It would appear, therefore, from the foregoing considerations that the forecasts, even for one week ahead, have not any success. They are not, in fact, any better than could be obtained by purely fortuitous predictions, and they agree with what one would expect from chance in a very marked way. Nevertheless, it would be interesting to have some account of the methods used. Lord Dunboyne has made a study of meteorology for many years, and if he were to propound a theory of forecasting it would meet with due consideration from meteorologists.

C. J. P. CAVE.

Regions of Compression.[1]

By Dr. J. W. EVANS, F.R.S.

II.

THE accumulation of great masses of sediment destroys for the time being the isostatic balance of the earth's crust, which is restored by the outward flow of the plastic sima beneath them to other areas where the amount of deposits is less, or towards mountains subjected to erosion that diminishes the superincumbent load.

As a result of this outflow the surface on which these thick deposits have accumulated is correspondingly lowered. Such a depression of a previously approximately level floor of deposition may be described as a *sedimentation subsidence.*

Thus thick accumulations tend, by the direct result of their weight, to form and fill hollows in the earth's crust, and so provide for their own preservation. Hence it is that, as the late G. W. Lamplugh pointed out, the areas in which geological formations have now their most important outcrops are those in which they were originally deposited in the greatest thickness.

Where such a sedimentation subsidence has occurred, we must distinguish two constituent parts of the resulting structure: the basal or *external* portion, consisting of the older and more consolidated rocks that formed the original floor of the area of deposition, and the *internal* deposits made up of the sediments and other materials accumulated upon the former.

The depth of the accumulated sediments, and consequently the amount of the subsidence, is greater near the foot of the mountain slopes, and gradually diminishes as the distance from the mountains increased, although at equal distances it will be thicker opposite the outflow of important rivers and less where these were absent.

At a greater distance from the region or regions of erosion, where the amount of sediment deposited was less, the accumulation of calcareous material from the growth of organisms or the precipitation of carbonate of calcium, also derived originally in the main from organic sources, must often have played a similar part in causing subsidence by their weight.

The eruption of lava and ashes will have a like result, intensified by the removal of the material from beneath. The general tendency would, however, be for the load and depression to diminish as the distance from the source increased. At the same time, the inflow of the plastic material from the area of maximum sedimentation would add to the effect of the decrease of the load. Ultimately, at a greater distance, where the deposition was still more reduced, elevation would replace depression.

In the period of comparative quiescence that intervenes between paroxysms of earth movements, resulting in folding and thrusting, the horizontal compressive forces in the earth's crust, which had (for the time being) been exhausted, are once more slowly developing and increasing in strength. At last the crust yields to the pressure where the resistance is weakest. Other things being equal, this will be where the solid crust is bent most deeply down in a sedimentation subsidence. There it is no longer flat and horizontal, and directly opposed to the forces of compression. It has consequently very much diminished powers of resistance, precisely as a pillar bent out of the vertical line is incapable of sustaining the same weight as if it were straight and erect. The weakness of the crust in the subsided area is increased by the fact that the depression of the solid floor through some thousands of feet brings the rocks into regions of higher temperature, and the increase in temperature must be accompanied by a considerable decrease in strength, while the unconsolidated deposits of the interior of the subsidence can add little or nothing to its powers of resistance.

Accordingly, it is in a tract of subsidence that the crust gives way under the forces of compression. It is true that these forces operate on the whole surface of the globe, but immediately the portion with least resisting strength yields, however slightly, the remainder of the great circle on which the yielding takes place is released *pro tanto*, adjusting itself by a movement of elastic expansion, so slow that the resistance opposed to it by the viscosity of the subjacent plastic sima is inappreciable.

It must be remembered, however, that, as already indicated, there are other horizontal forces affecting the earth's crust that may increase or diminish the forces of compression locally, and these may in some instances determine whether the crust yields at one subsided tract or another. When such a yielding has taken place, the probability of the crust giving way at another point is at once greatly diminished, at any rate for the time being.

The first effective action of such compressive forces usually antedates by a considerable period the epoch of maximum disturbance, and is as a rule very gradual and gentle, so that it merely narrows slightly and deepens the area of subsidence. The deposition of great thicknesses of a succession of shallow-water strata is usually explained as due to subsidence by way of isostatic adjustment of the earth's crust, to correct the disturbance of equilibrium from the weight of the sediments accumulated. Prof. A. Morley Davies has, however, directed attention to the fact that there is a limit to such an adjustment, because the density of the sediments laid down is less than that of the plastic subcrustal sima displaced.

Let s be the original depth of the sea, and l the

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[1] Continued from p. 17.

amount by which the sea-bottom is lowered; then $s+l$ will be the thickness of the deposits if they reach the surface of the sea. Let the density of these sediments be ρ_a, that of the plastic sima displaced ρ_b, and that of sea-water ρ_s. Then, if isostatic conditions prevail both before and after the sedimentation, we shall have $\rho_s s+\rho_b l=\rho_a(s+l)$: that is to say, the weight of the sea-water over a unit of area before the deposition of the sediments, *plus* the weight of the sima displaced by the subsidence, is equal to the weight of the sediment deposited. Hence $(\rho_b-\rho_a)l=(\rho_a-\rho_s)s$; so that

$$\frac{l}{s}=\frac{\rho_a-\rho_s}{\rho_b-\rho} \text{ and } \frac{l+s}{s}=\frac{\rho_b-\rho_s}{\rho_b-\rho_a}.$$

Accordingly $l+s$ (the total thickness of the sediments)

$$=\frac{\rho_b-\rho_s}{\rho_b-\rho_a}s. \quad (1)$$

If, however, the subsidence be slowly deepened as the result of gentle lateral pressure, *compression-subsidence*, it is possible for a much greater thickness of deposits to accumulate without rising above sea-level than would be possible according to these calculations, and this appears not infrequently to happen. But it must be remembered that this downward movement imposed on the crust will cause the displacement of still more heavy plastic sima below, and the isostatic balance will be destroyed, because the sediments deposited are less in mass than the material displaced. There should, therefore, be a defect of gravity in areas of deposition affected by gentle lateral pressure. This is, in fact, the case in the Gangetic Plain, as well as in the low tracts lying east and north-east of the Andes.

The strength of the original crust, reinforced by the lateral pressure, may nevertheless be sufficient, for a time, to resist the upward pressure from below. But, if the horizontal forces cease to operate, the downward fold of the crust will ultimately yield to the pressure of the plastic material beneath, and the terrain will rise until isostatic adjustment is restored. It is not improbable that the alternation of marine and continental conditions which is so frequently observed may, in some instances at least, represent changes of this description accompanying intermissions and variations of moderate horizontal compression.

With a continuance, and still more with an increase, of compression, the exterior framework of the subsidence will gradually close, and throw the interior sediments, still soft and plastic, into folds of ever-increasing complexity. As these develop, the interior accumulations will tend to rise instead of sinking, and to pile themselves up into mountain masses concentrated on a limited portion of the earth's crust, which will be once more loaded in excess of the isostatic balance. A new subsidence—a *folding subsidence*—will ensue, with greatly increased displacement of the sima.

When the isostatic balance is once more restored, the summit of the mountain folds will still rise high above the adjoining plains; but a much greater portion will lie far below, and the protection of most of the sediments of the internal structure from future destruction will be still further assured.

Let, as before, ρ_a be the density of the sial and ρ_b that of the sima, and let j be the depth below the sea of the base of the mountain folds, consisting mainly of sediments, including for the present purpose both the rocks of the original surface of deposition and the later, interior, sediments; and let h be the height of the mountains above the sea, m the height of the plains, and c the thickness of the sial of which they are formed.

Then, in order to preserve isostatic balance, we must have

$$\rho_a c+\rho_b(j+m-c)=\rho_a(h+j). \quad . \quad . \quad . \quad (2a)$$

So

$$\rho_b(j+m)-\rho_a(h+j)=(\rho_b-\rho_a)c. \quad . \quad . \quad (2b)$$

and

$$c=\frac{\rho_b(j+m)-\rho_a(h+j)}{\rho_b-\rho_a}=j-\frac{\rho_a h-\rho_b m}{\rho_b-\rho_a}. \quad . \quad (2c)$$

The upper portion of the folds will commence to be eroded as soon as they rise above the surface, and will never reach the height which is obtained by continuing and completing the portion of the folding that can now be observed. Consequently, the base of the folds is not now and never has been so deep as would have been the case, but for the progress of erosion and consequent removal of load.

The gravitation data obtained by the Coast and Geodetic Survey of the United States in North America are best interpreted as indicating that the maximum depth of the folds is about 86 km. below sea-level. The average height of the crests may be taken as about 3500 m. above sea-level. We thus know roughly both j and h, but the value of c, the thickness of the sial of the plains, remains to be determined.

This amount is also concerned in the isostatic balance between the continental plains and the sea-bed. Let the depth of the sea outside the continental shelf be S, and the height of the plains above the sea be, as before, m. Then the mass of the sial below the plains must be in isostatic balance with the sea-water and the sima below it, down to the level of the base of the sial of the plains.

Hence

$$\rho_a c=\rho_s S+\rho_b(c-m-S) \quad . \quad . \quad . \quad (3a)$$

when ρ_s is, as before, the density of the sea-water.

So

$$(\rho_b-\rho_s)S+\rho_b m=(\rho_b-\rho_a)c \quad . \quad . \quad (3b)$$

and

$$c=\frac{(\rho_b-\rho_s)S+\rho_b m}{\rho_b-\rho_a}. \quad . \quad . \quad . \quad (3c)$$

But since $\rho_b(j+m)-\rho_a(h+j)$ also $=(\rho_b-\rho_a)c$, $\quad . \quad (2b)$

we have $\rho_b(j+m)-\rho_a(h+j)=(\rho_b-\rho_s)S+\rho_b m. \quad . \quad (4a)$

Hence

$$\rho_b(j-S)=\rho_a(h+j)-\rho_s S \quad . \quad (4b)$$

and

$$\rho_b=\frac{\rho_a(h+j)}{j-S}-\frac{\rho_s S}{j-S}. \quad . \quad . \quad . \quad (4c)$$

If h is taken as 3·5 km., j as 86 km., S as 4·7 km., and ρ_s as 1·03,

$$\rho_b=1{\cdot}10086\rho_a-0{\cdot}059545.$$

In view of the uncertainty of the data, these figures can only be regarded as a provisional approximation; but they are sufficient to indicate the general nature of the relation between ρ_b and ρ_a. The probable values of ρ_b for different values of ρ_a are shown in the first and second columns of the accompanying table.

With any corresponding values of ρ_a and ρ_b we can determine the value of c from either of the equations ($2c$) or ($3c$). These values are set out in the fourth column of the same table.

ρ_a. Assumed density of the sial.	ρ_b. Corresponding density of the sima.	$\rho_b - \rho_a$. Difference.	c. Thickness in kilometres of the sial of the plains.
2·35	2·5275	0·1775	41·1
2·40	2·5825	·1825	41·4
2·45	2·6376	·1876	41·7
2·50	2·6926	·1926	42·0
2·55	2·7476	·1976	42·2
2·60	2·8027	·2027	42·5
2·65	2·8577	·2077	42·7
2·70	2·9128	·2128	43·0

It is remarkable how little the calculated thickness of the sial of the plains varies with the different values of the density of the sial and sima. It is considerably greater than the 15 km. deduced by Dr. H. Jeffreys from seismic considerations or the value assigned to it by H. Washington, 15 km. to 20 km., or, indeed, than I should myself have thought probable, but much less than the figures arrived at by Wegener. Although the data are only known approximately, it is difficult to see how the thickness can differ very considerably from 40 km., unless the depth, j, of the mountain folds is much greater and the difference $\rho_b - \rho_a$ less. For provisional purposes a density of 2·60 for the sial and 2·80 for the sima may be assumed. Such a density for the sima would imply that it is partly crystallised.

While the interior sediments of a subsided area are thrown into complex folds which sink ever deeper below the surface, the exterior rocks that formed the surface of deposition are forced down into hollows, which constitute folds simpler than those of the interior sediments and distinct from them. In the course of these movements they are stretched, and ultimately torn apart into lenticles. In addition, as a result of lateral compression and of isostatic adjustment, they may be and usually are fractured in thrusts and slip-faults. When the interior rocks have become compacted like those of the exterior, they too are forced to accommodate themselves by similar faulting to the forces acting upon them. Thrust-faults will predominate, and result in still further local accumulation in the subsided area and still further subsidence, a *thrusting subsidence*.

The approximate coincidence in the Boulonnais of the post-Jurassic infra-Cretaceous movements, as well as those of later date with the Hercynian folding, induced a number of observers, such as Godwin-Austen, Marcel Bertrand, and Charles Barrois, to formulate a law that movements tend to repeat themselves along the same tracts. That there is some truth in this principle cannot be denied. Unless folded rocks have been thoroughly consolidated and welded together, a renewal of the folding on the same lines will be comparatively easy, and in the case of faults it is a familiar fact that successive movements frequently take place along the same fault-plane. At the same time, T. O. Bosworth, in describing the relation of the Trias to the pre-Cambrian rocks of Leicestershire, has shown that the settlement of later rocks overlying an ancient ridge will cause deformation in the stratification more or less parallel to the contours of the surface of the older rocks. Probably still more important is the fact that the accumulation of the sediments at the foot of a mountain range will, on the principles already explained, tend to produce another system of folding parallel to the first. But this result will be controlled to a considerable extent by local conditions and more especially by the thickness of sial beneath; for it is probable that a sedimentation-subsidence forms more easily where the depth of the sial is less, as even at moderate depths and temperatures the sima is more yielding than the sial in the absence of volatile constituents. However, as Prof. Pruvost has shown, the correspondence is by no means so close, even in the Boulonnais, as to amount to identity of direction.

O. Barré, A. Bigot, and Paul Lemoine suggest the existence of a supplementary inverse principle, according to which an anticline succeeds to a previous syncline, and vice versa. This Lemoine illustrates by the buried ridge beneath the Thames Valley syncline and the supposed syncline beneath the Wealden anticline. But in the former case the synclinal axis is only approximately parallel to the ridge below it; and there is no reason to believe that the Palæozoic floor rises up on the south side of the Weald. It is far more likely that its descent on the northern side is in the nature of a monocline.

The tracts of folding and mountain building that I have discussed belong to great systems in different parts of the world with a direction approximating to the parallels of latitude, and would seem to owe their orientation to the meridional forces, which may themselves be attributed to variations in the angular velocity of the earth's rotation. I have no time to refer to the folds associated with the great ring of compression that encircled the Pacific in Mesozoic and early Kainozoic times. The position of this compression would appear to be determined by a general drift of continental masses towards the centre of that ocean, caused, I have suggested, by a maximum of gravitation beneath it.

To these two great systems of folding, their intersections and interference, may be referred nearly all the orographical features of the globe which have come into being since the close of the Caledonian activity in early Devonian times; while the mountain ranges that belong to neither category not improbably owe their position and orientation to the existence of pre-existing ranges which have determined the development of new regions of folding in the manner already indicated. We know too little of the distribution and orientation of the continental masses and their relation to the position of the equator and the poles and to the variations of gravitation in older Palæozoic and still earlier times to enable us to say how far the directions of earlier folding are consistent with these suggestions.

I make no pretension to enunciate a new theory of mountain building. It has been my endeavour to tell a connected and consistent story of the steps by which mountain folds have come into existence and developed; how they owe their origin in general to great accumulations of sediments, the product of the denudation of the mountains raised in a previous period of folding; how a tract of subsidence resulting from sedimentation and filled by sediment becomes a tract of weakness in the earth's crust; how the time arrives when under the slowly increasing horizontal compression the subsided area yields and closes, so that the contained sediments are forced up in folds to form a new mountain range, while the earth's crust is left for the time being in a state of relaxation, at the mercy of minor forces which in the time of its strength it had no difficulty in resisting; how it is gradually consolidated once more by the reviving forces of compression, while new regions of weakness are being prepared by new accumulations of sediment, and another cycle of mountain building begins.

Obituary.

SIR WILLIAM AUGUSTUS TILDEN, F.R.S.

BY the death of Sir William Tilden on Saturday, Dec. 11, in his eighty-fifth year, British chemistry lost one of its best known and most loved representatives. Born before Frankland had endowed the atom with valency, or Cannizzaro had used the implications of Avogadro's hypothesis to fix its relative weight, his span of life bridged the gulf between conceptions so widely separated as the indivisible unit of that remote time and the *congeries* of protons and electrons of the present day.

As a boy, Tilden was sent to various private schools and finished that part of his education at Bedford Modern School, where, during the two years of his stay, he helped to found the school scientific society, which bears his name. So far as can be ascertained, his interest in chemistry was first aroused by the experiments which a visiting tutor at the last of these private schools carried out in class to illustrate his teaching. Being given the choice of a career, Tilden in 1857, on leaving school, chose that of chemist. But through a confusion of ideas on the part of his guardian, more pardonable then than now, he started as the apprentice of a pharmacist, the late Alfred Allchin of Barnsbury in North London, who had been Redwood's assistant in the Pharmaceutical Society's School in Bloomsbury Square. He was therefore of the company of Scheele, Dumas, and others, who found their way to eminence in chemistry through the discipline and experience of the old type of pharmacy.

While attending classes at Bloomsbury Square during his apprenticeship, Tilden was attracted to Hofmann's lectures at the Royal College of Chemistry in Oxford Street, which opened up to him a new world and exercised a profound influence on his career. In 1862 he became assistant to Dr. John Stenhouse, F.R.S., but a year later returned to the School of Pharmacy, this time as demonstrator in chemistry under Attfield—a position he occupied until 1872, when, abandoning pharmacy for chemistry, he became science master at Clifton College under Percival, afterwards Bishop of Hereford. It may not be without interest to note that one of his students at Bloomsbury Square, the late W. A. Shenstone, F.R.S., who like himself had been a Jacob Bell Memorial scholar, succeeded him at Clifton.

From Clifton, Tilden went to Birmingham in 1880 as professor of chemistry and metallurgy in the newly founded Mason College and took an active share in the development of that institution; but in 1894, three years before it achieved university status, he was called to the chair of chemistry in the Royal College of Science, South Kensington, in succession to the late Sir Edward Thorpe. On his retirement from South Kensington in 1909—he had succeeded the late Prof. J. W. Judd, F.R.S., as Dean of the College in 1905—he received a knighthood and was given the title of emeritus professor in the Imperial College of Science and Technology. Thereafter, he occupied himself with literary work—chiefly studies in historical chemistry—and, for recreation, with his garden, of which he was justly proud. Among the more important of his books may be mentioned "Short History of the Progress of Scientific Discovery," published in 1899; "The Elements" (1910); "Chemical Discovery and Invention in the Twentieth Century" (1917); "Famous Chemists: the Men and their Work" (1920).

In the field of original research Tilden was first busied with subjects of pharmaceutical interest, out of one of which, the study of dilute nitro-hydrochloric acid, a method was developed in 1874 for the production of nitrosyl chloride in quantity, a reagent used largely by him in the investigation of the terpenes. Pinene nitrosochloride, the first of the additive compounds formed by its aid, was isolated by him in 1875, and others followed; but his work on these unsaturated hydrocarbons, and the conclusions reached about their constitution, are less likely to be remembered than his discovery of the polymerisation of isoprene into caoutchouc, which supplied the first clue to the manufacture of indiarubber by synthetical means. Among the other subjects which claimed his attention, mention may be made of his work on the relation of specific heat to atomic weight which formed the subject of the Bakerian lecture before the Royal Society in 1900. By awarding him the Davy medal in 1908, that Society set its seal on the merit of his contributions to knowledge.

Recognition also came to Tilden from universities and scientific societies. He received the honorary degrees of Sc.D. (Dublin), D.Sc. (Victoria), and LL.D. (Birmingham); became a fellow of the Royal Society in 1880; was a fellow of the University of London; corresponding member of the Russian Imperial Academy of Sciences; and honorary member of the Pharmaceutical Society; president of Section B (Chemistry) at the Bath meeting of the British Association in 1888; president of the Institute of Chemistry in 1891–94; treasurer of the Chemical Society in 1899–1903, and its president in 1903–5. His British Association address was noteworthy as an expression of his views on the teaching of chemistry; his tenure of the chair of the Institute of Chemistry for the adoption of the figure of Williamson's statue of Priestley in Birmingham for the seal of that body; and his presidency of the Chemical Society for the initiation of the invaluable series of "Annual Reports on the Progress of Chemistry," and of the movement for the admission of women to the fellowship, which, to his regret, was not endorsed by the Society until after the War.

Always sure of a welcome at any meeting he might attend, and listened to with pleasure when he intervened in discussions or debates, Tilden maintained his interest