On the Cause of the Great Earthquake in Central Japan, 1891.

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With Plates XXVIII-XXXV.

Introductory.

CONTENTS.—Introductory. I. Dislocations. II. Geology and Topography of Mino and Owari. III. The Great Earthquake of the Mino-Owari Plain. IV. Various Views as to the Origin and Cause of the Earthquake. V. Relation of the Great Fault to the Recent Earthquake. VI. The Course of the Line of the Great Fault that caused the Earthquake. VII. Concluding Remarks.

Geologists have rarely enjoyed so good an opportunity as that afforded them by the convulsion in the Mino-Owari plain, of observing those great displacements of rocks called "*faults*," which may only be brought about in the course of ages. Only a very few cases have ever been recorded in the annals of earthquakes, of the formation of throws of strata accompanied by subterranean shocks.

Lyell mentions in his classical work, *Principles of Geology*, a case that occurred in New Zealand, in 1855. A tremendous earthquake was experienced there, by which, especially in the vicinity of Wellington, in North Island, a tract of land comprising 4,600 square miles is supposed to have been permanently upraised from 1 to 9 feet. The line of fault was distinctly observed in the sea-cliff, called Muka-Muka, where the uplifted older rocks abut upon the lower, Tertiary plain of Wairarapa; and the course of the fault was traceable inland to the extraordinary distance of about 90 miles, in approximately

north-south direction along the Remutaka Mountains.

Another well defined case is that of the ever memorable Calabrian earthquake of 1783. The southern extremity of the mainland of Lower Italy is chiefly composed of primeval rocks. Gneisses and granites occupy the greater part of the country, being partially covered by Miocene and Pliocene of the facies of Flysch. A great *peripheral* or *longitudinal fissure* is said by Suess,* to traverse the whole length of that part of the country called Calabria, and along this tectonic line, the fearful shocks of 1783 found their way, having for their destructive centre the city of Oppido. The seismic activity continued for some weeks, and the shocks spread north, south, and west, but very little towards the east, chiefly confining their motion to the fissured line of the fault. The maximum point of the convulsive attack was transferred from one place to another through Soriano and Polia up to Girifalco near the northern end of the fault, and then returned with equal fury towards Radicena near Oppido, which was the epicentrum. The statement of Dolomieu on this earthquake is very interesting, especially from a geological point of view. The Apennines, he says, consist for the greater part of granite, and at their base are seen new (Tertiary) strata which constitute the plain of Calabria. The usual effect of the earthquake, he continues, was to disconnect all those masses of newer formations which were supported only by lateral adherence. Hence it follows that throughout the whole length of the chain wide chasms were formed between the solid granitic nucleus and the sandy Flysch soil.

The lines of dislocation of Lower Italy and also that of New Zealand are peripheral, i.e., longitudinal, running parallel with the axes of the mountains; and in both cases it is remarkable to see either that the dislocation has taken place along the boundary of the two entirely foreign formations; or

* *Das Antlitz der Erde.*

else that the direct contact of rocks of different ages has been the result of the faulting or slipping of one upon the other. Geologists are altogether silent as to whether the formation of faults and chasms should be considered as the direct cause, or only the outcome, of subterranean convulsions.

An unique, rhapsodic movement of land, and one which is often cited in text-books on the authority of Sir Ch. Lyell, as evidence of the actual upheaval of a large tract of country, is the formation of Ullah-bund. The 'Mound of God' or Ullah-bund suddenly made its appearance at the time of a violent earthquake which occurred at Cutch, in the delta of the Indus, on June 16, 1819, when the fort of Sindree, on the eastern arm of the river, sank down under the salt water of the Runn. The Ullah-bund is not such a mound as is usually constructed along a river, or thrown across a river-bed. It gives indeed the deceptive appearance of an artificial dam, but only when we behold it far away ; in reality it is the upraised edge of the land which imperceptibly dips away inland. It has also been ascertained that this new-raised country is upwards of *fifty miles* in length from east to west, running parallel to the line of subsidence, while its breadth from north to south is conjectured to be *sixteen miles*, its greatest ascertained height above the original level of the delta being *ten feet.** *Lyell saw in this newly created dam a true upheaving of ground, while Suess considers it in another light. According to him, we have here to deal not with the elevation of land, or with the formation of foldings of strata near the surface, but with the mere settling of the country in consequence of a pressing up of the ground-water of a muddy alluvial plain. These eminent geologists seem, however, to be in accord with the view that the change in the relief in this special case was the result, and not the cause of the terrible shocks which devastated the Runn of Cutch, in 1819.* The question at once arises in the mind, " Was the tectonic disturbance the cause or effect of an earthquake ? "

* Lyell, *Principles of Geology*, 12th edition, p. 161.

The causes of earthquakes.—A popular subject with the men of science of all ages has been the causes of earthquakes, upon which much has been written, but of which little is yet known. As earthquakes are, in one place or another, of daily occurrence, especially in the *ruptured circle* which separates the northern from the southern hemisphere, and as the depths of curiosity are stirred up in the minds of people who have unhappily experienced the startling tremblings of what is usually looked upon as the symbol of fixity—all sorts of explanation have been offered as to their origin; and hence the world has had, both in past and recent times, the misfortune to see the sporadic appearance of monstrous theories on the subject. It lies, however, beyond my present limits to give here the various views as to the causes of earthquakes. This has been already done by Franz Toula in his "*Ueber den gegenwärtigen Stand der Erdbebenfrage*," and readers are referred for details to that small treatise.

One of them is, however, worthy of mention, as it was for a time held in much favour in Europe. Rudolf Falb, the editor of the popular astronomical journal, "*Sirius*," is the chief supporter of this sideric hypothesis.* A cosmic body, especially the moon, is, according to him, able to exert its influence *upon the nucleus* of the terrestrial globe in causing a tide in the interior and simultaneous contraction of the earth, and by so acting may induce a subterranean volcanic explosion which results in a shake on the surface.

While the Austrian journalist is engaged with his favourite idea, but more in popularizing it than in establishing it on a firm scientific basis, we see in another direction an endeavour made to inquire into the causes of seismic phenomena through researches on the formation of mountains. The study in this direction is an effort to bring together into scientific shape the facts ascertained through detail-

* *Grundzüge zu einer Theorie der Erdbeben und Vulkanausbrüche, 1869.*

ed studies of individual earthquakes, and a comparison of the results obtained therefrom with the facts of the geological structure of the region concerned. The chief merit in this line of study is due largely, at least, to the Austrian geologists, Suess, Hoernes, and Bittner. The last-mentioned author gave a finishing blow to the fantastic hypothesis of Falb, in his work on the earthqnake of Belluno, in 1873.*

Although we are as yet not in a position to be perfectly clear on the dynamics of the formation of mountain-ranges, still we are already in possession of a certain knowledge on this subject through the study of the Alps. Long ago, Elie de Beaumont saw in the origin of mountains a radial, elevating power, but to this C. Prévost made strong objections. The latter taught us that the elevation is only the effect of a depression of neighbouring regions; and the same view is advanced in the works of Le Conte and of Dana, in a more or less modified shape.

Suess was led by his investigation of the tectonics of the Alps, to express himself to the effect that unequal contraction and the horizontal shifting of the earth's crust resulting therefrom are the cause of foldings of strata.

Again, in his "*Entstehung der Alpen*," Suess says that all mountain-ranges are of one-sided, unsymmetrical structure, the probable explanation being that they originate at the margin of a great depression which exerts a horizontal, lateral pressure. The concave side of mountain-chains on which they face depressed regions we may naturally expect to be much disturbed and ruptured; and seismic activity and volcanic eruptions are usually manifested particularly at this weak point. Professor H. Credner† holds the same view about the

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* *Beiträge zur Kenntniss des Erdbebens von Belluno.* Sitzber. d. k. Akademie d. Wissenschaften. 69 Bd., 1874.

† (a) *Das vogtlandische Erdbeben vom 23 Nov., 1875.* Zeitschr. für die ges. Naturwissenschaften. 48 Bd. 1876. (b) *Das dippoldiswalder Erdbeben von 5 Oct., 1877.* Zeitschr. für die ges. Naturwissenschaften. 50 Bd.

earthquakes of the Vogtland and the Erzgebirge, with regard to mountain-structures. Hoernes tells us in the concluding remarks of his paper,* that earthquakes may take origin from different causes; at one time, the falling in of subterranean cavities, though very rarely, and at another, a volcanic explosion, may bring about locally terrible convulsions; *but by far the greater number of earthquakes and the most terrible ones are the direct outcome of the process of mountain-making.* Under the last category are included those shakings whose frequency and seismic area are more or less closely connected with certain lines, upon which the shakings are repeatedly observed. As they appear to have some direct relation to the activity of mountain-building, Hoernes gave them the name of *tectonic earthquakes.*

Having given a general retrospect of views as to the causes of earthquakes, I may now proceed to the immediate subject of this paper, which is divided into five sections, as follows :—

I. Dislocations.
II. Geology and topography of Mino and Owari.
III. The great earthquake of the Mino-Owari plain.
IV. Various views as to the origin and cause of the earthquake.
V. Relation of the great fault to the recent earthquake.
VI. The course of the line of the great fault that caused the earthquake.
VII. Concluding remarks.

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* *Erdbeben-Studien.* Jahrbuch d. k. k. geol. Reichsanstalt, 28 Bd., p. 448.

I. Dislocations.

Whatever may be the cause, whether depression or unequal contraction of the earth's crust, the formation and structure of mountain-ranges are surely due to the folding, rending, and fissuring of strata. Therefore it is not entirely out of place to insert here some considerations on the topic of *dislocations*, which Professor Suess has ably sketched out in his "*Das Antlitz der Erde.*"

"*Die sichtbaren Dislocationen in dem Felsgerüste der Erde sind das Ergebniss von Bewegungen, welche aus der Verringerung* des Volums unseres Planeten hervorgehen.*" A stress originated in this process may be resolved into tangential and radial components. The first is horizontal, folding and shifting the mass; the second is vertical, often causing a large tract of land to be depressed. The tangential component is more superficial, pressing up the strata into mountains; the radial component acts more profoundly in the interior of the crust, and as a rule volcanic explosions accompany the dislocations due to it.

a) We begin with the tangential movements of the lithosphere. The simplest result of a horizontal thrust of any superficial part of the

* Every theory which has hitherto been proposed to account for the elevation of mountains and the folding of the stratified rocks forming the earth's crust hinges finally on *changes* of temperature. Thus the tangential force generated in the rigid crust of low temperature by the cooling and shrinking of the earth's nucleus has been invoked to account for the crumpling of the crust into mountain-ranges; the crumpling skin of a dried apple being the stock illustration. In this case, the force called in is continuous contraction by loss of heat. The theory which Mellard Read has elaborated is the one dependent upon *alteration* of temperature in the crust, contraction and expansion both being agents of uplift and lateral pressure. Mellard Read: *Origin of Mountain-ranges by Sedimentary Loading and Cumulative Recurrent Expansion.*

crust is the production of a series of folds with alternating geosynclinals and geanticlinals; the crests of such wave-like folds correspond to longitudinal mountain-ranges, the intervening troughs being longitudinal valleys. The direction in which the force acts is at right-angles to the strike of the saddles, or to the axis of a mountain-chain. Folding such as we have mentioned of course involves tilting, and all the different forms of inclination have been described as occurring in nature. We may cite, as an example of such, a chain of the Sambagawan schistose rocks that stretches from the city of Tokushima to Cape Sadano-misaki in the Island of Shikoku; while the valley of the Yoshinogawa, which runs parallel with that range and discharges its waters into Linschoten Strait, may be taken as the model of a longitudinal valley.

When the stowing of mountains and the puckering of beds are carried to a certain degree, the limit of elasticity of rocks will be overstepped, and one effect of this may be that the beds of the upcast side are bodily shoved over those of the downcast side. A set of such "creeps" (*Wechsel*) will produce what is termed the overlap fault or *Schuppenstructur*. At the same time part of a mountain may be dislodged along a fissure running parallel to the axis and strike of a ridge. The movement of a complex of strata in such a case along the line of *longitudinal or peripheral* fault will cause a *longitudinal earthquake*.

If the horizontal force do not act with equal intensity over the area affected by it, one part will be more strongly compressed by it than another, and will consequently be pushed forward along a fissure that is directed at right-angles to the axis of a mountain. In this way, parts of a mountain-chain may be thrust forward along sets of *transverse fissures*. At the same time the strata will suffer downward displacement, and such a dislocation be accompanied by what is called a *transverse earthquake*. That the great earthquake of October last,

should be counted among this class of convulsions will be argued out in detail in the sequel.

β) As we have already said, the stress proceeding from contraction of the earth resolves itself into two elements, of which one acts more or less in a tangential or horizontal direction, while the other works vertically, and dislodges a large tract of land into a *caldron-like* depression. Of the dislocations due to the tangential component, we have already given a general sketch. Now it will be clearly apparent that, while these horizontal shiftings are going on, especially along transverse faults, some parts will receive a passive movement in the vertical direction, resulting in a local downfall of beds and in landslips on a large scale, as if also the radial component were working from great depths.

The genuine radial movement should not be confounded with such a local depression of strata into a hollow in the superficial part of the crust, as that of Fujitani in the Neo valley, which, up to the present, is supposed to have been the sole cause of the earthquake that convulsed nearly the whole of Southern Japan in October, 1891. True radial displacement, of which we are now speaking, is the downward movement of an immense tract of the solid crust, and its effect does not usually come clearly into relief in a country, except in a less disturbed bed like that of the Plateau of Colorado.

The caldron-like depression resulting from vertical displacement, topographically known as a basin, can be found in various localities along the inner or Japan-Sea coast of the Main Island, which curves down from the Kuriles (Chishima) to Kyu-shū, with its convex side towards the Pacific Ocean. Here, as on the Tyrrhenian coast along the inner side of the Apennine curve, we find, with Dr. E. Naumann*, a number of depressed basins, each having a gigantic

* *Ueber den Bau und die Entstehung der japanischen Inseln*, p. 74.

volcano in its centre, such as Iwaki, Moriyoshi, Chōkai, Gassan, Daisen, Sambé, and Aono.

Nearly at the middle of the Pacific side, a notable indentation of the coast-line forms the Bay of Isé, whose northern prolongation is a kettle-like depression. This is the low plain of the twin-provinces of Mino and Owari, which was the scene of the disaster occasioned by the subterranean convulsion in the autumn of 1891. This flat has the appearance of a basin, circumscribed on all sides by walls of mountains, except at its rim on the south, which is, as just stated, open to the Bay of Isé. The west, north, and north-east are built up of Palæozoic formations, while the mass of granites of Mikawa lies on the east.

Mr. Kochibe, of the Geological Survey, *made known in his official report his view as to the cause of the late earthquake, which is based on the assumption that the above-mentioned plain is a geological sag or 'Graben-Depression,'* as Prof. Suess would say. He supposes that beneath the surface a number of fault-lines run north and south, and also east and west, and that in consequence of the downward movement of strata interposed between the planes of fault, displacements have eventually formed the present plain ; and he also believes a paroxysmal sliding of a complex of rocks on these old geological lines to be the actual cause of the earthquake. Our geological knowledge of this part of the country is as yet very imperfect, and some time must elapse before we can expect to see any successful attempt to establish so daring an hypothesis on a tolerably safe scientific basis. So much in technical treatment of dislocations.

II. Geology and Topography of Mino and Owari.

We have already pointed out the geographical situation of the provinces Mino and Owari on the Tōkaidō, lying nearly half-way between Kōbe and Tōkyō. The picturesque Lake Biwa with an area of 715,5 square kilometres, lying to the eastward of Kyōto, is separated from the neighbouring Mino-Owari plain by the meridional ridge of Suzuka. The range is mainly built up of Palæozoic formations, with a subordinate mass of young biotite-granite rising to a considerable height, and over which the old road of the Tōkaidō winds up through the well-known Pass of Suzuka (373 m.).

The Palæozoic formations are chiefly composed of multifarious alternations of a greyish, medium-granular, arkose sandstone, and imperfectly fissile, blackish clayslate; with these are associated hornstone and *Radiolarian* slates (Profile *a*—*b*, Pl. XXVIII.). All these thick complexes are sterile in well-preserved fossils, and as yet no detailed geological studies have been made of them; so that we are at present obliged to call them simply by the vague term of transition formations. There are, however, a few bands of compact limestones inserted between them, which afford tolerably abundant organic remains. These fossiliferous limestones have already been made the subject of a special study * by the late C. Schwager who discovered in them many well-characterized petrifactions, *viz.*:—

Fusulina japonica Gümbel.
„ *exilis* Schwager.
Schwagerina Verbeeki Geinitz?
„ *craticulifera* Schwager.
Fusulinella sp.

* Richthofen, *China*, IV. Bd.

Lingulina sp.
Tetratatis conica Ehrenberg.
Endothyra crassa Brady.
Climacammina protenta Schwager.

Dr. Gottsche* added to the above list the following forms : *Archaeocidaris*, *Poteriocrinus*, *Pentacrinus*, *Favosites*, ? *Cyathophyllum*, *Pleurotomaria*, ? *Murchisonia*, *Bellerophon aff. hiulcus* Sow., 3 Fusulina, 2 *Schwagerina*, *Endothyra*, *Trochammina* and *Textilaria*.

From what has been given of the organic remains, it is clear that the limestones are of the Carboniferous age, and the thick complexes occurring together with the calcareous beds must represent partly or wholly Palæozoic formations. These Primary strata dip towards the north-west, and their strike is north-south. The ridge of Yōrō (840 m.), which is a detached mass of the Suzuka, rises precipitously from the plain below and forms the western boundary of the lowland of Mino and Owari.

As may be judged from the direction of the limestone outcrops, in the rectangular geological map, Section Nagoya, † the whole Primary formation seems gradually to change the strike at the north-west corner of the plain, and the well-known fossil locality of Akasaka is just at this turning point (Pl. XXX.). Afterwards the strike shifts a little to the north-east, then east to west, and finally, at the north-east corner of Mino, the Palæozoic beds proceed directly in a north-easterly direction far into the mountainous province of Hida. On the east we find the massive mountains of Mikawa, largely composed of granites in which at times hornblende, at others biotite or muscovite, occurs as prevailing component. The granite, frequently

* Zeitschrift der deutschen geolog. Gesellschaft, 1884.
† Published by the Geological Survey of Japan.

showing gneissose structure, takes up large geological blocks or "*Schollen*" of gneiss, gneiss-mica schist, mica-schist and also amphibole-schist, which may be classified into Laurentian, and Upper Archæan (the Takanuki and the Gozaisho series). The writer has been recently engaged in a special study of these ancient rocks, and the results will be found in earlier pages of this volume.

Thus the twin provinces are on three sides bounded by masses of mountains, and in their very centre lies an extensive populous plain, with an area of not less than 1,051 square kilometres or 68 square ri. The general aspect of the plain, which inclines slightly towards the foot of the Yōrō ridge is monotonous and flat. It is covered with a net-work of rivers and artificial canals which, owing to the special orographic condition of the low-lying tract, mostly concentre at the western margin (see Map, Pl. XXIX.). The largest of the rivers is the Kiso-gawa, which starting from the dense impenetrable forest of the Kiso-kaidō, is fed by several tributaries before entering the plain, where it joins with the Nagara and Ibi. These confluent streams branch off at one point and reunite at another, discharging their waters at the head of the Bay of Isé, near the port of Yokkaichi.

The head-waters of the Kiso drain the granitic area of the primeval forest of Shinano, and the swift current, carrying with it an enormous amount of detritus and sand, unloads its contents in its lower course. The formation of the plain is, I think, largely due to the sediments of this river. The lowland of Mino and Owari is usually spoken of as having been once an immense swamp, since converted to the present paddy-land within historical times, and having as the last remnant of its former grandeur the Lake of Shimo-ike, at the foot of Yōrō. It now stands foremost in rank among all the rice-producing districts of Japan, and supports hundreds of thousands of people, Nagoya, Gifu, and Ōgaki being the chief centres of its commerce.

Although the story of the wide marsh seems to be a great exaggeration, still we see in it some germ of truth; for, if all the artificial canals and dams were to be removed, the present fertile land would in a moment be nothing better than a moor. It is these dams and the drainage system that suffered the greatest damage by the last earthquake, so that to reconstruct them in their former state will cost the people an almost incredible sum. The length of embankment and moat, surveyed officially for repair, is not less than 510,5 kilometres.

There are strong reasons for believing that the low-lying tracts experienced the shocks to the greatest degree, not that they were at the epicentrum of the earthquake, but because of the sandy nature of the ground. The soil which makes up the greater part of the paddy-land, especially the eastern, severely damaged by the last earthquake, consists of loose, incoherent, fine sand with but little clayey matter. This soil I consider to have been formed out of the sediment of the Kiso-gawa.

The rivers, Nagara and Ibi, take their origin high up in the Palæozoic mountains of the northern border, and the rocks upon which they exert their denuding action are sandstones, hornstones, and clayslates. The sediments are therefore more or less clayey and heavy. The land formed from the silt of these rivers occupies the western part of the plain, through which they make their way to the sea; and this is the seat of least damage by the late subterranean convulsion.

The North of Mino, as already briefly stated, is a mountainous district, consisting mainly of Palæozoic formations. A cordillera runs from south-west to east, and then north-east, proceeding directly through the province of Hida to the volcanic group of Hakusan of Kaga, the Japanese Alps (Pls. XXIX., and XXX.). It is the main divide which separates the river-systems of the Pacific and the Japan

Sea. Beyond the mountain-ridge lie the provinces of Echizen and Kaga, where the Mesozoic formation is extensively developed, and later on has been intruded into in places by masses of Tertiary eruptives.

A plain of considerable extent, worthy of mention here, is the basin of the Kudzuryū-gawa, in the centre of which lies the city of Fukui. This region felt severe shocks during the late earthquake, and suffered calamity surpassed in extent only by that felt in Mino and Owari. During winter-months the icy winds from Siberia, crossing the waters of the Japan Sea, blow strongly against the ridge, and copiously precipitate moisture in the form of snow. This part of the country presents a dreary aspect, and is untrodden land within the heart of the Main Island. It is rarely visited by geologists, but Mr. Kochibe, during his reconnaissance survey, once crossed the range in going northward from Gifu, through the Neo valley, which is well known since the last earthquake, to Echizen, over the pass of Haibōshi. The line of section, *c*—*d*, Pl. XXVIII., is constructed from his field-sketch, supplemented by one by myself.

This section is one drawn northward from a point south of Yamaguchi up to the top of Hakusan (Gongen-yama), for a distance of 27 km., and goes obliquely through the whole Palæozoic formations of the North of Mino.

Just at the entrance of the valley near Yamaguchi, a bed of hornstone is exposed with a band of limestone in it which encloses abundant remains of crinoids and foraminifera. This complex is followed to the north and overlaid by slate with the strike nearly east to west; then come hornstone, sandstone, and again slate, and so on, with northerly dips usually at very high angles. The lithological characters are rather constant throughout the whole valley, and the multifarious alternations of the above-mentioned rocks constitute the Palæozoic formations of this district. The strike of the rocks remains

the same till we come to Kiré, whence it changes very slightly to the north-west. The youngest and consequently the northernmost of the series is the hornstone of the upper Neo, where it abuts upon the *granite-porphyry* of Hakusan (Hakusan Mayeyama). Near the point of contact an intrusive rock of the character of *hornblende-porphyry* is pressed up through the stratified complex.

The petrographical characteristics of the porphyries are here given :—

a) **Granite-porphyry.**—This is a rock which presents peculiarities in many respects, and is of wide distribution throughout Japan, especially in the highlands of Hida. It was once called granite, then diorite, but now goes generally by the name of porphyrite in all the Geological Survey maps. It is, however, not a typical mica-hornblende-porphyrite, since it is of granitic structure, and contains moreover a large quantity of monoclinic feldspar. On the other hand, the name diorite does not suit it. It resembles a biotite-hornblende granite most closely both in mineralogical composition and in structure; but the presence of porphyritic crystals precludes its being classified as that. It is a greyish-white, mediums granular rock of dioritic aspect, decomposing into angular fragments, like chips of a hornstone-mass. Phenocrysts are scarcely distinguishable in hand-specimens, a- the component minerals are nearly of the same size. *Feldspar* and *hornblende* enter largely into its composition, and, when examined under the microscope, *quartz* and *biotite* are observed, together with *magnetite*, *epidote*, *zircon*, *titanite*, and *apatite* as accessories, the last one being especially characteristic of this rock.

The feldspars are the dominant ingredients, and fall into plagioclastic and monoclinic varieties. Which of the feldspars is present in larger quantity is not easy to say. Speaking generally, the porphyritic, tolerably idiomorphic crystals are mostly but not exclusively plagioclase, with the well-developed zoning which is the characteristic of rocks of a porphyritic structure. The feldspars are mostly oligoclase, sometimes schillerized, extinguishing light at about 13° with the twinning sutures, and with their centres frequently kaolinized over a definitely marked area with patches of chlorite, the surrounding zones being apparently untouched by weathering. The feldspars are the only components that deserve the name of phenocryst.

The rest of the mass is a granitic aggregate of feldspars mostly orthoclase,

and of hornblende, biotite, and quartz. The hornblende, appearing macroscopically as a porphyritic ingredient, is really an accumulation of amphibole and biotite, and these decidedly belong to the second generation of crystals. The irregular plates of hornblende, deeply indented by grains of quartz, and interlarded throughout by prisms of apatite, are of a deep bluish-green colour and pleochroic. The brown fibrous biotite has usually grown with amphibole into irregular tufts, and with them clumps and crystals of magnetite are commonly found. In one slide examined, both magnesium-bisilicates are greatly decomposed into a green fibrous mass, finally changing into a chloritic substance. In this case a large quantity of dust and numerous crystals of magnetite, together with leucoxene, have settled within the confused aggregates, accompanied by secondary epidote.

The feldspar of the general mass is not striped, and is much more decomposed than the phenocryst. Its form is imperfect, being conditioned by the mutual disposition of the same species and of the magnesium-bisilicates. The quartz is present only in small quantity, and is irregular in its form, having filled up the interstitial spaces left by other ingredients. It is of course fresh, displaying the usual vivid chromatic polarization, while the other components are more or less decomposed, and consequently appear dull. Well-finished crystals of it are nowhere observed. It is interesting to note that the quartz contains abundance of liquid and gas-inclusions, the former often holding dancing bubbles and also *small cubes, probably of sodium-chloride.* Glass-inclosures are so far not observed.

Zircon is found in the combination of P and $\bar{\infty}$P, and titanite is found in irregular grains. Apatite is plentiful; its cross-sections are *hexagons with alternately truncated corners*, the longitudinal sections being lath-shaped exactly like those of a tourmaline. Neither the transverse nor the longitudinal section of the apatite becomes totally dark in any position during complete rotation upon the stage. Its crystals contain, especially in their central portion, a large number of gas and liquid-inclusions with spontaneously moving bubbles.

Another slide, made of a specimen from the same locality, presents characters somewhat deviating from the above, in respect to structure, the general mass being for the greater part made up of an intimate intergrowth of quartz and feldspar in *à la grec* form. The general aspect of our granite-porphyry seems to have a close resemblance to the rock, called by v. Richthofen,* the Corean granite, from Kauli-

* "*China.*" Cfr. R. Schwerdt, *Untersuchung über Gesteine der chinesischen Provinzen Schantung und Liautung.* Zeitschr. d. d. geol. Gesell. Bd. 38, p. 214.

mon, the Gate of Corea, situated at the south-east corner of Liau-tung.

β) **Hornblende-porphyry.**—This is a hornblende-diorite-porphyrite, of an ashy-looking aspect, with tolerably large (5mm.), well-defined crystals of *hornblende* as the porphyritic ingredient, seemingly forming dykes in the Palæozoic complex. The general mass is a greyish, fine-crystalline aggregate, in which no other component except the above-mentioned hornblende is to be seen. The amphibole-phenocrysts are of two varieties; the one is in well-defined prisms of compact texture, with the cleavage face perfect and showing a sub-metallic lustre; the other is rather greenish and fibrous with imperfect crystallographic outlines. The distinctive features of the two become more pronounced, when viewed under the microscope.

The compact hornblende is of a deep-brownish colour with different tones in centre and periphery, and is bordered by greyish and blackish granules of *leucoxene*. Its pleochroism is distinct; its outline is tolerably regular, and twinned in that shape which was formerly considered as anomalous twins whose plane of contact was supposed to be the prism $\infty P \bar{2}$ (120).† The other variety is of a yellowish-green, fine, parallel-fibrous texture, resolving oftentimes into chloritic patches. A large quantity of magnetite is present, being scattered through the whole mass.

The rest of the rock is holocrystalline, being built of lath-shaped *feldspar*, *chloritic hornblende*, and black *iron-ore* with borders of leucoxene. The greyish, more or less decomposed feldspar is simply or doubly twinned. There seems to occur another feldspar which is of rather larger size than the other, and of irregular outlines with no signs of a twinning structure. It is probably orthoclase. Allotriomorphic angular *quartz* fills up the interstices left by other ingredients. It is present only in small quantity, and shows a greyish tinge between crossed nicols with undulatory extinction. The quartz contains abundance of liquid-inclusions with spontaneously moving bubbles. The general colour of the ground-mass is grey, on account of the presence of a large amount of leucoxene and chloritic matter, with an aggregate of more or less decomposed, greyish feldspar.

As may be seen from the sketch in Plate XXX., the strike of the Palæozoic formations changes its direction in a most peculiar manner.

† Becke; Tschermak's mineralog. und petrogr. Mitth. Bd. IV, p. 365.

At first, it points a little west of north as in the Suzuka ridge, then turns to the north-east at Ibuki. Afterwards the strike is due east-west, then again it imperceptibly deflects towards the north-east, retaining the dip always on the left side (compare the profiles *a*—*b*, *c*—*d*, Pl. XXVIII.). In fact, the course of the direction of strike makes a sigmoidal curve, from which it is easy to conceive that the strata must have sustained stress from various directions.

Under such circumstances the axis of the saddles must have received an excessive twisting stress, and we may reasonably expect that during the movement the beds of rocks must have given way to fracture somewhere within the mountain, like the group of fissures in a pane of twisted glass, as experimented upon by Daubrée.* There are, I think, a number of such weak, geological lines in this region as the effect of torsional movement ; the four valleys, Tokuno-yama, Neo, Mugi, and Itatori may be taken as of this class of dislocation, upon which the atmospheric agencies have exercised their denuding action during the course of ages in producing the present deep ravines. As may be clearly seen from the sketch given in Pl. XXX., the courses of the above-mentioned valleys are tolerably regular, running parallel to each other from north-west to south-east, and thus stretching from the Kisogawa to the province of Echizen.

There seems to occur, besides the above-mentioned parallel lines, a number of fissures at right angles to the *paraclases*. These transverse clefts, or to use Daubrée's word, *diaclases*, may be traced in the zigzag run of the valleys. *The valleys in the North of Mino therefore present such regularities in their course, that they can by no means be attributable to the result of mere erosive agencies and their origin must be ascribed to deep-seated discontinuity in the earth's crust* (P. XXX.).

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* *Synthetische Studien zur Experimental-Geologie*, p. 236.

III. The Great Earthquake of the Mino-Owari Plain.

It was on October 28th, 1891, at 6h., 37′, 11″, when the first shock of the great earthquake was experienced, that being far and away worse than any of the many which succeeded it. It brought down the heavy tiled roofs and stone-laden thatches, and in a moment buried thousands of living people beneath them. At Ōgaki, Gifu, Kasamatsu, Takégahana, and many other places, immediately after the first great shocks, fires broke out amongst the ruins, and many who might otherwise have been extricated were burned to death.

In the alluvial plain, especially in the neighbourhood of Nagoya, the ground was riven with myriads of fissures ; small mud volcanoes were thrown up along the Shōnai-gawa, comparable to the sand craters of Achaja, in Greece ; and for the length of a mile, near Biwashima, a suburb of Nagoya, numerous fractures made their appearance in the banks of this river (Fig. 2, Pl. XXXI.). Here too a very strange thing happened. There was a large bamboo grove and a few pine trees, just at the west side of the embankment, and this slid bodily some *sixty feet* back, the bamboos and trees remaining upright (Fig. 2, Pl. XXXII.). In this figure will be seen a thatched roof fallen intact, and it was in this manner that most of the farmers' houses, which so thickly covered the Mino-Owari plain, gave way, and the country became dotted over with their roofs, which from a distance presented the appearance of gigantic saddles (Fig. 1, Pl. XXXI.).

Going northwards from Nagoya to Gifu, we find a series of villages, one running into the next; that is to say, there is a nearly continuous street of ten *ri*, or more than twenty miles, in

length. The rows of houses were thrown over by the shocks, and these twenty miles of road became simply a narrow lane between two interminable heaps of *débris* (Fig. 1, Pl. XXXII.).

Gifu, the provincial capital, was for the greater part overthrown, and then burnt by fire. Ōgaki, once the resident town of the Princes Toda, seven miles west of Gifu, was entirely levelled with the ground, and then also consumed by fire. Kasamatsu, just on the north bank of the Kisogawa, suffered the same fate, and all that was left of it was a reddish coloured expanse of tiles and rubbish. The fate of Takegahana was as bad, or worse.

What has been stated can convey but an imperfect idea of the destructive work done by the late great earthquake. Still greater convulsions happened in the mountain district of the North of Mino, traversed for a distance of more than forty miles by the line of fault, the birthplace of shocks, where all things were destroyed that happened to lie in the proximity of the great throws of strata, to which I shall have to return in the sequel.

Professors J. Milne and W. K. Burton, of the Imperial University, have given a lively account of the subterranean convulsions in "*The Great Earthquake in Japan, 1891*," illustrated with twenty-nine permanent-photographic plates in *boudoir* size, well printed by Ogawa, and the preceding statements relative to the devastations are mainly taken from this excellent work.

The most dreadful earthquakes within memory were the catastrophes of 1854-55, well known among us as the *Earthquakes of Ansei* (*i. e.*, of the 'Ansei' period), at which time Japan seems to have been the centre of universal earthquakes. Both years proved very calamitous. Nice, Alexandria, and Turin felt more or less severe shocks in 1854. During the following year, 1855, New Zealand, on both shores of Cook's Straits, was visited by a terrible earth-

quake. A shock was felt much about the same time at Truro, South Australia. A fearful earthquake also shook the opposite coasts of the Sea of Marmora; on the 28th of February, and in July of the same year, a smart shock traversed parts of Switzerland, Lombardy, and the south of France.

In the first year of Ansei (1854), the whole of Southern Japan, especially the Island of Shikoku, was visited by terrible subterranean convulsions. The earthquake-period was a long one. In the next year, the centre of the subterranean activity shifted more to the east, and in the greater part of the Main Island, particularly over the districts around the "excellent and singular" volcano of Fuji, towns and villages were reduced to heaps of ruins by most destructive earthquakes. Great as were the effects of the earth-convulsions at that time, the later catastrophe of October, 1891, seems to have been far the more dreadful in intensity as regards Mino and Owari, judging from the destructive effects of the disturbance, and the statements of people who survived the event of the Ansei period.

The Mino-Owari plain (68 square *ri*) is one of Japan's great gardens, covered with rice fields and dotted with clumps of trees and with hamlets; rising from it on the north and south may be seen the castles of Nagoya and Ōgaki. This flat supports a population of perhaps 4,686 per square *ri*, or 304 to every square kilometre, and is therefore the most densely peopled region in this country, except Sanuki in the Island of Shikoku. The meisoseismic area includes all this plain and the mountainous district of Mino and Echizen. By the disturbance which occurred in this portion of the Empire in October, 1891, the land became at once a sea of waves, with movements greatly magnified on the soft alluvial plain. As this lay near the origin of the disturbance, the

waves were short and rapid, and overthrew towns and villages, fissured the ground, and ruined the strongest engineering structures.* According to the official returns, about seven thousand people lost their lives, seventeen thousand were wounded, and two hundred seventy thousand buildings were levelled with the plain, while six thousand houses, less shattered by the shocks, were burnt down by fire.

The following are the statistical accounts of damage in the six provinces, coming under the five Prefectures of Gifu, Aichi, Fukui, Miye, and Shiga :—

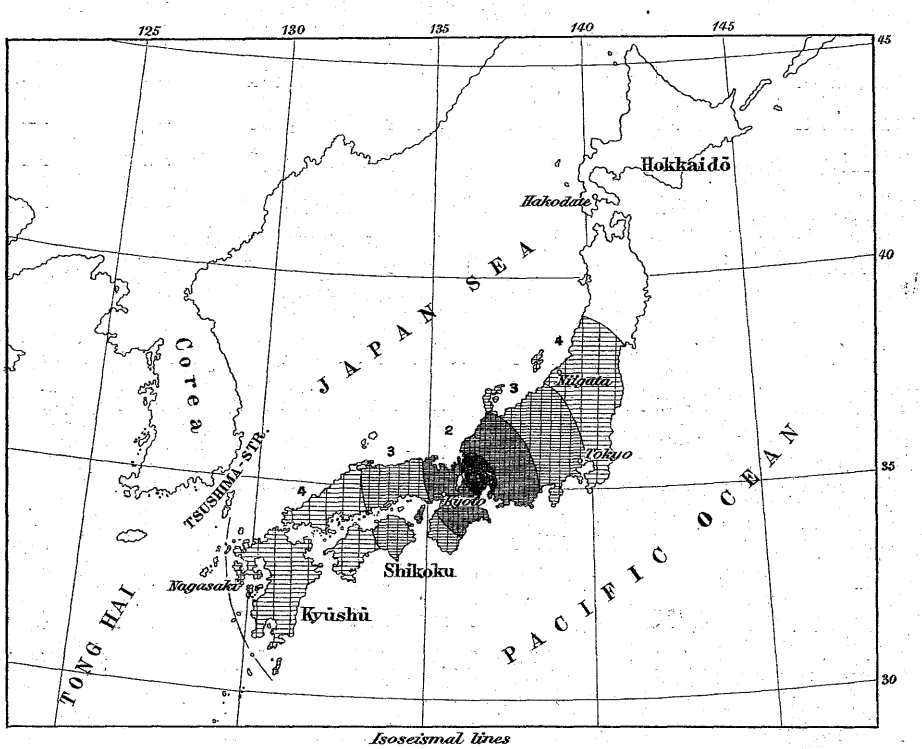
Provinces.	Wounded.	Killed.	Buildings entirely destroyed.	Ditto half destroyed.	Burnt.	Shattered and burnt.
Mino	12,311	4,889	114,616	30,994	249	5,934
Owari	4,877	2,357	80,428	43,845	196	—
Mikawa	49	13	1,020	1,464	—	—
Echizen	98	12	1,080	1,188	—	—
Ōmi	47	6	153	366	—	—
Miye	11	2	233	439	—	—
Total	17,393	7,279	197,530	78,296	445	5,934

The following three cases are selected as examples out of a long table, to show to what degree some of the cities and towns suffered in regard to both life and property :—

Names.	Population.	Number of ménages.	Wounded.	Killed.	Houses entirely destroyed.	Ditto half destroyed	Burnt.
Gifu	28,731	6,035	1,200	230	740	3,002	113
Kasamatsu	4,732	1,006	408	221	983	23	553
Takegahana	4,950	1,180	283	268	1,172	2	524

* The account given in this paragraph is based upon that contained in Milne and Burton's *Great Earthquake in Japan, 1891*, already referred to.

But this was by no means all the havoc wrought by the great earthquake. There was not a building in the entire meisoseismic area, and not one of the embankments which have been constructed along the nets of rivers and canals, that wholly escaped damage; and, as I have already said, it was officially reported that the embankments calling urgently for repairs extended for 130 *ri*, or 510 kilometres, while the length of the railroad demolished was found to be 17 kilometres. When steps had been taken to estimate the loss, the amount of injury disclosed was found to be much greater than had at first been recognized. The direct and indirect damage done to the trade and commerce of Nagoya alone, was calculated to amount to 1,778,693 *yen*.



Isoseismal lines

According to the *Official Gazette*, the epicentral district, the seismic area of the first order, which of course included Mino and Owari, along with some portions of the neighbouring provinces, extended over 11, 111 square kilometres, and over this area destruction of buildings and engineering works was well-nigh complete. That of the second order reached as far as Kōbe on the west and Shizuoka on the east, over an extent of 44,907 square kilometres. Within this area several houses fell, walls, embankments, roads, and bridges were partially damaged, and the water of wells rendered turbid. That of the third order, within which walls of houses were fissured, clocks were stopped, and crockery ware, vases, etc., fell off shelves, embraced 52,315 square kilometres. Effects such as the above were produced in the eastern half of Shikoku, and also in Chūgoku, and very much the same thing happened in Tōkyō and Yokohama. Lastly, disturbances were distinctly felt from Sendai, in the north, to the west coasts of Kyūshū in the south, or over an area of 134,722 square kilometres. This was the last or fourth order of seismic area. Altogether, the area shaken by this earthquake in Central Japan will have been about 243,000 square kilometres, or more than 60 % of the whole extent of the Empire, as may be easily seen by a cursory glance at the annexed chart.

The earthquake, which brought with it such disaster, seems to have been of a paroxysmal nature, and one for which the inhabitants were totally unprepared. Generally speaking, the frequency of shocks was high during the month of October, 1891, and the earth was by no means tranquil then at any time, especially in the provinces of Musashi and Shimōsa. Seventeen separate quakes had been already recorded by the seismographs, previous to the 28th, all however confined to the vicinity of Tōkyō. Central Japan itself

showed no signs whatever of the coming disaster and there the ground remained quiet up to the very moment when the sudden catastrophe overtook Mino and Owari.

The following table shows the lingering of the after-shocks of the great earthquake throughout the succeeding month, and for several months after, minor shakes, which in Tōkyō would be considered strong, continued to be felt.

Days, 1891.	Frequency of earthquakes in Gifu.	Frequency of earthquakes in Nagoya.	Excess in number of earthquakes in Gifu.	Days, 1891.	Frequency of earthquakes in Gifu.	Frequency of earthquakes in Nagoya.	Excess in number of earthquakes in Gifu.
Oct. 28	102	126	−24	Nov. 14	29	12	17
„ 29	318	135	133	„ 15	29	12	17
„ 30	173	93	80	„ 16	28	13	15
„ 31	126	79	47	„ 17	21	15	6
Nov. 1	99	56	43	„ 18	18	9	9
„ 2	92	30	62	„ 19	17	4	13
„ 3	81	31	50	„ 20	33	9	24
„ 4	78	20	58	„ 21	21	9	12
„ 5	53	20	33	„ 22	12	5	7
„ 6	67	16	51	„ 23	23	9	14
„ 7	45	29	16	„ 24	18	9	9
„ 8	42	18	24	„ 25	9	9	0
„ 9	44	16	28	„ 26	15	5	10
„ 10	40	12	28	„ 27	11	8	3
„ 11	38	5	33	Sum-total	1.757	884	+873
„ 12	40	7	33	Down to the end of March, 1892.	2.588	1.093	+1.495
„ 13	35	13	22				

It should be remarked that the difference in number between the earthquakes which occurred in Nagoya and Gifu is very great indeed, those in the latter amounting to nearly double those in the former, and that from this it follows that Gifu lay nearer to the origin of the convulsion than Nagoya. In the record of the 28th of October, the day of the great event, an anomaly is apparent as

to the frequency in the two cities; but it is known from an authentic source that while the seismic observations were re-opened from 1h., 55′ p.m. in Gifu, in Nagoya they were started just at 1 p.m., the seismographs previously set up having been completely shattered by the terrible shocks in the morning.

Down to the 25th October, 1892, the number of earthquakes recorded on seismometers run up to 2,992 in Gifu, and 1,170 in Nagoya, so that the excess of separate earthquakes in Gifu over those in Nagoya is 1,822.

IV. Views of Others as to the Cause of the Earthquake.

After the earthquake several suggestions as to its probable cause appeared in the newspapers. It will suffice to notice two of these.

Since no volcanic outburst had occurred it was felt by many that the earthquake must have had its origin in the downfall of a superincumbent mass of rock into some subterranean hollow. Among those who advanced such a view of the matter is the Chief of the Meteorological Observatory in Gifu, Mr. Iguchi. Commissioned by the Local Government, he visited the Neo valley a few days after the event, in order to make investigations on the spot under which lay probably the seat of origin of the shocks. The facts stated in his report are interesting and curious. The account of them runs as follows:—

At the foot of the mountain of Haku-san (Gongenyama), 1,811 m. high, which stands on the border of the two provinces of Echizen and Mino, lies Fuji-tani in West Neo-mura, a division of the Ōno district of Gifu Prefecture. It is about 20 kilometres or 5 *ri* from the summit of Haku-san, with chains of hills rising on two sides of it. In this place, some fifty years ago, there appeared two or three holes, measuring 6 or 8 feet across. When stones were thrown into these fissures reverberations caused by their falling could be heard, it is said, for several minutes, from which it may be inferred that the fissures extended to a depth of many hundred feet. At thirty-five minutes past six on the morning of the 28th of October, simultaneously with a deafening noise, enormous landslips in the two chains of hills bounding the district took place. Clouds of dust were thrown up like smoke, to a great height, darkening the whole region, and in many places the contour of the hills was perceptibly changed. At the base of the hills the consequences were not less marked. Houses and fields in the vicinity of Nagamine, Tenjindō, Midori, and Itasho were disturbed, bridges fell, roads were obliterated, and the general features of the landscape were radically changed. The

bed of the river Neo was so much altered that rapids appeared in parts of it which had previously been pools, and deep pools were formed where shallows had formerly existed. *It would seem as though the cause of the last earthquake was the crumbling away of Fuji-tani at the foot of Hakusan.*

By this local depression six seismic lines were formed radiating from this very spot. The first line goes down the valley southwards, bifurcating close to Itaya; one branch proceeds south-eastwards through Takatomi, Akutami, and Inuyama, the other follows the valley down through Toyama, Gifu, and Kasamatsu. The second line takes the southern course along the western ridge of the Neo valley. The third runs north-east over the Pass of Haibōshi to Ōno gōri, while the fifth and sixth go right through Mount Hakusan to Imadate gōri, both in the province of Echizen. *Thus by a landslip of Fujitani, the great earthquake was occasioned, all districts traversed by the above-mentioned six lines being severely shaken.*

Dr. J. C. Berry,* of Dōshisha Hospital, Kyōto, offered another hypothesis in explanation of the cause of the earthquake, this being the possible dependent relations of seismic disturbances upon the electric condition of the earth.

Dr. Berry, while staying in Ōgaki, experienced the severe shakings and the distant thunders of the shocks, sometimes heard for three seconds (?) before the tremors could be felt. *He was profoundly impressed with the thought that nothing but the power of electricity could produce this result. He regards an earthquake shock as but an electric storm in the earth.*

* *The Japan Weekly Mail*, Nov. 14. 1891. Yokohama.

V. Relation of the Great Fault to the Recent Earthquake.

As introductory to the account of the late event, it seems well to insert here a few notes of my own experience of the earthquake of Kumamoto, of which no details have as yet been given in any foreign language. *On July 28th, 1889, a violent earthquake occurred in the neighbourhood of Kumamoto, a flourishing city in the Island of Kyū-Shū.* Being entrusted by the Geological Survey with making a reconnaissance survey of the province of Bungo, I was at the time engaged in that work in the vicinity of Cape Sagano-seki, and thus had the fortune to feel the shocks which caused much damage to both life and property in Kumamoto, killing fifty-three persons and destroying about four hundred and sixty-three houses. On receiving the intelligence of the catastrophe in the neighbouring province, I immediately started for the scene of disaster to examine its effects, and on my arrival saw a large number of houses that had collapsed, and many others supported from falling by wooden poles.

The night of the 3rd of August was particularly distressing. Shocks came regularly almost every hour, seemingly increasing rapidly in intensity. At last, at about 2h., 18′ midnight, a great earthquake, next only to the shock of the week before, visited Kumamoto, throwing the whole city, with its population of fifty thousand, at once into wild agitation, and filling the mouths of one and all with the question, where was the source of the disturbance.

To the west of the city of Kumamoto lies an extinct volcano, locally known as Nishi-yama, the "western mountain." whose effusive nature was then hardly suspected. Ascending it next day

I found it to be a typical volcano, with the somma, caldera, and baranco all preserved; and at its centre, as is usually the case, standing somewhat excentrically, a sharp conical point, called Kimpō-zan (Kibō-zan). Within the atrio are the villages of Noidé, Omonoki, and Hirayama. Tracing the positions of the landslips and of the destroyed houses of the villagers, *I became convinced of the fact that there are two main lines, along which the hills had glided, houses been shattered, and the ground convulsed and broken into chaos* (see the map PL. XXXIII.). The first line runs from the north-west along the Kawachi valley through Hirayama to the small but thriving town of Takasé. The second taking the same direction starts from Noidé, at the southern foot of Ninodaké, which seems to have been the active centre, proceeds through Daké down to the southern slope of Arao-yama, and thence to the city of Kumamoto. Between the two nearly parallel lines stands the Peak of Kimpō-zan. The second one sends off a branch line to the east down to Tōmonji.

These seismic lines, by which I mean the lines of fault, are not favourably visible on the surface as in the case of the recent catastrophe of Mino and Owari, but still I think I was able to trace them by the fissures in the ground and along the slopes of the hills. The facts that Kimpō-zan, the whole group being generally called by this name, is volcanic, being made up of augite-andesite; that the faults though very indistinct are found there in three lines; and, lastly, that the seismic area was considerable, embracing the whole of Kyū-Shū, as well as a part of Shikoku and the west end of the Main Island,—*all seemed to me to point to the conclusion that the seismic disturbance in Kumamoto was caused by a combined process of dislocation and an unsuccessful approach to a volcanic explosion. Which of these will have been the main factor in*

producing this dreadful calamity, I am quite unable to say. The lesson I have learned from this physical convulsion of Kumamoto, is that a violent earthquake often manifests itself its activity along some narrow line or fissure within the earth's crust.

The residents of Tōkyō experience yearly about sixty earthquakes which are, as a rule, fortunately of a feeble nature. These comparatively speaking languid earthquakes and such paroxysmal varieties, as the convulsions of Kumamoto and of Central Japan, show some great differences between them in their effects, but these are not fundamental. Terrible dislocation-earthquakes present special features of their own, not usually observed in slight shocks. The seismic disturbance in the latter is not so uniformly felt over a large area as in the former. On the contrary, the severely shaken area is commonly confined to a narrow zone, say a valley or a mountain slope. In other words, strong earthquakes possess *seismic lines*, as in the case of Kumamoto.

On account of this peculiarity, a series of towns and villages, one running into the next, may be completely shattered and laid in ruins, while at a short distance on both sides damage is comparatively slight. While travelling in Mino and Owari after the great convulsion, I frequently heard people complaining of their own deep suffering, and grudging the happy state of villagers just a few kilometres away. Dr. Berry* puts the matter well in saying that he witnessed all over the region (Mino and Owari) the peculiar freaks and destructive violence of its (the earthquake's) course—leaving houses untouched, passing under whole villages, and only to appear again miles beyond with destructive violence. Even in common earthquakes such as are experienced weekly in Tōkyō,

* *Loc. cit.*

such seismic lines or zones may possibly exist just as in violent earthquakes; but as their magnitude is very small, these lines must generally escape our recognition, and it is habitually, though erroneously, considered that the disturbance is uniform over a circular seismic area.

When the intelligence of the outbreak in Mino, Owari, and Echizen, which took place on the morning of October 28th, 1891, was received in Tōkyō, seismologists, architects, and other representative scientific men were sent out to the shaken district from several Government Departments. Particulars of the earthquake soon began to reach Tōkyō, but nothing of any volcanic eruption having anywhere taken place.

A telegram from Gifu announced a rumour that the centre of the seismic disturbance must be in the neighbourhood of Neodani. Report of remarkable physical changes in that quarter having been received, an official of the Meteorological Bureau was sent thither, and he reported that at Nogō a marked subsidence had taken place, and that the general appearance of Midori had undergone a complete transformation. On hearing this news, I started for the scene of disaster to examine *lines of fault like those in Kumamoto*, should there be any in the devastated region. I ascended the Neo valley, which is said to contain the source of the great earthquake, and found the condition of things very remarkable. The first thing that attracted attention were many boulders that had been hurled from the steep mountain sides, the number of which increased at about Kimbara to such an extent that practically the sides of the valley had slidden into the river, while the road had totally gone in places. Ascending the valley higher, landslips were more

and more frequently seen. Indeed in the upper dale it may be said that the greater part of the mountain slopes had slipped away, carrying with them the forest they were covered with.

Amongst the extraordinary things done by the earthquake, one that always drew my attention was the earth-rent. It strikes across hills and paddy-fields alike, cutting up the soft earth into enormous clods and raising them above the surface. *It resembles the pathway of a gigantic mole more than anything else* (Pl. XXXV.) Indeed it is known by this appellation among the villagers. An old Japanese superstition about earthquakes is that a monstrous cat-fish lives underneath the Empire of Japan, and whenever this fish moves there is an earthquake. The origin of this belief is not known, but no doubt it has undergone several changes or modifications since it was first originated. A representation of it was given as a drawing in an almanac of the eleventh century. There it was depicted as the *earthquake-insect*—a wonderful flat creature with numerous appendages and a head like a dragon, carrying on its back a map of Japan. *The earth-rent which has very much the appearance of the track of a mole, as just stated, strongly reminded me of the fancy of the earthquake-insect. It is probable that the belief of the earthquake-insect as the author of subterranean convulsions may have arisen from the outward aspect of the fissure, produced by a tectonic earthquake as in the case of the Neo valley.*

The formation of crevices is the never-failing attendant phenomenon in violent earthquakes ; but the one in question is not of a common sort. Being interested in this remarkable earth-rent I have actually traced it for more than forty miles. It starts from about the village of Katabira, not far from Katsuyama, on the bank of the Kiso-gawa on the Nakasendō, running north-westwards up to Fukui in Echizen through the Neo valley (Pl. XXIX.). Although the

geological structure of the region traversed by this great fault is not so well known as that of Lago di Croce in the Eastern Alps, still I think, as has been already pointed out, that I am justified in supposing the existence of a number of shifted lines of dislocation, stretching from north-west to south-east across the North of Mino. *The event of October*, 1891, *seems to me to have been a renewed movement upon one of these prëxisting fissures—the Neo valley line of fault, by which the entire region lying to the right of it not only moved actually downwards but was also shifted horizontally towards the north-west for from one to two metres along the plane of dislocation. This vertical movement and horizontal shifting seem to me to have been the sole cause of the late catastrophe.*

VI. The Course of the Line of the Great Fault that caused the Earthquake.

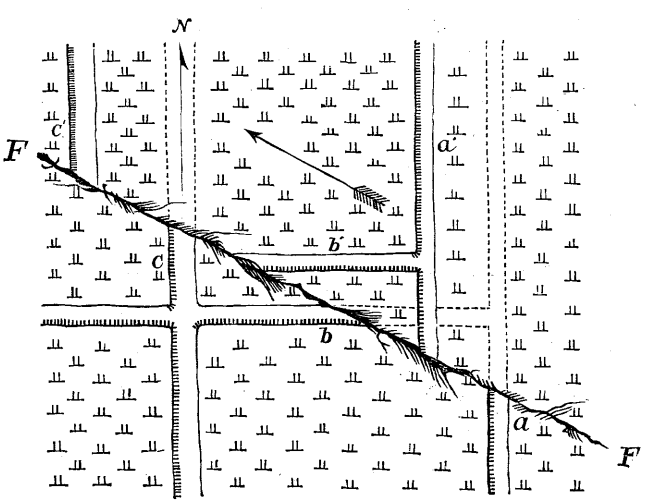
The great earthquake of Central Japan shook the extraordinarily large superficies of 243,055 square kilometres, or more than three-fifths of all Japan, and must be counted as one of the greatest physical events of modern times. Let us see now how the fault looks which produced such a tremendous effect?

Faults or throws may be observed almost everywhere in the earth's crust, and geologists and miners are quite familiar with their structure. But it rarely happens that a fault comes into relief in complicated mountainous districts. In less disturbed regions such as the Plateau of Colorado, or the eastern border of the Central Asiatic plateau, the lines of displacement can be traced with great certainty; and the underground structure is usually reflected in a great measure in the topography of the region concerned. In the Alps and Central Europe, most of the earthquakes have hitherto been ascribed to a tectonic movement of the solid crust through lineal extension of the disturbed area, but no actual fault has anywhere been found which was formed at the time of an earthquake, and could be reasonably assumed to be the originator of the disturbance.

The case of 1891 is quite otherwise. Here we could not only positively observe the fault on the surface, but also measure the height and length of it. At a place called Midori in the Neo valley, the flat bed of the valley was split longitudinally, and one side was tipped off so that there is an abrupt step, measuring 5.5 to 6 metres vertically. The earth very regularly took its angle of repose at the break; and the appearance, as we come to it eastwards from below, is as if we were approaching a railway embankment (Pl. XXXIV.).

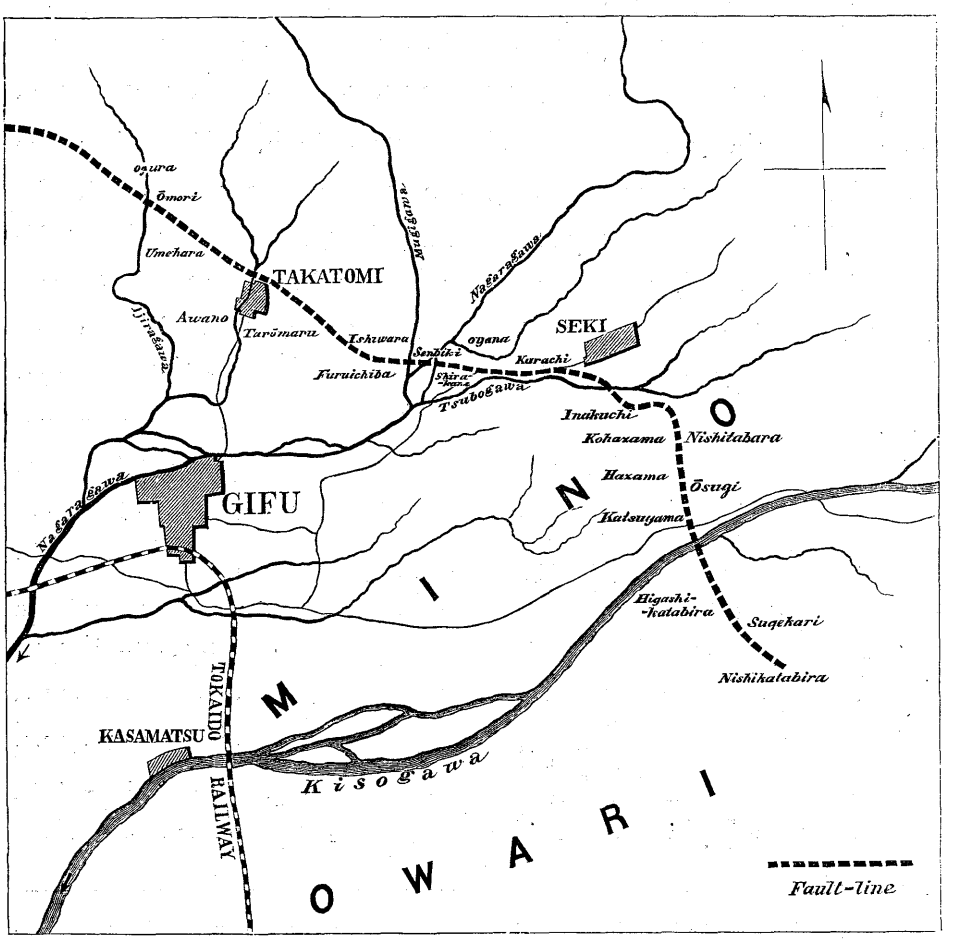
Where the vertical displacement is not considerable, the line of the fault appears on the surface like a rounded ridge of soft earth 30 to 60 cm. high and, as I have already stated, *resembles very much the pathway of a gigantic mole* (Pl. XXXV.).

In tracing the course of the great fault (indicated by the heavy line, Pl. XXIX.), I begin with what I suppose to be the south end.* In Nishi-katabira, a small village amidst hills of a greyish Tertiary sandstone, in the district of Kani, Mino province, there is a place locally called Kozé. Here, upon the slope of a spur of hill, stood the old monastery of Fukudenji. The hill together with the entire building slipped down into the paddy-field which in turn was broken into clods of earth, and swelled up 5 metres high. Following the direction of this remarkable landslip towards the north-west, the paddy-field was seen sharply cut by a line, along which *the north-east side had slightly subsided, and had moreover been shifted horizontally towards the north-west for a distance of 1 to 1.2 metres.* That besides the vertical movement an actual horizontal shifting had taken place is proved by the fact that the originally straight mound or ridge called Azé which separated neighbouring fields, was



* On close examination in the field, especially at about Kukuri, Ikeda, and Takayama, I was not able to find any trace of the fault, which may be looked upon as the prolongation of the main line of dislocation.

now cut obliquely and sharply by the line of fault. Moreover, the continuity of the mound was really broken and the mound with the entire ground so shoved forwards that the detached ends could not afterwards be rejoined—(see the accompanying wood-cut). It is evidently quite different from what the miners call a 'heave',—an *apparent* horizontal displacement of strata by a *mere vertical* throw in inclined beds, for in the present case the horizontal shifting can be actually traced in *perfectly even ground*.



Sketch map between Nishi-katabira and Ogura in Mino province, showing the course of fault (heavily dotted line). After S. Mori.

The above-mentioned line takes the direction of NNW. At Tsuchida, ground was depressed for a mile's length along the embankment of the Kani river, a small affluent of the Kiso-gawa. Mount Daitenjin, lying to the south-west of Tsuchida, on the south side of the Kiso-gawa, was sharply cut by the line of dislocation, and the east side of this hornstone-slate mass slipped a little downwards. The vertically dislodged line is visible on the steep precipice of rugged hills, at the foot of which the Kiso-gawa foams over its rocky bed. The line crosses the bed of the river at the east end of Katsu-yama, on the Nakasendō, and completely reduced the village to a heap of rubbish. We find here terraced ground for raising wheat and barley on the hill slope, and a piece of this ground about 2,000 square metres (2 *chō*), lying within the precincts of the Buddhist monastery of Kakuzenji, was so thoroughly turned over from the very bottom that all the original marks were entirely effaced from the dry field (*hata*), and there remained but clods of earth and upturned roots. Although nothing of the under-ground solid crust was to be seen on the surface, still it is almost certain that the origin of the disturbance did not lie within the superficial covering of the soil, but must be sought for in the deeper portion of the crust. It appears as if the loose soil had been jerked off from the hard under-ground by an intense shock from below.

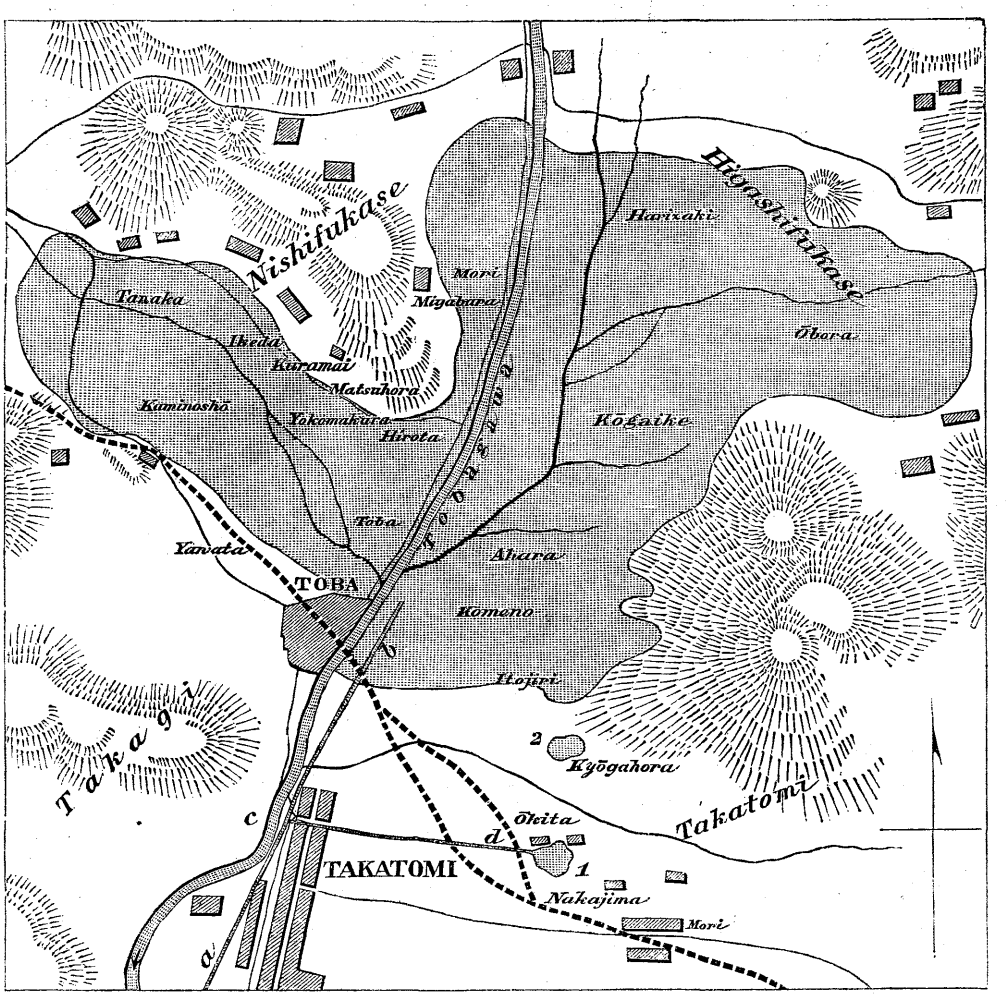
The main line of disturbance now points N. 10° W.; it then goes through spurs of hills and paddy-fields, causing damage to the villages, Ōsugi, Hazama, and Nishi-tabara. After making a sinuous curve it crosses the Tsubo-gawa, passes through the villages of Kurachi and Oyana, crosses the Nagara-gawa at Shimo-shira-gané, and then taking a north-westerly direction, goes through Sen-biki and Toda, passes over the Mugi-gawa, and proceeds towards Mori and Sebo, till it reaches Ishiwara. In the last-mentioned

village there is an artificially constructed pond of considerable size, for irrigating neighbouring paddy-fields. It was fed by a small stream from the north with its outlet on the south, but the line of fault going right through the middle of it in the east-west direction, its northern half together with the neighbouring fields of 17,851 square metres (1 *chō* 8 *tan*) subsided, and was also shoved a little to the north-west. The result of this vertical as well as horizontal movement of the north side was that the outward passage at the south end of the pond lies now on the higher level. The quantity of water remains nearly the same as before, and the deserted pond is still fed from the entry passage on the north, so that it is probable that the water soaks away through the new fissure as fast as the small current enters the pond through the channel.

The line now runs, through Taromaru, a few steps southwards along the newly macadamized road that connects Seki and Takatomi. One could easily recognize the fault as such by a slight difference in the level of a perfectly even field, the north side being a little the lower. About five hundred steps east of Takatomi, it crosses the road obliquely at Mori, and the north side became again the lower by 1.5 metres and at the same time was horizontally shoved about 1 metre westwards. Takatomi is a tolerably large village, with a population of 1,746, lying north of Gifu, and I saw in no other place within the devastated region such a complete destruction of buildings as occurred here. All was shattered and levelled with the ground. About 87 persons were killed and 158 wounded. At the north end of the village the fault appears in double lines (see the accompanying sketch map), along which the ground had been shifted horizontally, and also become continuously lower towards the north, so that a once even paddy-field now forms a good natural slope.

the Toba-gawa lost their outlet, and the villages of Nishi- and Higashi-Fukasé, comprising an area of 2 square kilometres, or nearly 220 *chō*, were transformed into a deep swamp in consequence (compare the annexed sketch map). When I was there last autumn, the farmers were obliged to cut the grain in boats, October being the month of the rice harvest. It was very remarkable to see that a group of farmers' cottages, standing at the northern border of the newly created swamp, had miraculously escaped the collapse, though scarcely 2 kilometres north of Takatomi, a phenomenon due perhaps to the fact that the place is just behind a low hill which seems to have absorbed the wave motion of the earthquake on its way. The earthquake-shadow so created, finds analogy in the action of a strongly blowing wind, cut short by a hill in its path, leaving the other side in the wind-shadow. It is almost beyond doubt now that the destructive motion of an earthquake depends like that of the wind, more upon the topography of the shaken district than upon the angle of emergence of waves from an assumed origin within the earth's crust. I could easily multiply such examples of the earthquake-shadow between Takatomi and Ōmori along the great fault. Houses between or near side-valleys generally escaped the destruction, while those on the plain through which the line passes, could not withstand the shock and were thrown down.

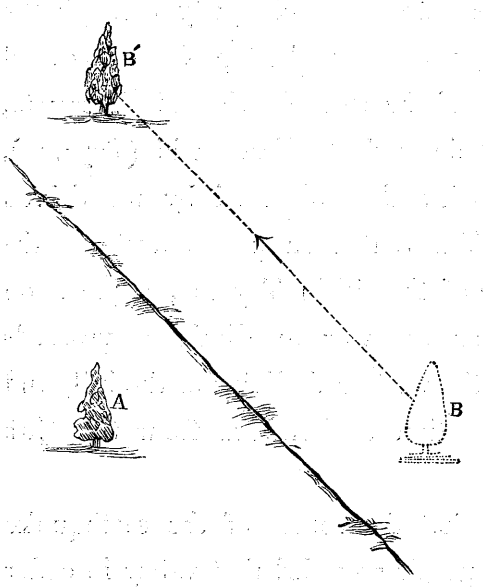
The great fault-line crosses Toba, where the houses were crushed to rubbish, and proceeds directly westwards to Horachi. In the latter place again the north side subsided and became part of the new swamp, already referred to. The line enters a hill at Mochi-nari, cuts through a spur of hill at Azuki-zaka, and then follows the northern foot of the hills westwards. It appeared for some time after on the surface through the whole region, exactly like the track of an enormous mole.



Sketch map of the environs of Takatomi, showing the course of fault (heavily dotted lines). The stippled portion on the right is the depressed side of the fault being the newly created swamp of Fukasé; ab, the new channel specially constructed for drawing off the waters of the swamp. (1) and (2) the two other depressions formed at the time of the earthquake, now filled with water; cd, being the channel for the pool (1).

The small Toba-gawa, rising high in the northern mountains, flows down by Takatomi towards Gifu, to join the Nagara-gawa. By the great earthquake a tract of land and the river bed, lying to the north of Takatomi, were considerably lowered, so that the contents of

It goes right through the hamlet of Jōbara (Uméhara),* where, in a front garden adjoining a farmer's house, there are two stately persimmon trees, *Diospyros kaki*, which had stood time out of mind in an east-west line. The line of fault traverses the space between the two from the south-east to north-west, and as usual the north side was shoved north-west, so that, to the great astonishment of the owner, they now stand in a north-south line instead of east-west, without being in the least impaired, and still adorn a corner of the inclosure. The plane of dislocation, which served at the same time as that of shifting, appeared on the hard face of the ground as a *mere line*, so that to any person not initiated into the structure of a fault the displacement of the trees was quite unintelligible, and appeared to the astonished peasants as a marvel with no apparent cause. A few doors beyond, there was a water course in front of a cottage, as is common in Japanese villages, which being cut by the line of fault, and the ground on which the house stood, sinking slightly, unexpectedly inundated the place. After this, the line appears in the muddy fields of Nakamura and Kōden, with the north side dislodged. In consequence, a second swamp resulted which has an extent of 25 hectares, or nearly 25 *chō*. From here to Ōmori the road ascends the slight elevation of Koshigirizaka, at the very top of which the fault cuts off the solid rock, leaving the north side depressed.



* See the sketch map, p. 332.

The villages of Ōmori, Ogura, Fujikura, Horada, and Matsuo are all clustered in a basin-shaped widening of the Ijira valley, which in conformation with the general system of valleys in the north of Mino, runs in a south-easterly direction across the strike of the Palæozoic formations. As it is situated in an old river bed, Ōmori suffered the most by the earthquake, many portions of the soil being raised or sunk, and innumerable fissures traversing the village in all directions; so that it is somewhat difficult to follow the main fault in such a chaos. The whole system of drainage was deranged. The line of displacement next crosses the bed of the Ijira-gawa, cuts obliquely through the boundary of Horada and Matsuo, passes over the top of a hill, called the Nishimuné pass, at the border of the three districts of Yamagata, Katagata and Motosu, and then descends to Kawa-uchi (Toyama), with always its north side depressed, and as observed by me driven northwards for about 2 metres. The rent then points north-north-west, runs along the eastern slope of the hill in Toyama, appears on the steep descent of Kané-zaka on the way to Kimbara, proceeds thence directly northwards along the western declivity of the hill, and enters the Neo valley for the first time at Kimbara from the Ijira valley lying east of it.

When it had become current that the source of the earthquake had been in the Neo-dani, many people ascended that valley in order to satisfy their curiosity to see the site from which reputedly the severe shocks had originated. They usually took the road from Gifu through Yamaguchi at the entrance of the valley, along the Neo river to its source, and in so doing, were somewhat disappointed while ascending its lower course. Less destruction was visible than was anticipated, an impression produced by seeing some houses still standing, after having passed along the road in the Mino-Owari plain lined with ruined houses on both sides, and many visitors positively

asserted that the earthquake could not have originated in this valley. Had they come to Kimbara, where I left off the description of the earth-rent, this notion would soon have vanished.

Kimbara itself lies on the left of the fissure, but so near to it that all the buildings in the village entirely collapsed. At the north end of it the road descends the steep slope of Dando-zaka, and brings us to the beginning of the place of greatest destruction in the valley. Beyond the steep descent there was no trace of road left by the earthquake; rubbish and blocks of hornstone had obstructed and buried it under them. For a few days after the great shock there was still every now and then, the crash of some mass of rocks falling from precipices on either side of the valley that had been left by a landslip.

The rent now runs east of Hinata, where the river bed makes crooked turns, and at Hirano, the next village, passes on the right, and at the south of Midori, it appears on the left side of the Neo-gawa, and here one of the most wonderful effects of the earthquake was to be seen. A fine new road (see Pl. XXXIV.) leading to Gifu had been obliquely cut into two, and the lower end with the surrounding fields had sunk about 6 metres below the upper end. The road is here on the west side of the river, and the eastern half of the valley, which includes the Neo-gawa and opposite hills, shows the tilting edge, or cutting of the fault. That the *east half had been pushed 4 metres northwards*, in conformity with the general rule, is well seen in the photograph by an abrupt change in the direction of the displaced road. So far as I am aware, the formation of such a colossal fault on the surface, as this in Midori, is exceptionally rare, and finds its equal only in the 'Ullah-bund,' or God's dam at the Runn of Cutch, in the lower course of the Indus.

Those who have followed me with patience to this point in my

description of the earth's rent from the village of Katabira, will have seen that I have always spoken of *subsidence of the right side*, accompanied by *horizontal shifting towards the north or north-west*, and now looking at the fault at Midori, may object to my contention that the great throw is a prolongation of the main fault, that the *west half* had here sunk instead of the *east*. It seems, however, that we have here an abnormal case, and that the *east half, including the river became raised. What would seem to favour this view is that a little higher up the river what was formerly a shallow rapid stream 27 metres across and easily fordable, broadened out into a small lake, 63 metres in width, of still water which a boatsman's pole cannot fathom.* A dam was formed below and the current now finds its way in a narrow diverted stream under the opposite hills. In explanation of this special case, I would say that, in the enormous convulsion caused in the valley between the two chains of hills, the weight of the hills on either side caused a cracking and upheaval on the east side of the valley, in the same way that a severe shaking given to a heavy abutment of an arch may force up its crown or centre.

At the north end of Midori, the road crossed the valley to Itasho, where there was formerly a bridge; but it is now necessary to cross in a ferry boat, the valley having been transformed into the lake, already referred to. At Itasho, again the fissure appears being like a mole's track when seen by me, both sides being nearly on the same level, though the east half had been shoved northwards as shown by the horizontal displacement of a broken ditch in the rice fields. It passes through Ichiba, and Kōdokoro, reappears on the road at Naka, and goes through the middle of the fields at Osso, with its usual characteristics.

The villages of Kadowaki and Nagaminé lie out of the exact line of rent, and the damage suffered by them were therefore comparative-

ly speaking not very heavy. Still it is not to be supposed that their houses were entirely spared, the whole surrounding soil at the time of the great earthquake heaving in a state of vibration and doing much mischief. There was terrible destruction on the line, as in Tenjin-dō, a few hundred steps beyond Nagaminé. The next village is Nagashima where the rent was to be seen on the road side. The ground was bodily shifted with the houses 2 metres forward, and subsided 1 metre on the right side. Turning off from the main course of the Neo, and passing over by a bridge to Nogō, we find the rent striking across the mountain stream, depressing the eastern portion of the bed, and thus converting a torrent into a slow stream.

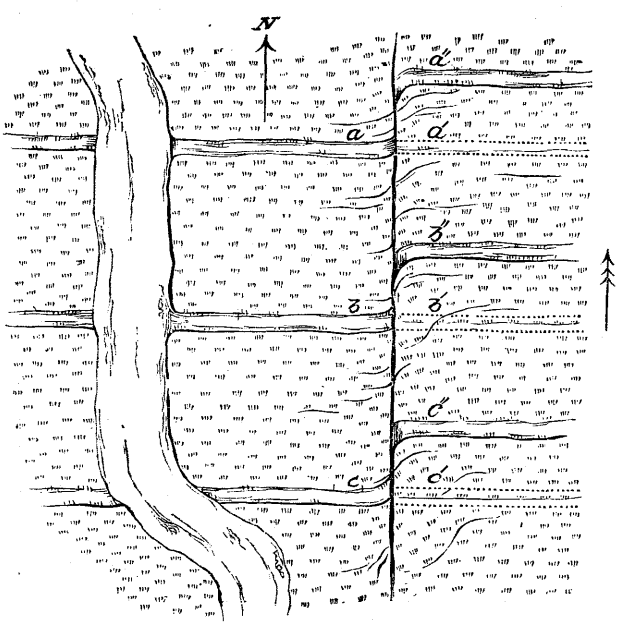
Running northwards, it enters the hill at the back of the temple of Gongen, having caused landslips all along its path. This temple was founded in 717 in honour of the Gongen of Haku-san, a Japanese deity in a Buddhist form, and though small in scale was of ancient date, having been erected in 1673 on the southern slope of the hill, overlooking the Neo-gawa. This wooden building of rare antiquity for Japan was hurled to the ground in ruins, attesting how long a period had elapsed since a shock of similar violence had visited that quarter. Yet if we were asked whether the twin provinces of Mino and Owari were a place where earthquakes had not been frequent we should reply in the negative. In Japan there are some seven hundred stations where earthquakes are observed, and from several of them situated in the Mino-Owari plain, we find that in the six years from 1885 to 1890 the number of shocks recorded in that district have been respectively 9, 4, 10, 12, 15, and 36.* Still going backwards in the annals of earthquakes, we find again that violent disturbances took place in the district in 745, 762, 1596, 1707, 1723, 1819, and 1854. Many dwellings, store-

* Milne-Burton, *The Great Earthquake of Japan*, 1891. p. 6.

houses, and even mountains suffered, people and animals were killed, rivers were stopped up, and floods were occasioned. But in spite of these subterranean convulsions, the temple in Nogō, erected in 1673, had stood well-preserved down to the present generation.

From the facts already given, it seems not improbable that the centres of disturbance of former times have not been located in the Neo valley. In pre-historic times, however, there must have occurred several great earthquakes, as is evinced by the geological structure of its mountains. In the great earthquake of 1854, which is still within the memory of many, the Neo valley had been but very little disturbed, we were told by old folks in Nagaminé, whose houses had collapsed completely in the last catastrophe, and that many of them built more than a century ago, had remained till that event in tolerably good condition, and without being impaired by any former earthquake.

The rent appears again at the bottom of the Konokana-dani, a side-valley which we followed up from Nogō, here diverting the main course of the Neo-gawa. It might be traced with great exactitude as far north as the entrance of the sunken gully of Fuji-tani, where the line of displacement of the rocks appeared on the surface like a rounded ridge of soft earth 1 to 1½ metres high, as seen in Plate XXXV. The ground had been



depressed on the right side, and shifted horizontally in the usual manner, as will be clearly understood from the annexed wood-cut. Lastly, we arrived at the place called Fujitani, which is now tolerably well known through the suggestion of Mr. Iguchi, that it was the seat of the source of the earthquake. It is a branch valley of the Konokana-dani, circumscribed by hills, except on the south. At the centre of it, we were told, a hole 1 to 2 metres in diameter had existed, into which large stones and boulders being thrown were heard for some time striking and echoing in their descent to an (?) unfathomable depth. Time had closed, it was said, the opening, and there remained but a shallow depression in its place. The ground indeed had been intensely convulsed, and the face of nature entirely changed. The sides of the hills which flanked the valley had slipped down, and the forest upon them still presented a singular scene of confusion; trees standing inclined in every direction, many with their trunks and branches broken. The course of a small stream was stopped and a new lake were created there. When these marvellously great changes occurred, the shaking must have been terrific—inconceivable—yet I cannot believe that the slight depression in Fujitani to have been the origin of an earthquake which had shaken a great part of Japan. The sunken gully of Fujitani, already alluded to, is only a prolongation of the rent which we followed up there for about 52 kilometres.

The fissure cuts off the rear of the depression of Fujitani, and comes in sight again beyond the hill of greywacke sandstone and clayslate, at the bottom of the main course of the Konokana valley, which terminates at the foot of Front Haku-san. The valley here is narrow and forms a deep gulch, bounded by overhanging precipices on the east and west. By the earthquake, the surfaces of hills on either side slipped down the valley, and left them almost bare of the fine timber which had clothed them. The fresh verdure of the steep

mountain-side had given place to a rocky desert, and even, as we passed down, avalanches of rocks, accompanied by a noise like that of an immense torrent or cascade and by a vibration of the ground, occasionally occurred. The shocks had been far more destructive there than in Fujitani. If any one had been as the villagers were, in a position to look on at a distance at this colossal sliding of hills, he would have seen columns of dust rising up, and heard tremendous sounds, and might have taken these phenomena as those of a volcanic eruption, for the effects of landslips and volcanic explosions closely resemble each other. The configuration of the valley was entirely changed; the course of a small stream, running on its west side, was transferred to its east side, and at places now takes an underground course, reappearing farther on. Unfamiliar obstacles made themselves apparent, and small hills covered with forest had come into sight which had not been seen before.

At about 10 kilometres from Nogō, the earth-rent goes over to the left and cuts the top of a ridge, called Shijūgara-daké, right through its middle. We passed a stormy cold night in the open air on this summit. The line of fault then enters Shiratani, a branch of the Tokuno-yama valley which, as I have already said, runs parallel to, and lies to the west of the Neo valley. The gulch of Shiratani was severely torn and rent. It appears shattered and half-naked, and no longer affords a fine green prospect, as before, but is stripped of its woods and natural verdure. The fissure advances still further northward, touching the eastern shoulder of Haku-san.

So far we had traced the great earth-rent up to the north boundary of Mino, beyond which is the province of Echizen. It was the 16th of November, the nineteenth day after the earthquake, when I began the ascent of Haku-san, in company with Mr. Wakimidzu, a student of geology. But it was too late in the season to go on. The

weather was cold, and some of the high points were already white with snow; mountain-passes had become impassable, the road had totally gone in places, or left nothing but a difficult foot path. Such being the state of things, I had to abandon the idea of reaching the town of Fukui by the pass of Haibōshi, and returned direct to Gifu, for many additional days would have been necessary to get to Nukumi, Kumagō, and Minomata, all in Echizen, where extensive landslips were said to have taken place.

Although I could not examine personally the devastated region in the south-east of Echizen, at the boundary of Mino, still I am fortunate enough to have received several reports from village-masters and the police authorities of Nukumi, and, last but not least, from Mr. Hiki, another student of geology in the University. From their brief accounts it seems highly probable that the rent proceeds from the summit of Haku-san to the poor hamlet of Nukumi in the district of Ōno, where eleven out of thirteen houses were completely shattered and the remaining two narrowly escaped collapse. It is stated in one of the reports that there is a fissure running from south-east to north-west, just as is the case in Mino, and that one side of the fissure has been bodily shifted horizontally for about 3 metres. It passes by Kumagō,* along a rivulet, and then crosses the pass of Minomata down to the village of the same name on the western foot of the ridge. The line seems to continue through the villages of Anzenji, and Mizumi to Taniguchi, and eventually reaches Hirose, after traversing the bed of the Asuwa-gawa which flows at its lower course by the city of Fukui. Throughout the valley of Minomata, dotted with the above mentioned hamlets, extensive landslips are said to have occurred, causing damage to both life and property. To the westwards within the Tertiary terrain, I

* It is erroneously spelled as *Kumagawa* in the map, Pl. XXIX.

am not quite sure of the presence of any fissure as the prolongation of the great fault-line, still I have strong reason to believe that there were faint indications of such a rent in the lineal extension of the disturbed area, which beginning at Hirosé, extends over Nishi-kōchi, Ainoki (between these two villages is the slight elevation of Nakaban-saka, much disturbed by fissures), Ochiai, Kawashima, Matsunari, and then makes an abrupt change in a northerly direction towards Minami-i, and crosses the pass of Yenoki-zaka to Kōkita as far as the city of Fukui, in Echizen.

It will be seen from the map (Pl. XXIX), that the neighbourhood of Hikoné at the eastern border of Lake Biwa, was severely shaken and deeply damaged by the earthquake, whereas the stretch of land between this and the Mino-Owari plain suffered very little. Such an abnormal phenomenon had been already noticed by Kluge, long ago as 1861, when he says: "dass ein Erdbeben durch seine letzen, abgeschwächten Wellen an einem anderen, weit entfernten Punkte eine selbständige Erschütterung hervorrufen kann, die möglicherweise einen ganz anderen Ursprung hat, als dieses primäre Erdbeben. Es ist dies eine Erscheinung, welcher bis jetzt noch nicht die Beachtung gewidmet worden ist, welche sie verdient. Es giebt nämlich Stossgebiete, welche gewissermaassen den Wiederhall oder das Echo weit entfernter Erdbeben bilden, in denen zwar die Disposition zu einer Erderschutterung vorhanden ist, dieselbe aber häufig erst, wie es scheint, durch eine andere geweckt werden muss."* A. v. Lasaulx** named such an earthquake the sympathetic, or *Relaisbeben*. The destructive shocks near Hikoné, especially Nagahama, at the time of the great convulsion in the neighbouring provinces, seem to me to have been caused by the above-mentioned secondary earthquakes or *Relaisbeben*. It must, however, be remarked that the intensity of shocks felt on the surface has greatly to do with the *orographic* condition of the region concerned, besides the reason given by v. Lasaulx.

* *Ueber die Ursachen der in den Jahren 1850 bis 1857 stattgefundenen Erderschutterungen.*
** Kenngott's *Handwörterbuch der Mineralogie*, etc.

VII. Concluding Remarks.

Speaking generally, it may be said that all large earthquakes are accompanied by the formation of fissures. The cracks, fissures, and slips formed at the time of earthquakes are of *various natures*, and of *different dimensions*. Some occur along a road, or run near the upper edge of a cliff. The reason that cracks should have occurred in such a position as the latter rather than in others is probably owing to the greater motion at such a place, due to the face of the cliff being unsupported and with nothing opposed to its outward motion. Similar remarks may be applied to the banks of rivers and to all depressions, whether natural or artificial, which have a steeep slope. At such places the waves of the shocking emerge on a free surface, tending to project the superficial parts away from those behind, and thus form a fissure parallel to the free surface.

Moreover, slips and fissures depend upon the *structure of rocks*, and occur on a particularly grand scale where the strata dip into or against the slope of the walls of a valley. We have numerous examples of this in all the side-valleys of the Neo river, which run parallel to the strike of a complex of clay-slates, sandstones, and hornstone-slates, the main course of the river, as already stated, being directed against the strike of the Palæozoic formations. This often misled observers to see in the side-valleys the seat of the origin of the earthquake, because the shocks were far more destructive there than in other places. *However great the destruction was, it was nothing more than the superficial effects of the earthquake, but not the cause of it.* There are other fissures, slips, and cracks of great geological importance, and of quite different origin, which should by no means be confounded with those already mentioned; as has unfortunately been

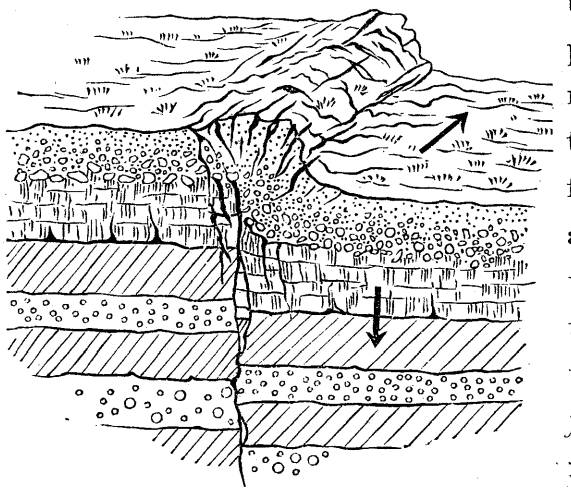
often done. They are really connected with underground structure and are due to displacement of the rock-masses which constitute the external crust of the earth. They therefore occur where there exists a discontinuity of rocks, and the earth-rent which we have described, and which is the main point in the present paper, must be regarded as an example.

This rent at the surface took multifarious forms. When traversing a ridge of mountains or a spur of hills, it caused extensive landslips, one side of it descending considerably in level, carrying the forest with it, but with the trees complicatedly interlocked or prostrate on the ground, as on the ridge of Haku-san. On flat ground it sometimes created a terrace of about 6 metres in height, as in Midori (Pl. XXXIV.), somewhat like a railway embankment seen from afar. When the vertical displacement was not very considerable, the earth-rent left a mark on the ground, *resembling very much the pathway of a gigantic mole or the track of a plough-share* (Pl. XXXV.).

The manner in which this peculiar low mound was formed may be explained by reference to a monoclinal flexure—a geological structure well exhibited on a grand scale in the Plateau of Wahsatch.* Suppose the flat bottom of a valley like the Neo, filled up with soil and gravel which rest unconformably upon the hard mass of the older rocks, and form their 'cover,' and that the basement should give way by faulting along the vertical thrust-plane; there a certain portion of the uncompressed 'cover' will thereby be uplifted, so as to form a rounded ridge of earth by the lateral compression of a subjacent mass along the line of discontinuity. In this way a monoclinal flexure in the loose superficial covering, which appears in section as a flexure connecting two horizontal bars of strata, would be

* C. E. Dutton, *Report on the Geology of the High Plateaus of Utah*, p. 25-54.

produced by direct lateral pressure exerted at the ends of the bars.* Besides the vertical movement, horizontal shifting of either side would take place along the same plane of fault, and the raised ridge would be much disturbed and become a confused mass of clods of earth, as shown in the subjoined wood-cut. The flexure in this case had better be called the *monoclinic diagonal flexure*. The peculiar soft mound of earth, of which we have often spoken, belongs to such a flexure.



This unique track, though at first sight it seemed quite insignificant and was consequently usually overlooked by casual observers, is of great geological bearing. Unlike other accidental fissures it is characterized by constancy of direction and regularity of course. Starting from Katabira near the Kiso-gawa, it runs up its length through the Neo valley to Haku-san (a distance of 64 kilometres), and then seems to proceed north-west up to the city of Fukui, for the extraordinary distance of 112 kilometres, or 28 *ri*. The one with which we are most concerned, is the line of fault or displacement of rock-complexes, along which, as I have repeatedly pointed out, the ground on the *left side had subsided from* $\frac{2}{3}$ *to 6 metres, and at the same time been horizontally shifted for* $1\frac{2}{3}$ *to 2 metres in a north-westerly direction*. The only exception to the general rule was the fault in Midori, where the land was lower on the west than on the east; the manner in which this special condition may be supposed to have been

* See *The cause of Monoclinal Flexure*, by A. J. Jukes-Brown, Geol. Mag. 1891, p. 505.

brought about, has been already stated, namely, that it was the east half, which was *elevated* through some local circumstances and not the west side depressed.

In regard to alterations of relative level, none of my observations, however, establish which side it was that moved, or whether both moved but in a different manner. It must always be remembered that to ascertain a change of level is a subject of considerable difficulty almost incapable of determination, except where the sea-coast happens to have participated in the principal movement. In the last earthquake we had no opportunity of observing such phenomena on the sea-coast, either of the Pacific Ocean or of the Japan Sea; probably because of the line of the principal fissure being entirely confined to the interior. Had it been possible to observe the fissure on the shore, it might even then have been impossible to determine whether an elevation or a depression, even of several metres, had occurred, because there would be usually nothing at that point to mark the mean sea-level.

As data on which I could rely, in ascertaining the actual instead of the relative change of level of the ground, were not at my disposal, it seems to me very natural to suppose that it was subsidence rather than upheaval which took place along the line of the shift; and it is the eastern wing which stands usually at the lower level. But it is another problem to be solved how far this depression extends easterly; whether the whole of Eastern Japan participated in the downward movement, as in the "sunk country" of New Madrid,* created at the time of the great earthquake of 1811-12, or the "sag" or *Graben* of the Lake of Baikal, at the mouth of the Senega river,** or whether the movement was limited to only a few kilometres to

* Lyell, *Principles of Geology*, 12th edition, Vol. II, p. 108.

** Perry, *Note on the Earthquake of* 1862, cited by Suess, in his *Das Antlitz der Erde* Bd. I, p. 44.

the east. So far as my local knowledge extends, there seems to exist only one regular line of shift in the convulsed district, from which we may fairly conclude that the subsidence attending it, is not of the kind called "sag;" and I do not believe that the half of Japan sunk down, but that only the land near the line of fault became slightly depressed.

Of every large earthquake, we find the accounts full of the mutations which the earth underwent through the agency of subterranean movements; for instance, the formation of cracks and fissures, besides permanent upheavals and depressions, accompanied usually by spirting up of the squeezed groundwater and sliding of detached portions of the mountain-sides. Of movements like these, that of the *Ullah Bund*, in the delta of the Indus, is the most remarkable. The real occurrence of the much talked of rhapsodic movements along the western shore of South America, is not entirely free from doubt. Immediately after the convulsion of 1819, the inhabitants of Sindree, in the Runn of Cutch, saw at a distance a long elevated mound, where previously there had been a low and perfectly level plain. To this terraced tract they gave the name of 'Ullah Bund,' or the 'Mound of God,' to distinguish it from several artificial dams previously thrown across the eastern arm of the Indus.*

This 'Ullah Bund' seems from its description to have a close resemblance in its outward aspect, to the fault at Midori, in the Neo valley. As to the manner in which the 'Mound of God' was formed, the views of geologists are divided. Lyell saw in this newly created dam a true upheaving of the ground, while Suess considers it in another point of view. Suess** says, "*Es handelt sich hier weder um Erhebung von Land, noch, wie ich selbst einmal, irregeführt durch andere*

* Lyell, *loc. cit.* p. 100.

** *Das Antlitz der Erde*, Bd. I, p. 62, and *Entstehung der Alpen*, p. 152.

Darstellungen, vermuthet habe, um Faltenbildung an der Oberfläche, sondern nur um das Hervordringen von Grundwasser uud des Nachsitzen eines scharf abgegrenzten Theiles des schlammigen Bodens." Suess explains in similar manner the formation of the '*sunk country*' of New Madrid, the depression of Baikal Lake, and those subsidences at the mouths of the Ganges and the Brahmaputra, at the time of violent earthquakes. *They were not, according to him, connected with deep-seated movements altering the relative level of sea and land.*

The great fault of Neo, by which I mean that long line of earth-rent which traverses a distance of 112 kilometres from the Kiso-gawa to the city of Fukui, cutting the hills, mountains, and plains alike with remarkable regularity and sharpness, is clearly not like that of the Ullah Bund, caused by the mere settling of superficial Alluvial soil.

The sudden elevations, depressions, or lateral shiftings of large tracts of country which take place at the time of destructive earthquakes are *usually considered as the effects rather than the cause* of subterranean commotions; *but in my opinion, it can be confidently asserted that the sudden formation of the 'great fault of Neo' was the actual cause of the great earthquake of the 28th of October, 1891, which shook an area comprising 243,055 square kilometres, or more than 60% of the whole extent of the Empire of Japan;* that is to say, an area equal to those of the British Isles, Holland, and Denmark put together.

It is an established tenet of geology that a sudden faulting of the earth's crust will cause a shaking which is designated by the general term of *tectonic earthquake.* The faults resulting from tangential movements are of two classes, those running parallel to the strike of rock-complexes, across the axis of mountain-ranges. All kinds of tectonic earthquake are usually considered destructive and extensive, as compared with those caused by a depression or by a volcanic

explosion; and of all the tectonic earthquakes a sudden faulting of the solid crust *across* the strike of strata are said to produce the most fearful kind of earth-movements, as is evinced by the Spanish earthquake of 1884, along the transverse fractures of Malaga, Motril, and Guadix across the Betic chain of Andalusia* (Suess' *Blätterbeben*). One of the characteristics of the transverse faulting is the simultaneous occurrence of the horizontal 'carriage' of a thick mass along the vertical thrust-plane, which is very rarely observed, if ever, in longitudinal fissures.

The backbone of South Japan—the cordilleras of the Sinical system, traverses the boundary of the two provinces of Mino and Echizen, in the east-west direction, with the prevailing dips of the Palæozoic formations towards the north, as is shown in Pl. XXVIII. A system of parallel, transverse valleys intersects the axis of the mountains in an oblique direction from north-west to south-east, and the Neo valley, along which the 'great earth-rent of Neo' going deep into the rocky crust was produced, is one of these. *A sudden falling of the Palæozoic strata on the right wing along the line of the 'fault of Neo,' accompanied by lateral shifting toward the north-west, caused the shaking which constituted the late dreadful catastrophe of Mino, Owari, and Echizen.*

I wish here to express my thanks to Professors Edward Divers and Dairoku Kikuchi for their kindness in undertaking a laborious and time-wasting work to see the paper through the press.

April, 1892, Geological Institute of the College of Science.

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* *Mission d'Andalousie : Études relatives au tremblement du terre du 25. Décembre 1884, Mem. Acad. des Sciences,* T. XXX.

PLATE XXVIII.

Plate XXVIII.

This plate is intended to show the geological formations and structures, in general of the Mino-Owari plain; the positions of the line of section a-b,and c-d are indicated with corresponding letters by the heavily dotted (red) lines in Plate XXIX.

The upper section a-b, representing Palæozoic formations, is drawn from Yamasaki in Owari through the ridges of Yōrō and Fujiwara to Yominadō in Ōmi.

SC,—sandstone and clayslate; L,—limestone; Q,—quartz-porphyry; GR,—granite.

The lower section c-d, likewise of the Palæozoic complex, is taken in a north, westerly direction from Yamaguchi near Gifu along the Neo valley up to Haku-san. The rock represented are the sandstone and clayslate, hornstone and fossiliferous limestone; the mass of Haku-san being made up of granite-porphyry.

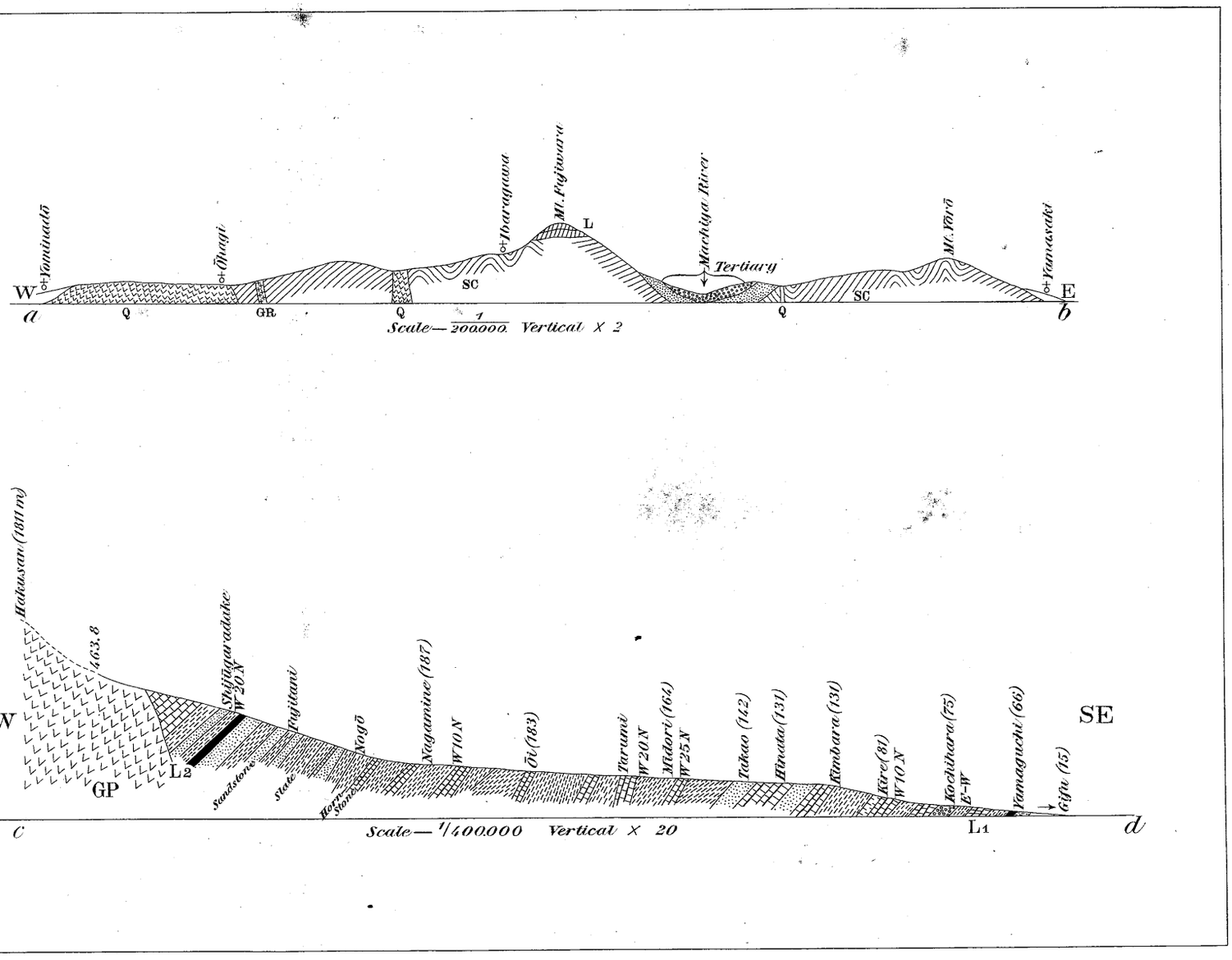

W
Yamiuadō
Ōhagi
Ibaragawa
Mt. Fujiwara
L
Machiga River
Tertiary
Mt. Yarō
Yamazaki
E
SC
SC
Q
GR
Q
Q
a
b
Scale— 1/200000 Vertical × 2
NW
Hakusan (1811 m)
463.8
Shijūgadake
W 20 N
Fujitani
Nogō
Nagamine (187)
W 10 N
Ōe (183)
Tarumi
W 20 N
Midori (164)
W 25 N
Takao (142)
Hinata (131)
Kimbara (131)
Kire (81)
W 10 N
Kochihara (75)
E-W
Yamaguchi (66)
Gifu (15)
SE
GP
L2
Sandstone
Slate
Horn-stone
L1
C
d
Scale— 1/400000 Vertical × 20

PLATE XXIX.

Plate XXIX.

Topographic map, published by the Geological Survey, representing the earthquake district of Central Japan between the Japan Sea and the Bay of Isé. The heavy red line indicates the course of the great fault from Katabira in Mino to Fukui in Echizen, the shaded portion being the meizoseismic area. The dotted lines A-B, and C-D show the direction of sections, given separately in Pl. XXVIII.

MAP OF THE EARTHQUAKE DISTRICT.

136° 30′ 137°

36° 30′ 35°

ABBREVIATIONS

Ka. Kami (Upper)
Sh. Shimo (Lower)
Na. Naka (Middle)
Ki. Kita (North)
Hi. Higashi (East)
Mi. Minami (South)
y. s. t. d. Yama, San, Zan or Sen (Mountain)
K. G. Kawa, Gawa (River)
t. d. Take, Dake (Peak)
t. Tôge (Mountain Pass)

Scale 1 : 400,000

10 Km. 5 0 10 20 30 Km.

Ri. ½ 0 1 2 3 4 5 6 7 8 9 10 R

PLATE XXX.

Plate XXX.

General plan for the geological structure of Mino, Owari, and Echizen, in which are shown the regular course (blue lines) of valleys from N. W. to S. E., indicating the positions of the pre-existing transverse fault, and the black lines being the direction of the strike of Palæozoic complex, with the dips as marked with the arrow-heads. The heavy red line is the course of the 'great fault of Neo'.

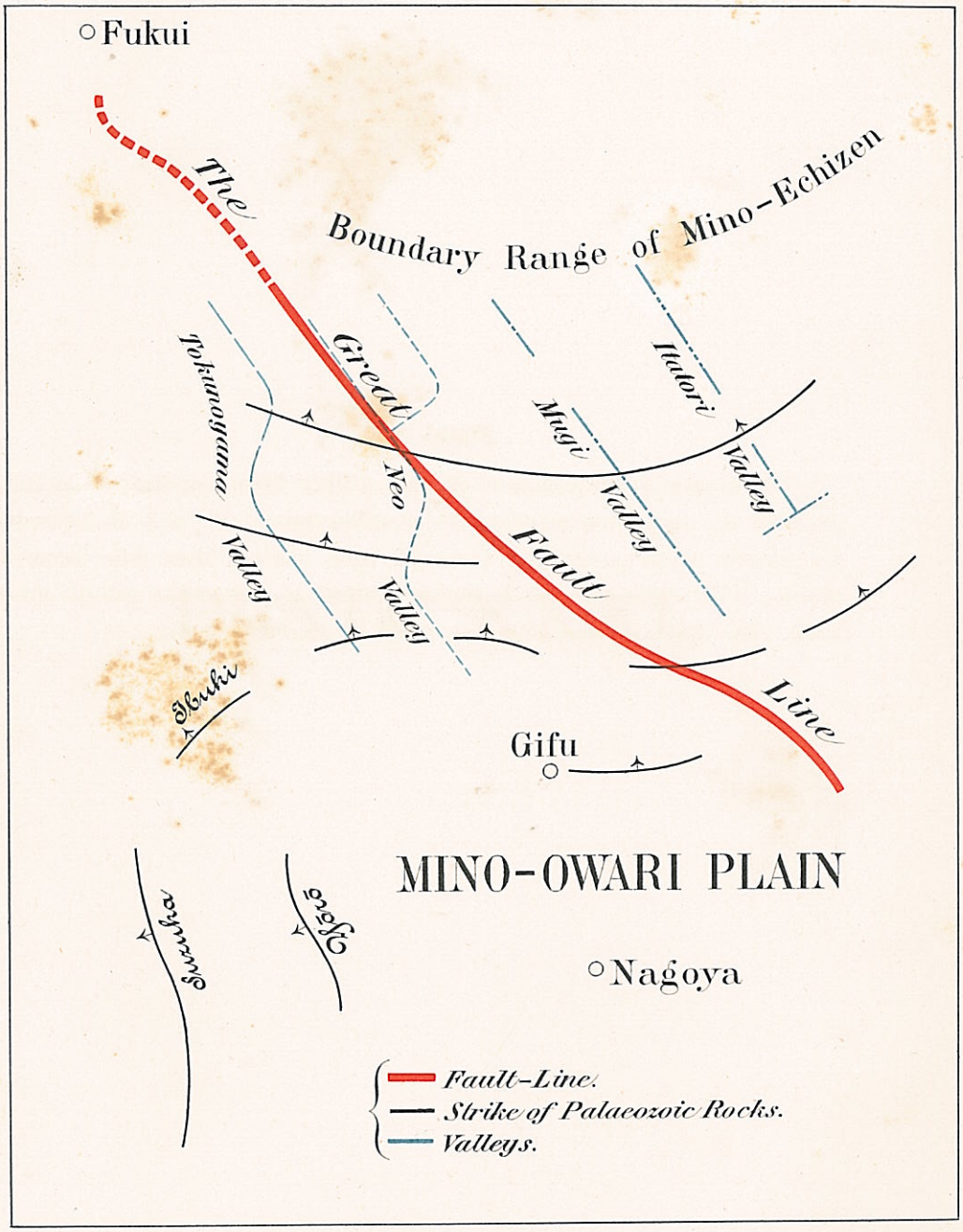

Fukui
The Great Neo Fault Line
Boundary Range of Mino-Echizen
Hatori Valley
Magi Valley
Tokuyogawa Valley
Valley
Ibuki
Gifu
MINO-OWARI PLAIN
Nagoya
Suzuka
Ogaki
Fault-Line.
Strike of Palaeozoic Rocks.
Valleys.

PLATE XXXI.

Plate XXXI.

The upper picture shows thatched roofs fallen intact, and it was in this manner that most of farmers' cottages gave way, presenting the appearance of gigantic saddles, when seen from a distance.

The lower picture is the representation of the banks of the Shōnai-gawa near Biwashima, a suburb of Nagoya, fractured for a mile's length, parallel to the course of the river.

Fig. 1

Fig. 2

COLLOTYPE BY K. OGAWA.

PLATE XXXII.

Plate XXXII.

FIG. 1.—A view of Kitakata (5 kilometres west of Gifu) after the earthquake, showing the rows of houses thrown over by shocks, and the road became simply a narrow lane between two interminable heaps of *debris*.

FIG. 2.—A very strange horizontal shifting of earth along the Shōnai-gawa, near Nagoya, by which the ground together with a large bamboo grove and a fallen thatched roof slid bodily some sixty feet westwards, the bamboo grove and a few pine trees remaining upright.

Fig. 1

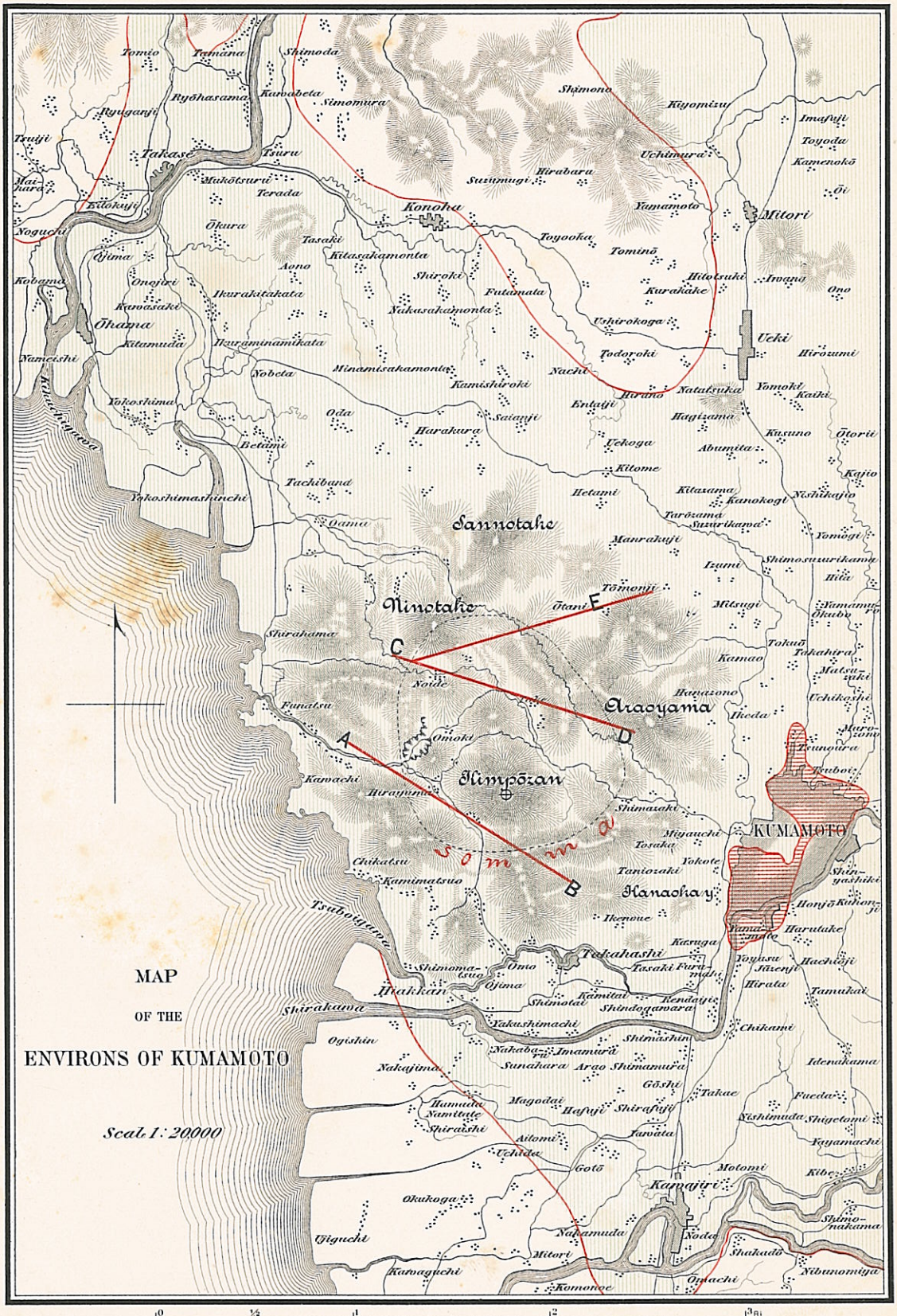
Fig. 2

COLLOTYPE BY K. OGAWA.

PLATE XXXIII.

Plate XXXIII.

The map of the neighbourhood of Kumamoto in the island of Kiū-shū, compiled by myself from various sources. It shows the seat of source of the earthquake in 1889, in the extinct volcano of Kimposan (Kibō-zan) with an old somma around it. A-B, C-D, and C-E are the lines of fissure, formed at the time of the severe shocks; the shaded (blue) portion being the meizoseismic area in which buildings had been all more or less damaged. A portion of the city of Kumamoto, shaded in red, had been intensely shaken, on account of its being once marshy ground of which we have many historical proofs.



MAP

OF THE

ENVIRONS OF KUMAMOTO

Scal. 1: 20000

0 ½ 1 2 3 4 5 6 7 8 9 10 Ri

1000m 0 1 2 3 4 5 6 7 8 9 10 Km

PLATE XXXIV.

Plate XXXIV.

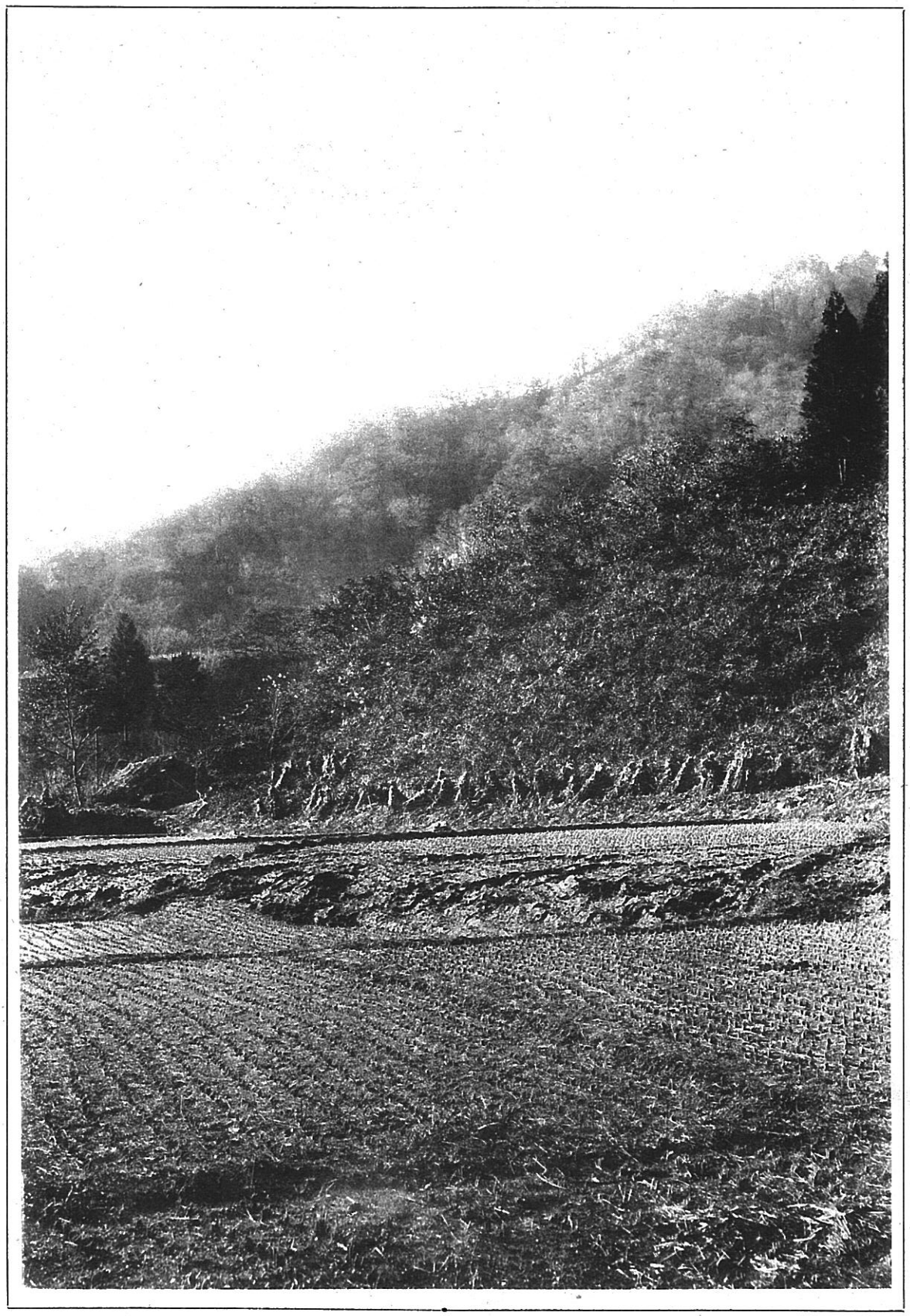
Amongst the extraordinary works done by the earthquake, the fault in Midor is the most remarkable. A fine new road had been obliquely cut into two, and the west half with the surrounding fields had sunk about 6 metres below the upper end. The eastern half had been pushed 4 metres northwards, as is well seen in the photograph by an abrupt change in the direction of the displaced road.

COLLOTYPE BY K. OGAWA.

PLATE XXXV.

Plate XXXV.

The plough-share-like appearance of fault near Fujitani in the Neo valley, along which again the depressed eastern wing, in conformation to the general rule, had been shifted in a northerly direction.



COLLOTYPE BY K. OGAWA.