountain folds are by no means the largest known to the stratigraphical geologist. Look at any geological section crossing our type continent of North America, and it will be found that the whole of the Rocky Mountain range on its western side and the Alleghany range on the east are really two mighty compound geological anticlines, while the broad sag of the intermediate Mississippi Basin is actually a compound geological syncline made up of the whole pile of the geological formations. That is to say, the continent of North America is composed of a pair of geological folds, the two arches of which are represented by the Rockies on the one side and the Alleghanies on the other, while the intermediate Mississippi syncline is the common property of both. Here, then, we reach a much higher grade of fold than the orographic or mountain-making fold, viz., the plateau-making fold or the semi-continental fold, which, because of its enormous breadth, must include a very much thicker portion of the earth-crust than the ordinary orographic fold itself.

But which must be the real middle limbs of these two American folds, the septal areas where most work is now being done and the motion is greatest?

Taught by what we have already learned of the mountain wave, the answer is immediate and certain. They must be on the steeper sides of each of the two folds, namely on those which face the ocean. How perfectly this agrees with the geological facts goes without saying. It is on the steep Pacific side of the western fold that

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the crushing and crumpling of its rocks is the greatest. It is on the Atlantic side of the eastern fold that the contortion and metamorphism of its rocks are at their maximum, while in the common and gently sloping trough of both folds, namely, in the intermediate Mississippi Valley, the entire geological sequence remains practically unmodified throughout.

Again, which of these two American folds should be the more active at the present day? Taught by our study of the mountain wave, the answer again is immediate and conclusive. It must be that fold whose septum has the steeper gradient. Geology and geography flash into combination. The steeper Pacific septum of the western fold from Cape Horn almost to Alaska is ablaze with volcanoes or creeping with earthquakes, while the gently inclined Atlantic septum of the eastern fold from Greenland to Magellan Straits shows none, except on the outer edge of the Antilles, in the very region where the slope of the surface is the steepest. We see at a glance that the vigour of these two great continental folds, like those of our mountain waves, varies directly as the surface gradient of the septum.

But the geographical surface of North America, considered as a whole, is in reality that of a double arch with a sag or common trough in the middle. We have seen already that this double arch, must be regarded as the natural complement of the equally double Atlantic trough. Here, then, if the path of analogy we have hitherto so triumphantly followed up to this point is still to guide us, the trough of the Atlantic must be, not only in appearance but in actuality, formed of two long minor folds of the same grade as the two that form the framework of America, but with their members arranged in reverse order. If so, their submarine septa ought also to be lines of movement and of volcanic action. And this is again the case. The volcanic islands of the Azores and St. Helena lie not exactly on the longitudinal crests of the mid-oceanic *Challenger* ridge, but upon its bounding flanks.

But we have not yet, however, finished with our simple folds. If we draw a line completely round the globe, crossing the Atlantic trough at its shallowest, between Cape Verde and Cape St. Roque, and continued in the direction of Japan, where the Pacific is at its deepest, we find that we have before us a crust fold of the very grandest order. We have one mighty continental arch stretching from Japan to Chili, broken submedially by the sag of the Atlantic trough; and we see that this great terrestrial arch stands directly opposed to its natural complement, the great trough of the Pacific, which is bent up in the middle by the mightiest of all the submarine buckles of the earth-crust, on which stand the oceanic islands of the central Pacific.

But if this be true, then the septum of all septa on our present earth-crust must cross our grandest earth fold where the very steepest gradient occurs along this line, and it must constitute the centre-point of the moving earth fold, and of greatest present volcanic activity. And where is this most sudden of all depression? Taught once more by our geological fold, the answer is instantaneous and incontrovertible. It is on the shores of Japan, the mightiest and most active of all the living and moving volcanic localities on the face of our globe.

But the course of the line which we indicated as forming our grandest terrestrial folds returns upon itself. It is an endless fold, an endless band, the common possession of two sciences. It is geological in origin, geographical in effect. It is the *wedding-ring* of geology and geography, uniting them at once and for ever in indissoluble union.

Such an endless fold again must have an endless septum, which, in the nature of things, must cross it twice. Need I point out to the merest tyro in these wedded sciences that if we unite the Old and New Worlds and Australia, with their intermediate sags of the Atlantic and Indian Oceans, as one imperial earth arch, and regard the unbroken watery expanse of the Pacific as its complementary depression, then the circular coastal band of contrary surface flexure between them should constitute the moving master septum of the earth's crust. This is the "Volcanic Girdle of the Pacific," our "Terrestrial Ring of Fire."

Or, finally, if we rather regard the compact arch of the Old World itself as the natural complement of the broken Indo-Pacific depression, then the most active and continuous septal band of the present day should divide them. Again our law asserts itself triumphantly. It is the great volcanic and earthquake band on which are strung the Festoon Islands of Western Asia;—the band of Mount St. Elias, the Aleutians, Kamtchatka, and the Kuriles;—the band of Fusijama, Krakatoa, and Sangir. The rate of movement of the earth's surface doubtless everywhere varies directly as the gradient.

We find, therefore, that even if we restrict our observations to the most simple and elementary conception of the rock fold as being made up of arch-limb, trough-limb, and twisting but still continuous septum, we are able to connect, in one unbroken chain, the minutest wrinkle of the finest lamina of a geological formation with the grandest geographical phenomena on the face of our globe.

We find, precisely as we anticipated, that the wave-like surface of the earth of the present day reflects in its entirety the wave-like arrangement of the geological formations below. On the land we find that the surface arches and troughs answer precisely to the grander regional anticlines and synclines of the subterranean sedimentary sequence; and it may, I believe, be regarded as certain that the submarine undulations have a similar or complementary relationship. We find in the New Geology, as Hutton found in the Old, that geography and geology are one. We find, as we suspected, that the physiognomy of the face of our globe is an unerring index of the solid personality beneath. It bears in its lineaments the characteristic family features and the common traits of its long line of geological ancestors.

Such, it seems to me, is an imperfect account of the introductory paragraphs of that great chapter in the New Geology now in course of interpretation by geologists of the present day; and we have translated them exactly in the old way by the aid of the only living geological language, namely, the language of present natural phenomena, and I doubt not that sooner or later the rest of this great chapter will be read by the same simple means.

I have strictly confined myself to-day to the discussion of the characteristics of the simple geological fold as reduced to its most elementary terms of arch, trough, and unbroken septum; for this being clearly understood, the rest naturally follows. But this twisted plate is really the key which opens the entire treasure-house of the *New Geology*, in which lie spread around in bewildering confusion facts, problems, and conclusions enough to keep the young geologist and other scientific men busily at work for many a long year to come.

Into this treasure-house I often wander myself, in the few leisure hours that I can steal from a very busy professional life; and out of it I bring now and again heresies that sometimes amuse and sometimes horrify my geological friends. As you have so patiently listened to what I have already said, perhaps you will permit me in a few final sentences to indicate in brief some of those novelties which I see already more or less clearly, and a few of those less novel points on which it appears to me that more light is wanted. My excuse is twofold, first, to furnish material for work and controversy to the young geologists; and second, to obtain aid for myself from workers in other walks of science.

The account of the simple rock-fold which I have already given you is of the most elementary kind. It presupposes merely the yielding to tangential pressure from front and back, combined with effectual resistance to sliding. But in the layers of the earth-crust there is always in addition a set of tangential pressures theoretically at right angles to this. The simple fold becomes a *folded fold*, and the compound septum twists not only vertically but laterally. On the surface of the globe the double set of longitudinal and transverse waves brought about in this way is everywhere apparent. They account for the detailed disposition of our lands and our waters, for our present coastal forms, for the direction, length, and disposition of our mountain-ranges, our seas, our plains, and lakes. The compound arch becomes a dome, its complementary trough becomes a basin. The elevations and depressions, major and minor, are usually twinned, like the twins of the mineralogist, the complementary parts being often inverted, and turned through 180° (compare Italy with the Po-Adriatic depression). Every upward swirl and eddy has its answering downward swirl. The whole surface of our globe is thus broken up into fairly continuous and paired masses, divided from each other by moving areas and lines of mountain making and crust movement, so that the surface of the earth of the present day seems to stand midway in its structure and appearance between the surfaces of the sun and the moon, its eddies wanting the mobility of those of the one and the symmetry of those of the other. In the geology of the earth-crust, also, the inter-crossing of the two sets of folds, theoretically at right angles to each other, gives rise to effects equally startling. It lies at the origin of the thrust-plane or overfault, where the septal region of contrary motion in the fold becomes reduced to, or is represented by, a *plane* of contrary motion. It allows us to connect together under one set of homologies folds and faults. The downthrow side of the fault answers to the trough, the upthrow side to the arch, of our longitudinal fold, while the fault-plane itself represents the septal area reduced to zero. The node of the fault, and the alternation and alteration of throw, are due to the effects of the transverse folding.

These transverse folds of different grades, which affect the various layers of the earth-crust differentially, account also for the formation of laccolites, of granitic cores, and of petrological provinces. They enable us also to understand many of the phenomena of metamorphism.

Of the folds of the *third order*, I shall here say nothing, but I must frankly admit that the primal cause of all this tangential movement and folding stress is still as mysterious to me as ever. I incline to think that the motion is due to many causes—to tidal action, to sedimentation, and many others. I cannot deny, however, that it may be *mainly* the result of the contraction in diameter of our earth, due to the loss of its original heat into outer space? For everywhere we find evidences of symmetrical crushing of the earth-crust by tangential stresses. Everywhere we find proofs that the various layers of that crust have been most affected differentially, and the outer layers have been bent the most. We seem to be dealing not so much with a solid globe as with a globular shell composed of many layers.

Is it not just possible after all that, as others have suggested, our earth is such a hollow shell, or series of concentric shells, on the surface of which gravity is at a maximum, and in whose deepest interior it is non-existent? May this not be so, also, in the case of the sun, through whose spot-eddies we possibly look into a hollow interior? If so, perhaps our present nebulæ may also be hollow shells formed of meteorites; on the surfaces of these shells the fiery spirals we see would be the swirls which answer to the many twisting crustal septa of the earth. Our comets, too, in this case might be elongated ellipsoids, whose visible parts would be merely interference phenomena, or sheets of differential movement.

In this case we have represented before us to-day the past of our earth as well as its present. Uniformity and Evolution are one.

Thus from the microscopic septa of the laminæ of the geological formations we pass outwards *in fact* to these moving septa of our globe, marked on the land by our new mountain chains, and on the shores by our active volcanoes. Thence we sweep, *in imagination*, to the fiery eddies of the sun, and thence to the glowing swirls of the nebulæ; and so outwards and upwards to that most glorious septum of all the visible creation, the radiant ring of the Milky Way.

Professor George Darwin, in his Address to the section of Mathematical and Physical Science at the meeting of the British Association at Birmingham in 1886, with all the courage of genius, and the authority of one of the sons of the prophets, acknowledged that it seems as likely that "meteorology and geology will pass the word of command to cosmical physics as the converse." Behind this generous admission I shelter myself. But I feel absolutely confident that long after the physicists may have swept away these astronomical suggestions as "the baseless fabric of a vision," there will still remain in the treasure-house of the geological fold a wealth of abundant material for the use of the mathematician, the physicist, the chemist, the mineralogist, and the astronomer, of the deepest interest and of the highest value.

NOTE.—The first Part of the above Address was set up inadvertently from an uncorrected proof. Most of its errors explain themselves, but for the sake of clearness, the reader should substitute the following for the corresponding paragraphs on pp. 420–421.

In the earlier days of geology one of the first points recognised by our stratigraphists was the fact that the formations were successive lithological sheets, whose truncated outcropping edges formed the present surface of the land, and that these sheets lay inclined at an angle one over the other, as William Smith quaintly expressed it, like a tilted 'pile of slices of bread and butter.' But as discovery progressed the explanation of this arrangement soon became evident. The formations revealed themselves as a series of what had originally been deposited as horizontal sheets, lying in regular order one over the other, but which had been subsequently bent up into alternating arches and troughs (*i.e.* the anticlines and synclines of the geologist), their visible parts, which now constitute the surface of our habitable lands, are simply those parts of the formations which are cut by the irregular plane of the present earth's surface. All those parts of the great arches and troughs formerly occurring above that plane have been removed by denudation; all those parts below that plane lie buried still out of sight within the solid earth-crust.

Although in every geological section of sufficient extent it was seen that the anticline or arch never occurred without the syncline or trough—in other words, that there was never a rise without a corresponding fall of the stratum. Yet it is only of late years that the stratigraphical geologist has come clearly to recognize the fact that the anticline and syncline must be considered together, and must be united as a single crust-wave, for the arch is never present without its complementary trough, and the two together constitute the *tectonic*, *structural*, *or orographic unit*, namely, *The Fold*, the study of which, so brilliantly inaugurated by Heim in his "Mechanismus der Gebirgsbildung," is destined, I believe, in time, to give us the clue to the laws which rule in the local elevation and depression of the earth-crust, and furnish us with the means of discovery of the occult causes that lie at the source of those superficial irregularities which give to the face of our globe its variety, its beauty, and its habitability.—EDIT. GEOL. MAG.

REVIEWS.

EDINBURGH MUSEUM OF SCIENCE AND ART GUIDE TO THE GEOLOGICAL GALLERY. 8vo. Niel & Co., Edinburgh, and H. M. Stationery Office, 1892.

THE Science and Art Department having sanctioned the removal of the Collection made by the Geological Survey of Scotland, and its rearrangement in the Grand Museum of Science and Art in Edinburgh, it can now be most advantageously studied. An extensive gallery, the upper floor of the west wing, is devoted to the exhibition of minerals, rocks, and fossils, not only those collected by the Survey, but those given by Messrs. Dudgeon and Milne, Prof. Heddle, Dr. Wilson, and others, and illustrative of the structure and geological history of Scotland. The rock-specimens are arranged, together with the Geological Maps, as far as possible according to their respective Counties; and the rocks are most fully displayed under the district where they are most typically represented, with ample references, by means of numbers and otherwise, to the localities. Descriptive labels for the petrology, geology, and topography accompany the specimens. An index-collection of rock-types is also at hand for the use of students.

In the Guide here noticed, the order and contents of the cases illustrative of the petrological geology of the several Counties of Scotland are given in detail. The stratigraphical collection of Scottish Fossils is similarly treated, but not so fully: and the minerals are briefly noticed. Some geological models and photographs are also mentioned.

The Department of Science and Art has to be congratulated on the