SCIENTIFIC NEWS IN WASHINGTON.

Mr. Goodfellow's Report: the Locus of the *Temblor;* Description of the Great Fault; Damage to Towns; the Shaking-up of the Mountains; Fixing the Epicentral Area; Indications of Two or More Impulses; the Direction of the Wave; the Time. — Distortion in Plane-Table Sheets.

The Sonora Earthquake.

MR. GEORGE E. GOODFELLOW of Tombstone, Arizona, has just sent to Capt. C. E. Dutton, of the United States Geological Survey, a carefully prepared report on the earthquake which occurred May 3, 1887, in the south-western part of the United States and in the northern portion of Mexico. His observations were made during two journeys to the centre of disturbance in Sonora. Very little was learned by the first journey, principally because the time was wasted in searching for an alleged active volcano which had been graphically described by an imaginative correspondent of the New York *Herald*, but which never existed.

In a second trip, Mr. Goodfellow met Prof. José G. Aguileria, of the Mexican Exploring Commission, which was engaged in making a similar investigation. An arrangement was made with him by Mr. Goodfellow to exchange information; but, as he had received no report from Professor Aguileria as late as March 5 of the present year, his report is based almost exclusively upon his own observations.

After having explained why it was absolutely impossible to ascertain the time of the first shock in and about the epicentral area, and some other important data, on account of the absence of time-pieces, the illiteracy of the people and their indisposition to give facts if they had them, the sparse population and inaccessibility of the country, the absence of all means of rapid communication or transit, and, last but not least, the unparalleled severity of the rainy season of 1887, Mr. Goodfellow says, —

"The seismic movements of May 3, 1887, were felt from Toluca, capital of the State of Mexico, 26 leagues south-west from the City of Mexico, to Albuquerque or Santa Fé on the north, and from Yuma and Guaymas on the west, to a point about 60 miles east of El Paso on the east. . . . A central tract of maximum intensity, owing to superficial manifestations of ruinous energy, can be located with a considerable degree of certainty, and may be placed in the San Bernardino valley, and probably a contiguous portion of the Teras Mountains.

"The valley of the San Bernardino is a typical south-western one. It takes its name from an alleged stream, which rises near the border, in the United States, and, flowing southwards, empties into the Yaqui. These south-western valleys may be divided into three parts, — the narrow bed of the water-course; the alluvial overflow bottom; and the mesas, including the foot-hills of the encompassing mountains, for one merges into the other so rapidly, it is hard to tell where the dividing-line may be. Confining my description to the central seismic region, — the Cordilleras of Mexico, — the Sierra Madres, wherein it lies, may be said to have a general north-and-south course. The main chain is composed of numerous short ranges having a trend of 20° north or 30° west. Between each of these ranges is a pass with commonly an easterly and westerly direction, usually carrying more or less water. The valleys before described have the north-and-south direction of the bordering mountains. These mountains, varying in altitude from four thousand to ten thousand feet, are composed, for the most part, of tertiary metamorphic and eruptive rocks. In the range east of the Fronteras valley, and also east of the San Bernardino, are paleozoic strata, presumably carboniferous. The mesas are made up of more or less closely aggregated drift from the mountains. The depth of this detritus may be gauged by a description of some mesas in the neighborhood of Babispe. Between Babispe and the Madera Mountains is a mesa several miles in length which is completely isolated. The level of the river at Babispe is about 2,950 feet; and this mesa rises to the height of 4,500 feet, 1,500 feet above the altitude of the river, and is composed entirely of coarse drift. This is shown in many places by channels of lateral erosion.

"The water-courses display the usual phenomena of south-western streams, water appearing in occasional places throughout the entire length of the bed, but a great quantity from a few inches to a few feet beneath the surface. On the eastern margin of the San Bernardino valley, where mesas merge into foot-hills, close to the steeper part of the mountains; on the mesas and in the water-courses of the valley, — are located the evidences of the severity of the earthquake. These consist of a single large fault and many minor fissures and downthrows. The former is on the base of the mountains; the latter, on the mesas and in the immediate beds of the streams. The large fault begins at the northern end of the valley, a few miles south of the line, in what is called Elias Creek, a tributary of the San Bernardino. It commences very gradually on the southern bank of the stream, increasing in width as it makes a curve towards the cañon of Los Embudos, from which point to its end the general direction of the fissure is north and south. It has a winding course, following the tortuous line of the base of the ranges in all its sinuosities to and across the Yaqui River, into the Teras Mountains some miles. Its total length, as far as followed, is about thirty-five miles." In a private letter to Captain Dutton, Mr. Goodfellow says, "In a note to *Science*, I stated that the fault was one hundred miles in length. This was a great error." He then explains that there are no good maps of Sonora and Chihuahua, save one, and that one he had not seen at the time. He was therefore obliged to judge of the length of the fissure by the time it took him to travel, and by very uncertain Mexican reports of distances. "The average difference of level between the two sides is a little over seven feet. In some places, as opposite Pitaicachi, the difference is much greater. In its entirety north of the Yaqui, it conforms to the usual law of faults by having the hanging wall the lowest; but, after passing that river some two miles, there is a place for a short distance, some two or three hundred yards, where the hanging wall is the highest. The difference in level of the portion south of the river is about three feet. At the point mentioned, where the hanging wall is elevated, the variation is a trifle more.

"The first question rising in the mind, after viewing the fissure, is, 'Is it an ideal fault, or the mere changing of the drift of the mesas by reason of alteration in subterranean reservoirs of the valley?' As favoring the first view, is the fact that it lies so near to the base of the mountains its entire length. With the structure of the valleys, before described, did it lie out on the mesas away from the foot of the Sierras, the conclusion would be almost irresistible that it is nothing more than a slip of alluvial drift, as the river-bed downthrows undoubtedly are. But, by examining closely its *locale* and characteristics, there seems a preponderance of evidence favoring the first opinion. Still there is this one thing to be recorded: nowhere in its path, as far as I saw it, can be seen an instance of the solid rock showing a participation in the fissuring, except at Pitaicachi, where a dike may be seen in the breast of the slip. This, I think, is more apparent than real. There are but three places that I saw along the line where such rents could show. These are, first, a small cañon a short distance north of Pitaicachi; second, a cañon in the Cabellera Mountains; next, at the Yaqui River. In all of these places is running water, which would have been sufficient to destroy evidence of petrous rupture. In the upper cañon, which I will call 'Elisu,' the fissure passes some three hundred feet to the west, and below a stratified mass of shaly rock which rises abruptly at this point. The approaches to these cañons are very steep; the walls at the locus mentioned being on the southern side almost vertical, on the other at an angle of at least 45°. The causes, then, of partial non-appearance of the crack on the sides of the cañon are self-evident, — the inclination is too great. In every one of the other arroyos and cañons crossed by the fissure, the bottom had as great a rent as the surface of the mesa above, and the walls were depressed proportionately to their inclination. In the Cabellera Cañon the fault is somewhat closer to the rocks, but, aside from this, the other manifestations are the same. I have no doubt that in both, at the time of the first disturbance, the alteration of level in their beds was equal to that on each side above, but the stream soon filled and levelled them. That this is the true solution of the problem, I have had ample evidence in other arroyos usually dry. In these, succeeding the rains and consequent temporary torrential flow, the break was rapidly evened, and was no more visible than in the places mentioned. At San

Rafael, where it crosses the Yaqui, the explanation is not so easy. Approaching the river from the north, until within less than a mile, the average drop is maintained. There, however, it gradually diminishes until within about three hundred feet of the stream, where it becomes simply a crack in the bluff which leads to the river-bank. On the opposite side it recommences as gradually, but never attains the old width, not exceeding in any place over five feet, and gently lessening, until at the point I abandoned it, nearly five miles south of the river, the difference in level is a foot or less. On this southern portion may be noticed two facts, — first, the course is more directly into the mountains; no longer hugging their base, it strikes directly for their heart: next, and perhaps not the least important, is the phenomenon of the hanging-wall elevation instead of depression. At the place I left off following it, a division into two occurred, the split taking place at the foot of a moderately high hill of reddish-looking metamorphic rock. Whether the fissure extends farther to the south, I cannot of my own knowledge say. From some intelligent prospectors that went into the Teras Mountains afterwards, attracted by the idea that such terrestrial commotion ought to develop some leads of mineral, and whom I asked to note any peculiarities observed, I learned that it does extend about fifteen miles more to the south. From the diminutive size of the fault where I last saw it, this seems to me improbable. It certainly is not impossible, and the statement may be taken *sub judice*. One thing is assured: the Teras Mountains have been wofully broken up; this I personally know. I have been told by Colonel Kosterlitzky, who has recently been there, that on the Chihuahua side of the Espuelas and Pitaicachi, is a duplicate of the San Bernardino fault. I have endeavored to confirm this, but without success.

"When I first viewed the end on the northern side of the river at San Rafael, it seemed certain that there was the termination of the rupture; and it was not until one of my Mexican escorts had crossed the stream, and hunted in the thick brush, that it was discovered leading up the hill. The explanation of the diminution at this place to a mere crack on each side of the river is not entirely plain to my mind: therefore I leave the problem to you for solution. The rock is indubitably involved in the slip at this point, although the drift prevents it from being seen. If it was not, there could be no faulting of even an inch, for it is not loose mesa drift, simply a slight covering with the results of cliff denudation. The solid rock shows close on both sides of the fault.

"The pass through the mountains, where the Yaqui reverses its course, is a very narrow one, three or four miles in length. The walls are perpendicular on each side, rising to the height of several hundred feet, and are composed, as are the immediate hills on the north and the mountains on the south, of some reddish-gray looking rock, probably eruptive. At the point where the river debouches from the pass, and on the last bluff on the north, the fault passes through its centre, becoming a mere crack. The pass is, or was then, impassable, though some of the Mexicans with me said they had gone through it when the river was very low: at all other times it is impossible to penetrate the gorge.

"Some things to be noticed about the fault, in connection with its sinuous course, are the small fissures at each bend with any great degree of angularity. These occur on the salients of each angle, but have no great length, in no place extending over a few hundred yards, except opposite the Cabellera Mountains, where there is a triplicate division over a mile in length. This gives the main fault the appearance of having been compressed lineally from the south, most of them having the free end to the north. They are mostly ground-throws, not simply cracks.

"From Pitaicachi to Cabellera Cañon the fault is far up on the immediate foot-hills, and subsequently crosses them where there can be no doubt as to a petrous substructure at slight depth. But, as all of them are more or less extensively covered with *débris*, I saw no spot in the face of the fault where a rent of solid rock was visible. Neither did I follow it closely through this section, owing to the weather when there. Thus I missed exploring the locality of all others which might have illustrated the point at issue. No one, however, who might stand and look over the ground at that section could doubt, that, even if nowhere else there was slipping of solid rock, here certainly there must be. A point which attracted my attention, and which seemed significant, was the appearance of the foot-wall of the slip in many places, particularly where it abutted closely on the mountains. This was the polished surface, as if the same place had been the seat of similar perturbations in the past. At these points the drift appeared to be more thoroughly consolidated than at other localities. This striation and polishing began within a few inches of the upper margin of the wall, — a place where one would think slipping of the loosely aggregated mesa drift would cause such an appearance. In addition, the fault at these places usually was backed a short distance by the more durable portion of the mountains, generally a bluff of some extent from fifty feet to one hundred yards away. In no part of the line of greatest drop is the fall less than eight feet, while in many places it exceeds twenty. The estimated altitude of the mountains is, Guadaloupes, Espuelas, and Cabelleras, about 7,000 feet; the Teras, 9,000 to 10,000.

"This, then, is a description of the big fault. We will now consider the river-bed cracks and downthrows, for they come next in size. Beginning about the San Bernardino Ranch, at the line, these lesions exist as far as Granadas, which was as far south as I went. These ruptures are not continuous. This form is most marked about Batepito and Babispe. It is safe to say that the bed of every water-course in the San Bernardino valley has changed level relative to the mesa from six inches to two feet. This has nothing to do with the alteration of height as connected with, or caused by, the great fault: that is additional. These river-bottom dislocations seem to be a breaking-away of the bed from the enclosing mesa. The mesas composed of drift are from twenty to one hundred and fifty feet in height above the alluvial bottom, averaging perhaps fifty. The cracks begin at or within a few feet of the base of these terraces, and their course is that of the river-bed. The extent of these from San Bernardino in a direct line I have told. They also run from Bacerac to below San Miguelito, on the upper portion of the Yaqui, but are lost sight of at that point. Whether this be due to a total absence, or to the fact that the trail leads away from the river, I cannot tell; but from a short distance below San Miguel, to a crossing called 'Pedregoso,' I saw none, at such points as we struck the river in the line of the trail. These fords, however, were at places where the nature of the channel would have prevented any such phenomena, it being rocky and narrow. The Fronteras valley, east of the San Bernardino, but tributary to it, as may be seen by the water-course, was severely cracked up in the same manner, but in a degree not to be compared with the two first named.

"In addition to these cracks and dislocations in the valleys named, were lesions of another kind, — outbursts of sand and water through fissures and small crater-like holes, a few inches to a foot or more in diameter. This phenomenon was experienced in the Sulphur Spring and San Pedro valleys in the United States to a considerable extent, but not with the severity found farther south. At Batepito Ranch, an area two miles long by one wide was four or more inches deep with water immediately succeeding the first shock on May 3. This was the greatest quantity of water thrown up at any one place; but the total amount must have been very great, as the craters are met with wherever the river-cracks exist, and sometimes where they do not.

"The next class of fissures are simple cracks without depression existing on the mesas. None of them are, as naturally would be the case, through solid rock. They are many and extensive on the mesas of the San Bernardino valley, and have a general direction towards the main fault. Their width varies from an inch to a foot or two, usually under a foot.

"Next of the surface phenomena to be considered is the line of devastation in the mountains. Here we find millions of cubic feet of rock thrown down from the mountains to the cañons and water-courses below. Cliffs of solid crystalline rock are shattered and split, as if a charge of giant-powder had been lodged carefully amongst them for the express purpose of annihilating them. The magnitude of the quake can be appreciated more by the evidences of its force in the mountains than by the fault. The fault has the appearance, and gives the idea, that it could not be helped: it simply sunk, as Topsy growed. But the rending and splitting of such masses as the mountain-cliffs impress one with a profound idea

and respect for the forces at work. This line of devastation will again be referred to.

"Of the towns most damaged, the principal one was Babispe. This typical little Mexican town lies on the west bank of the Yaqui or 'Babispe' River, as it is there called. The old town is situated on a terrace of the larger mesa, where the new town is. This lower mesa is about thirty feet above the river-level, and about sixty feet below the surface of the upper mesa. The composition of the mesa is, as previously indicated, loosely aggregated drift from the mountains. At this place the superficial deposit is very imperfectly consolidated. Back of the town, to the west, is the Madera range of mountains, a branch of the Teras. The range is directly to the west, and it cannot be over three or four miles away. So far as the method of Mallet in noting angles of emergence, etc., is concerned, I have this to say: there is not the slightest doubt that Mr. Mallet, or one equally as expert, could have succeeded with it, for there were plenty of fissured walls and overturned objects on which to work. There were all angles of emergence in one building, — cracks ranging from ten degrees to vertical, with several diverging branches. It seems to me that all that can be gathered out of the chaotic state of affairs is, that there has been a considerable shake-up. Apparently the buildings are very substantial, being constructed of adobes 24 × 12. These are laid double, which makes all walls 24 inches in width. The average height is 8 to 10 feet; only one in the town having been greater, and that was 22 feet. The roofs are made by laying rafters, or 'vigas' as they are called, from one wall to the other; then covering these with cane, ocotilla, or brush, and that with mud, to a thickness of at least six inches. This makes an extremely heavy roof, but certainly the most suitable one for the climate. Above the vigas is built a slight coping, or fire-wall; and at intervals are openings with wooden troughs to permit the passage of rain-water. The remains of the building with the four corner posts standing are those of an exceptionally built one; and a very lucky exception it was in this case, for it saved the lives of four persons who were in it at the time.

"Of the dwellings destroyed, the major portion were on the northern and eastern side of the plaza. All walls facing the plaza on its west side whose linear direction was north and south were thrown down, falling toward the east. These were from eight to twenty feet in width, averaging probably ten feet. Of the houses on the south side of the plaza, which lie at the junction of the terrace on which the town is, with the foot of the mesa above, none were seriously damaged. They were more or less cracked, but were not prostrated. The church is the most conspicuous monument of the devastating energy of the *temblor*. It was not, perhaps, as substantial a structure as some of our slighter but more modern civilized buildings, but it certainly could lay claim to the dignity of having withstood the storms and prayers of at least two centuries.

"The destruction of life was, in my opinion, largely due to the style of architecture. The walls were not held together. In some instances I found the north-and-south walls had separated and let the vigas down into the house on one side. This involved motion of at least a foot. The walls two feet thick, viga laid to cover the entire width was obliged to slip that distance before it could drop. The horizontal cracks at the base of the walls indicated the motion. All damage was done by the first shock. The effect of subsequent tremors was visible only by psychological manifestations. Almost without exception, both sexes gave way to their terror, and devoted themselves to religious exercises for the purpose of propitiating the wrath of — so the priest said — a justly offended Deity.

"Opotu was the next town of any size to suffer considerable injury. This place lies south-west of Babispe, on the Yaqui River. It is situated on a bluff of alluvial drift on the bank of the river, some fifty feet above the stream. The axes of the two are pretty much the same as those of Babispe, almost north, south, east, and west; the population a trifle greater. There were nine people killed outright, and several others injured. I think the intensity of the shock here was fully as great as in Babispe; but the buildings did not possess the age of those in the latter place, none in Opotu being much over twenty-five years old, while none in Babispe were less than one hundred or two hundred. Perhaps this made less difference than at first sight seems possible. Owing to the manner of construction, a certain amount of repairs are constantly necessitated, which would, of course, tend to render them more stable. Of the walls thrown down, with two or three exceptions, all fell to the westward, though the upper portion of a few of the east-and-west walls had toppled over towards the south. Walls over twelve feet in length, with their linear axis east and west, suffered entirely in the east and west corners. Where they were shorter, they were thrown down, falling indifferently north or south. The characteristic damage received by all houses not prostrated was in the corners.

"In Fronteras several buildings were destroyed, and one child killed. Fronteras is just off the overflow bottom of the little stream which goes by the name of the 'Fronteras River.' The river is about three-quarters of a mile to the east of the village, and nearly on the same level. A portion of the pueblo is on an isolated drift mesa thirty to fifty feet higher than the remainder. On this mesa is where most of the damage was done. It is not over one hundred feet wide at any portion of it occupied by the houses, consequently presents facilities for amplitude of wave-motion not possessed by the lower town. The Fronteras valley is many miles in width, mesas included, and the alluvial part of it is thoroughly water-soaked. The river-bed skirts rather closely the ranges of mountains on the eastern side of the valley. The buildings of Fronteras are of great age, — one to two hundred years. San Bernardino Ranch may be considered as on the same isoseismal. Here were two buildings of adobe, presumably substantial, though slighter than the Mexican-built structures. Both were instantly prostrated at the time of the first shock, fortunately injuring no one.

"The foregoing makes up the pueblo line of maximum intensity. I wish now again to consider what I have ventured to name the mountain circle of worst disturbance, or the interior line of maximum intensity. The line of demarcation is as distinct as a street in a city. In the order in which I saw them, would be, first, the one on the trail to Babispe, south of Bedregoso. This is from one hundred to three hundred yards in width: it is difficult to tell, as the route is through a deep, narrow cañon, but through there the shattering of the rocks has been extensive. Tons have fallen into the cañons from the cliffs above. Before reaching that point, the disturbance has been moderate, and, after passing, the country has the same appearance. The next place passed having the look of equal dynamic energy was far to the south, on the range between Bacadehuachi and Granadas, about halfway, probably a trifle nearer the latter. Here identical phenomena were exhibited, — a narrow line where rocks, shaly and crystalline, have been terribly broken up. . . . On the trail from Opotu to Fronteras, between Nacosart and the Yaqui, and a little more than halfway from Fronteras to Batepito, similar phenomena were seen.

"The preceding localities form an isoseismal which I have called as above. Let me relate some of the objective symptoms which have determined my opinion in this matter. In the course of my journey, in spite of the condition of Batepito, I came to the conclusion that the epicentral area was in the Teras Mountains. The principal reason I had for this was the character of phenomena hourly occurring. During all the time I was circling that region, those mountains were continually the seat of various seismic manifestations. The principal of those was the rumbling, roaring, or, as it seemed to me, the groaning of those massive peaks. Usually this would be succeeded by a more or less severe shock; but many times the noise would be heard, lasting a minute or more, but no tremor followed. While I was in the neighborhood, certainly, all seismic disturbances had their origin from those mountains, irrespective of my situation. I had rigged up a seismograph, if such a contrivance can be entitled to the name, consisting of a bullet suspended in a large beer-bottle. This, with moderate accuracy, gave me the direction of the vibrations, and all seemed to come from the northern end of the Teras Mountains. Connecting these interior mountain-points, and erecting perpendiculars, the mean epicentrum is thrown south of the San Bernardino valley. If the Babispe, Opotu, Fronteras, and San Bernardino Ranch are joined, and the same plan pursued, the upper end begins about Pitaicachi, and the lower somewhere near the other mean.

"Admitting that the central region is about the north end of the Teras, and the southern portion of the San Bernardino valley, the

peculiarity which attracted my attention was apparently the two circles of maximum intensity, — the mountain-line, and the one indicated by the destroyed and injured towns. The solution is for you. But the thought has obtruded itself in my mind, why cannot there be areas of re-enforcement in earth as in water waves, where a succession of small impulses are followed by an aggregated one? This by reflection and accumulation of successive shocks from the focus. Of course, the point could be placed on the isoseismal of the towns, or considered as areas of characteristic epicentral disturbance.

Noteworthy is the immunity of Bacerac and San Miguel; the former nine miles south, the latter three and one-half miles to the north, of Babispe. Though the energy of the shock was undoubtedly great, no serious damage was inflicted, save to the feelings of the inhabitants; and the degree of religious frenzy originated, more than compensated for the lack of seismic perturbations. They can be put on the isoseismal of Tombstone.

"Of the effects of the *temblor*, none have been of greater interest or more importance than the modification of the water-supply of the shaken district. During the first shock, all over the area of severe and even moderate vibration, the phenomena of water-craters were exhibited. This, however, was merely a temporary affair, the flow ceasing as soon as the violent shaking was over. It is the permanent re arrangement of the water-distribution which we have to consider. Many apocryphal stories have been told of the wonderful increase of water in the Yaqui and other streams immediately succeeding the earthquake. In addition to the outpouring of the crater water, many springs were made. This latter effect was not, however, an instantaneous one. In most of the rivers and springs where there has been increase, at first they went almost dry; then in a few days or weeks was a gradual augmentation of water, this antedating the rainy season. At the present time there is an alteration in the water-supply, with others, of the following streams and springs: the rivers of Fronteras, Yaqui, and San Bernardino; the springs of Penuelas and several others with uncertain names; the arroyos of the passes, Elias, Elisu, and Cabellera. Most important is the Yaqui River. This gradually gained in volume after the first diminution, until the flow equalled its midwinter amount. The San Bernardino is now flowing from head to mouth, a thing never before known at this season of the year, and is said to be gaining. Several important springs on the eastern side of the mountains, opposite Babispe in Chihuahua, were increased in size, notably Penuelas on the Carretas Ranch. A number of entirely new springs were started. In fact, over the entire central seismic region, the water-supply has visibly augmented. In considering this, the effect of an unusually severe rainy season must be estimated.

"The rainy season of 1887 has been unequalled since 1881. There was, however, an unquestioned gain of water before this set in. But when it did come, there was nothing by which one could judge whether a specified enlarged flow was due to rain or *temblor*. The summer rainfall has been added to greatly by an extraordinary winter downpour. Altogether, there has been sufficient celestial increment to throw considerable doubt on the proximate origin of the terranean and subterranean surplus. Unlike the treasury surplus, there is no need of reduction. It is required. By reason of this extraordinary quantity of aerial moisture, the estimate of the value of the quake to the country must be held as subject to modifications in the future, should a dry season supervene, and demonstrate that the abundance of water was due to the heavens, not to the earth. One cannot contemplate the San Bernardino valley without believing that such stupendous changes as are there manifest must have caused some permanent alteration in the subterranean reservoir, — either increment or decrement. And if, at the lapse of a year, a decided increase is noted, as has been, the former result must be concluded to have taken place.

"It will be noted in all reports that the direction of the first shock is given as from west to east. This, perforce, in most instances can be nought but error, especially on the line of the railroads from Guaymas north. But let us consider the case of the Sulphur Spring valley. At the time of the primary quake a cattle round-up was going on at the station called Abbott's Ranch. The house is near the centre of the valley, which is here nearly thirty miles wide, and thoroughly waterlogged. There is no running stream; but over its entire area water exists, from a few feet in depth on the margin, to but a few inches in the centre, which is full of swampy holes. It is a mass of alluvium, neither the mesas nor the bordering ranges on the west or east encroaching much on the margins. All reports from this place (and I have interviewed at least thirty of the one hundred or less men present when the first shock occurred) say it came from the west. The explanation I have to advance for this may or may not be a tenable one. It is this: in all earthquakes, near the central region there is what may be called a 'resonant area' preceding the vibratory movements of the earth. This, in the *temblor* of May 3, antedated the onset of the tremors a sufficiently long time to have passed to the west and north-west at the instant the shake began. Of course, the noise being in the west, the origin of the simultaneous terranean movements was of necessity located there. This, however, does not entirely answer for the Sulphur Spring valley. There they claim to have seen the rocks falling and the dust rising on the western side of the valley first, and some seconds later the same phenomena on the eastern. I am inclined to think that this is to a certain extent true. My reasons are the character and continuity of the mountain-ranges extending from the western side of the epicentral area to the western portion of the valley, and the nature of the valley itself. The rate of vibration and wave-propagation must have been modified by passing through so saturated and heterogeneous a mass as the latter. The mountains are not actually continuous between the points mentioned, but there is less breaking, therefore slighter apparent chance of interruption, on that line than any other; and it seems not an improbable or impossible hypothesis to assume that the waves, both of sound and of movement, were propagated along that line most rapidly, and did reach the western side of the valley anterior to the time they made their appearance in the east. If this be not the solution of such united testimony, it must be solved in some other way. I think the time-data indicate this view of it, though in this you must be the judge.

"Among other *sequellæ*, the mountain-fires which the effects of the earthquake were the sole factors in originating, were due to two causes, — falling bowlders and the emission of ignited gases. The Sierra Madre fires were, beyond question, synchronous, and arose similarly. The evidences of gaseous irruption were few but striking. Primarily were the statements of many who claim to have seen streaks of flame at different points, in the course of the first night in particular, and several times thereafter during succeeding days and nights while the heavy shocks continued. This evidence might have been a subjective sensation purely, due to inherent mendacity, or phenomena of fright similar to the stellar exhibition of syncope. The objective testimony cannot, I believe, be gainsaid. The shifting of such a tremendous mass of earth must have had some concomitant phenomena; and, if water and gas shot out to varying but moderate altitudes, why should not ignited gas do the same? It did; and the evidence was found in several places, both in the river-beds and in the hills along the line of faulting. This consisted of cinders about the margins and on the walls of the river-fissures, and the discovery of burnt branches overhanging the edges of such places, as well as the same testimony on some of the hills and mountains near the main fault.

"Anywhere near one hundred and fifty miles of the centre the energy of the shocks was considerable. All along the Sonora Railroad, from Guaymas to Nogales, and from the latter place to Benson, Tucson, El Paso, and as far north as Albuquerque, general alarm was excited. From Charleston to Benson, in the San Pedro valley, was a section of quite violent and terrifying motion. Water-tanks slopped over, cars were set in motion on the track, chimneys thrown down, buildings cracked, and water spouted up from the ground. The last-mentioned phenomenon was not exhibited north of Fairbanks. The track sank and bent at a point where it runs in an east-and-west course, about two miles west of Fairbanks. The convexity of the bend was south. These villages and stations are in the narrow, alluvial bottom of the river-course.

"At Batepito are some old adobe houses. They were frail and in ruins many years anterior to the earthquake, but it is remarkable that the remaining walls were not prostrated by the shock. Of course, some of the upper portion was broken off, and one or two having roofs crumbled in. Such structures in Babispe, Opotu,

Fronteras, or San Bernardino, would have been demolished. These houses stand in the centre of the section mentioned as having been covered with water several inches deep, and which has sunk over four feet.

"Tombstone being the nearest place where a number of time-observations could be compared, it becomes requisite to know with as great exactitude as possible the instant the shock arrived. At the onset of the *temblor* I had just noted the time, and my watch was partially in my hand in the act of returning it to my pocket. When I looked, it was 2.48 mining time, which was that day thirty-five minutes faster than standard or railroad time. When, recognizing the nature of the phenomena occurring, I again looked at my watch, just one and three-quarters minutes had elapsed. This was after the tremors had passed. The noise, resembling artillery-firing more than any thing else, continued for some seconds, dying slowly away in the north, to return in a few seconds from the south. By careful comparison and consideration of at least thirty different statements as to the Tombstone time, I am compelled to put the onset at 2.13, with a possible and probable error of ten or fifteen seconds. From Guaymas to Benson I have made personal inquiries, and think there is room for more error than in the Tombstone time. The difference in Sonora time and standard was that day thirty-four minutes.

"As concisely as possible I have tried to convey to you the facts as seen by myself, and ventured some crude notions based upon my interpretation of the observed phenomena. My idea of the explanation of the opinion that the shocks came from the west is not altogether theory. I have had the good or bad fortune to have witnessed and felt a large number of mild and severe *temblors* the past year; and if the judgment of a non-expert, based upon personal experience, be worth consideration, then the assumption is not valueless, and is worthy of your investigation."

Mr. Goodfellow's report is accompanied by maps and photographs, references to which are omitted here, as have also been some few brief passages not essential to a comprehension of the facts.

Distortion in Plane-Table Sheets.

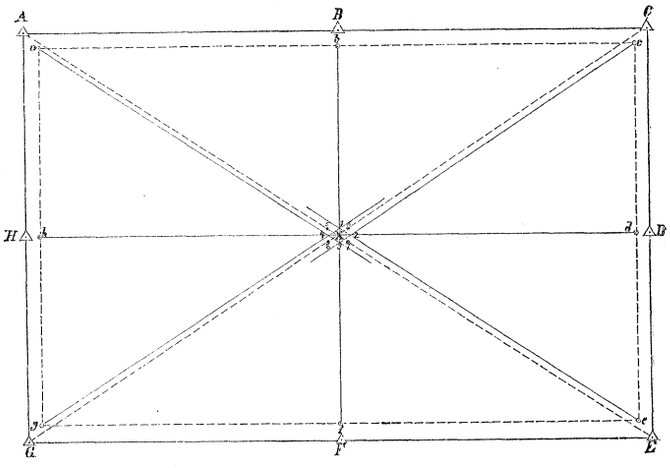
Mr. H. G. Ogden presented to the Philosophical Society, March 17, some observations on the effects produced in a plane-table sheet by its absorption of moisture. It is well known that wetting a sheet of paper causes it to swell or expand, and that, when the sheet has dried again, it has returned to about its original dimensions. Mechanical draughtsmen have realized the errors liable to occur in their work from this cause, and have effected a partial remedy by shrinking the paper upon a board, and securing the edges to prevent further contraction, and then to provide against expansion by working in a reasonably dry air. Surveyors using the plane table resort to the same devices when executing work of great refinement, especially if they have not the check afforded by the positions of a triangulation previously plotted on the sheet. But even with a well-conditioned triangulation, unless the paper is glued to the board, the contraction is frequently the cause of great annoyance, and sometimes of error.

When a sheet of paper expands from moisture, the percentage of increase in length is less in the direction of the grain of the paper than at right angles to that direction, or across the grain, and the difference between these percentages is practically the distortion. If the percentage of increase should be the same in both directions, there would be only a change of scale: all distances would be proportionally increased, and the points would bear the same relations to each other as before the expansion.

While it is true that the primary cause of the distortion is the absorption of moisture, the resultant effect is usually a permanent contraction, subject only to slight changes, except under the condition of excessive moisture. It is while this point of permanent contraction is being reached that the greatest annoyance is experienced and the most serious errors are likely to occur. Mr. Ogden then described a series of experiments made at the Coast Survey office some years ago, to ascertain the changes in length that took place in the hand-made antiquarian paper backed with muslin. Inspection of these observations, when plotted in the form of a curve, shows that there was a decided tendency to assume a state of permanent contraction. The readings at this point for each cross-section are 35 and 26 d. c. m., or at the rate of a little over .5 d. c. m. per inch of paper in one case, and .4 d. c. m. in the other. The difference between these rates is the average distortion in this case, — a quantity that is quite appreciable in a foot of paper, and very plainly so in two feet. In field-work, Mr. Ogden said that he had frequently found the distortion double this amount, and in one instance he remembered it nearly three times as large. He had also worked a whole season without any appreciable development of distortion.

In charts or maps printed from copperplates, or by any process that required wetting the paper, this distortion is largely developed, usually averaging as great as one per cent, and, if inferior paper has been used, as much as two or three per cent. The fact that this distortion exists is frequently not realized even by the most expert navigators, and some even magnify the errors by laying off courses with a protractor, discarding the compass-cards printed with the chart. These compass-cards are affected by the contraction exactly as the sheet is: directions ascertained by them are perfectly good, but the graphic angle between any two directions is erroneous, except in the case where the directions are on the lines of contraction.

Mr. Ogden then referred to a diagram, a copy of which is given herewith. *A*, *B*, *C*, etc., were plotted in the true relations. After



the sheet has contracted, *a*, *b*, *c*, etc., represent the relations those points have assumed. The paper contracts at a uniform rate in each direction.

The table is supposed to be at *X*, the exact centre of the figure, and it is required to determine the position by the distorted points *a*, *b*, *c*, etc. By reversing the telescope, we immediately ascertain that we are directly on the line *HD*. It will also show that we are on the lines *AE*, *CG*, and *BF*. But the distortion is not apparent until the telescope is pointed at the signals, and the lines are drawn on the sheet. Then if we orient by the line *HD*, we shall produce the figure of the diagram, giving five determinations, 1, 2, 3, 4, and *X*, each made with four well-conditioned points. Any one of these positions would be considered satisfactory if we had not the other points to show that something was wrong. To orient by the lines *BF* will produce the same result. But if we take the diagonal *AE*, we shall have two positions at 5 and 7, formed by the intersection of the diagonal points, with the lines from the other points running wild. Using the diagonal *CG* would give two points at 6 and 8, with the lines at the other points running wild, as before.

There is no question, that, out of the nine positions developed by these settings, that at *X* is the only true compromise. When the sheet is distorted, all positions are compromises; and *X* is the true compromise in this case, for it is on the lines *GC*, *AE*, etc.: *a* being below, and *e* above, the line connecting *A* and *E*, by equal quantities, a line drawn between the distorted points *a* and *e* must pass through the middle point *X*. The positions 5, 6, 7, and 8 cannot be true, because the lines forming them will not pass through the