Contents.

I. Introduction.

In the summer of 1865, I obtained six months' leave of absence from India, after eleven years of continuous residence. I was anxious to make the most of the brief opportunity to bring my thoughts into relation with those of the working geologists of Europe. My best available means of doing this was to visit some well-known ground, and to study what had been written of it. For such a purpose I was most fortunate in being able to select the Alps. No region has been more explored and written about; and, as much of my own work in India had been upon certain portions of the Himalayan range, it had long been my desire to compare my sections with analogous ones in regions geologically classical. The opportunity was so brief and without prospect of renewal, that I thought it best for my purpose to take a rapid view of a large area, rather than attempt the close examination of any one locality. Accordingly I devoted one month to the outer Alps, between the lake of Constance and Grenoble,—the Molasse and its relations to the mountain-range being the points to which my attention was specially directed. Immediately upon my arrival in India, at the beginning of the cold season, I had to start into camp. It has only been since my return

to Calcutta during the monsoon that I have had the opportunity of looking into the literature of Alpine geology; and I now venture to offer the following paper as a small contribution to the subject.

The progress of geology has not been equal. The more attractive branches have been cultivated far beyond those that seem less attractive; thus, as both must frequently appear before the public together, the effect is very incongruous. Such is the case presented in even the most recent works on the geology of the Alps. Alongside of the refined investigations of comparative palæontology, one finds stratigraphical features treated most loosely—from the point of view of assumption, and with little or no examination of evidence. The very language used in many cases would suggest that these structural phenomena were the performances of some uncanny mountain-sprites, rather than of forces or processes with which we had any chance of becoming acquainted. The mischievous effects of this are widespread; besides shaking the scientific credit of the men who can issue such uncritical work, and hence suggesting doubt in the value of their more special work, a shadow of darkness is thrown over the whole science. Stratigraphy in these mountain-regions is still appealed to in support of notions that have long since been refused general acceptance in geology. It seems to be forgotten that stratigraphy is the foundation of geology, as, without the initial physical fact of sedimentary superposition, palæontology, as we know it, could have had no existence. It is surely very unwise of the students of this younger branch so soon to assume its independence, while many of the positions from which it now provisionally works are still unproved. This mutual development is not, indeed, likely to take the exact form imagined by M. Barrande, in his speculation on the relations of the *haute stratigraphie* to the *haute paléontologie**; but that the problem will one day or other be worked out, no true naturalist will doubt. For the present, however, neglect, not to say contempt, seems to have fallen upon stratigraphy among a large section of professing geologists. By some the word is even appropriated to a department of palæontology, to indicate merely the *habitat* of fossils: M. Marcou says†, "En stratigraphie il n'y a encore à l'heure qu'il est, qu'un seul principe de vrai, de bon, d'utile; c'est de voir avec la plus grande exactitude, tout ce qui se trouve dans chaque couche de roches." Elsewhere (p. 48) the same author seems to make orography the geological complement of his "stratigraphy," assigning England as the birthplace of the latter, and Switzerland of the former. It would seem preferable to leave the word orography, as indicating the purely superficial features, to the physical geographer; and to use the term stratigraphy (in the same sense as M. Barrande) to mean the structure of the earth, the relations of rock-masses, as exhibiting the mode and sequence of events. If orography be used in this signification (as implying the *explanation* of superficial configuration), Switzerland has scarcely justified M. Marcou's dictum; it has been the stumblingblock rather than the

* Bull. Soc. Géol. France, 2e série, vol. xi. 1853–54, p. 311.
† M. J. Marcou, 'Lettres sur les roches du Jura,' Paris, 1860, intr. p. 9.

guide to rational geology. M. Thurmann's* elaborate classification of the structural features of the Jura seems to have led to no further conclusion than that the contortions were produced by lateral pressure.

One must have visited alpine regions fully to understand how indispensable palæontology is to the field geologist. It would be all but impossible to discover the structure of many large areas (and how much more so to assign the appropriate relative ages to the several rock-groups!) without the sure criterion of the fossil remains. But it must not be forgotten that this bare structure and these relative ages are but a portion of the mere data upon which a geological history of the region is to be founded.

It has often occurred to me that geologists are guilty of a general inconsistency in taking so little account of subsidence in the discussion of phenomena of disturbance. Subsidence is often introduced to admit of the continued accumulation of deposits; but, to account for the disturbance of strata, upheaval and intrusion are the agencies commonly appealed to. Yet in the most generally accepted theory of geogeny, the dominant character is shrinking and the consequent depression of the surface. The leading speculations upon crust-movements have indeed proceeded from the point of view of this theory; but I am now alluding to the lesser features of disturbance—the dips and strikes which form the elements of actual observation. If that theory be true, the features resulting from depression should greatly predominate in the detail-structure of the earth's crust. I am far from insisting that *à-priori* views should regulate rigidly our interpretations of phenomena. It would, on the other hand, be more in accordance with rational methods of research that those views should be taken into account, if it were only for the purpose of verification. In the case of the grand cosmological speculation of Laplace, the study of the earth's structure is almost the only direct test we can apply. The opposite course has been adopted: not only have the suggestions of this theory been disregarded, but the positive indications of mechanical laws have been set aside to warp observations into agreement with our superficial prepossessions. Many a scientific man cannot see a hill without taking for granted that it has been upraised, and attributing all its features to that process. In the particular case before us, the contortion of the Molasse is to this day the accepted proof of the last and greatest upheaval of the Alps. It can scarcely be necessary to say that such contortions can only indicate yielding, and hence an equivalent settlement of the mass from which the pressure is communicated. Flexures may, indeed, accompany an upheaval; but if so they must be a negative element in the total; and it is stepping beyond the limits of legitimate inference to take them *primâ facie* as evidence of upheaval. Such, however, is the only explanation offered of the flexures of the Tertiary strata at the base of the Alps, no account being considered necessary of the supernatural force demanded for

* Bull. Soc. Géol. France, 2e série, vol. ii. 1853, p. 41. I do not know if the work of which this paper is but a prodrome, ever appeared.

so peculiar a process. The united efforts of expansion and gravitation seem to me unequal to the task. Is it not absolutely certain that any natural lateral force in the shell of our globe can be neither more nor less than a component of gravitation—of the centripetal force,—and thus that any consequent compression must indicate a total result in the same direction? I cannot pretend to speak with any authority on a question of pure mechanics; nor do I, in using the word "supernatural" attempt to dictate the impossible; it is, however, a maxim that definite scientific speculation should keep within sight of ascertained facts. The accepted interpretations of Alpine sections seem to me to transgress this maxim. I have not found any very circumstantial explanation of the upheaval appealed to in those accounts; but the alleged result seems to me to necessitate the conception of this mountain-mass as of a very acute wedge, discontinuous from the enclosing matter (like the bung in a barrel), driven outwards—not by any general expansive force, for such must act with equal or greater effect upon the contiguous matter, which (not being hooped down) would rise rather than be compressed, but by some peculiar force acting only on the wedge. The onus of discovering such a force must rest with those who have evoked it. I would rather suggest that these features of contortion be taken only for what they *primâ facie* imply—the sinking of the mountain-mass. Subsidence, or at least shrinkage, as exhibited by the compression of strata, is seen in every region of the earth. In these matters geologists seem to have retrograded from the views of Deluc and other early fathers of the science*.

Actual observation has placed beyond doubt the fact of small, but rapid, elevation of large areas of the earth's surface. Long-continued slow rising is also an established fact. It is fortunate we have this information; for it were difficult to say what could be the positive *stratigraphical* evidences of upheaval. The burst-bubble performance, which is so largely accepted as accounting for the structure in the central regions of the Alps, is quite at variance with all we know of natural phenomena. As evidence of actual upheaval, the presence of marine deposits above the sea-level is, generally speaking, indisputable†. With reference to deposits not marine, a large correction must, however, be introduced into Alpine geology. The recently recognized power of rain and rivers to form extensive deposits at any level will no doubt remove the necessity for much of the prodigious rising and sinking hitherto demanded to account for such non-marine deposits, both in Posttertiary times and during the Molasse period.

* Bull. Soc. Géol. France, 2e sér. vol. vii. p. 54.

† The assumption of the absolute permanence of the sea-level (that its level has permanently maintained the same radial distance from the centre of the earth) has quietly taken the position almost of a postulate in geological induction. The notion is inconsistent with any progressionist doctrine, essentially so with Laplace's theory. A very grave obstruction may thus be introduced into the discussion of questions where very remote conditions may be concerned, as in this question of mountain-structure.

From what I have already said, it will not be expected that I can attempt to add to our knowledge of the Alps by more detailed observations of their rock-features. My suggestions must derive their force from other regions. I saw enough of the Subalpine ground to assure me that it presents a close parallel in geological history to the Subhimalayan region. The original and the superinduced characters in the two are strikingly similar. Whatever mode of explanation suits the one must fit the other. The interpretation I have put forward* of the Subhimalayan rocks, based perhaps upon sections more favourable for observation, differs so widely from what I find written about the Alps, that I am induced to call attention thereto. It will be necessary first to indicate, by reference to authors, what the views are to which I would take exception. I will, after that, sketch the results of my observations in the Himalayas, and finally indicate their possible application to the Alps.

II. Notice of Current Opinions on Alpine Sections.

The name of *Molasse* has long since been extended, from its original application to a particular soft sandstone, to the whole series of strata of which that sandstone forms a prominent member. The series has more recently been divided into several groups; but the same general term is still conveniently applied to all. They are of Middle Tertiary age. The home of the Molasse is along the northern base of the Alps, where it occupies the great valley of Switzerland, between the Alps and the Jura, extending eastwards through the Bavarian plains to Vienna. To the south-west, in Savoy, where the Jura-range becomes confluent with the Alps, the Molasse appears in the longitudinal valleys, along the continuation of the main valley. The actual area of these Miocene rocks represents approximately the original limits of deposition; and the strata are throughout strongly unconformable with the adjoining formations. In a zone along the base of the Alps, and several miles in width, the Molasse strata are more or less intensely disturbed, while beyond that zone they maintain their original horizontality.

Very conflicting opinions still maintain their ground regarding the bare facts of the Molasse section, both as to composition and as to the features of disturbance. One generally accepted feature is the continuous anticlinal flexure, observing an approximately medial position in the zone of disturbance. M. Studer described it in 1838†. In the same memoir a general descending order of succession is given —Nagelfluhe (conglomerate), molasse, and mottled argilaceous strata. There would thus be an ascending section up to the main line of junction at the base of the mountains, where the author speaks of these rocks as abutting against the Secondary formations of the Alps. The Rigi is referred to as typical of the common mode of contact, the strata there passing under the Cretaceous system. This is explained by the sliding of the older rocks on the top of the younger. The

* Mem. Geol. Surv. India, vol. iii. pt. 2.
† Mém. Soc. Géol. France, 1e série, vol. for 1838, p. 379.

figured section makes them apparently in parallel superposition, each being in its normal order. In another paper* M. Studer accounts for the great accumulation of the Molasse by subsidence along a fissure at the base of the Secondary mountains.

In his well-known paper on the structure of the Alps†, Sir R. I. Murchison adopts the most extreme views regarding the interpretation of the rock-disturbances. The great masses of subalpine Nägelfluhe in the Rigi and the Speer are not taken to be inverted (although MM. Studer and Escher de la Linth were the author's companions in these regions), but the junction of the Molasse with the mountains is spoken of as an enormous fault, whereby the topmost Nagelfluhe is brought into contact with low rocks among the older formations‡. The elevation and dislocation of the Molasse is described as demonstrably sudden, and as proving that the crust of the earth was then affected by forces infinitely greater than now. There is no attempt to specify the nature of the disturbing force; it is not even referred to the elevation of the Alps; but such a subsequent upthrow of the older rocks is almost necessarily implied in the word "fault," as applied to the junction of the Molasse with the mountains.

M. Rütimeyer§ gives an account of the intricate section at Ralligen. The figured section seems quite impossible in its details; but it exhibits some interesting facts, the abrupt appearance of much older strata at the base of the Cretaceous rocks near the junction, and the occurrence of a narrow band of crushed lower Molasse against which the Nagelfluhe abuts at a moderate inclination.

M. Lory‖, in his sections of the range of the Grande Chartreuse, shows a fact of importance. In some of the great flexures (Vallée de Proveysieux) the Molasse is represented as so parallel to the Cretaceous strata on which it immediately rests, that these must have been approximately horizontal at the time of deposition of the former. Sections of other authors in the same region (close to Annecy) give a very different relation.

In a memoir on the North Vorarlberg¶, Escher de la Linth expresses his views upon the general sequence of geological events in the Alps. The Nagelfluhe is described as dominating along the zone next the Alps, and as being there equivalent to finer deposits more to the north. For several miles to the north of the boundary with the Flysch, the underlie of the rocks is south-easterly; but in this zone there are several repetitions of the strata by folded flexures. The figured section (No. 16) is scarcely consistent with the text; at the junction, the critical point of all, there is no saying whether the Nagelfluhe is a top or a bottom band, or what its true relation to the

* Neues Jahrbuch, 1850, p. 221.
† Quart. Journ. Geol. Soc. Lond. 1848, vol. v. p. 157.
‡ The use of the word *inverted*, in the paper quoted, is confusing: being sometimes applied, in its usual English acceptation, to strata turned upside down, it is more frequently used in the more arbitrary sense of dipping in a wrong direction, being apparently put for the German "*wider-sinnig*."
§ Neue Denkschriften, Zürich, vol. vii.
‖ Bull. Soc. Géol. France, vol. ix. 1851–52, p. 226.
¶ Neue Denkschriften, Zürich, 1853, vol. xiii.

older formations may be, besides that of present apparent conformable succession. The author attributes all this contortion to the revolution which gave to the limestone-range its present aspect: much of the Vorarlberg was dry land during the Flysch period, and after it the whole mountain-region became dry land. The greatest revolution here occurred after the Molasse,—in proof of which M. Escher adduces, first, the great local contortion of the Molasse; secondly, the intimate connexion of the Molasse and the limestone mountain, so that the present position of both must be the result of the same effort; and, thirdly, the fresh and well-defined relation of the mountain-contours to the position of the strata, and the correspondence of these features throughout the whole mountain-section. In short, the abruptness and comparatively good preservation of the Alps seems to indicate their youthfulness! The independence of the outer mountain-fringe, and of the indented boundary of the central masses, suggests how much greater the force must have been which produced the former. Yet the general similarity in the features of disturbance proves both to have been acts of the same long process.

M. Rozet*, from the slight disturbance of the Molasse in the French Alps, considers that the greatest dislocations of the mountains occurred between the Eocene and Miocene periods.

In the Eastern Alps we find M. Stur† adopting the usual theories. After the Eocene period a great disturbing force broke up the hitherto little-troubled regular succession of formations, producing the fan-structure and the transverse valleys. After a succession of subsidences for the deposition of the Neogene strata, there came the last great fissuring and upheaval, the floods occasioned by which produced the diluvium.

M. Brunner‡ makes a great effort at a rational improvement upon the usual mode of explanation, but seems to involve the question in more difficulties and apparent contradictions. Thurmann's explanation of the flexures of the Jura mountains, by the Alpine upheaval, is rejected on account of the intervening area of undisturbed Molasse; and similarly the folds of the Stockhorn cannot be due to Alpine upheaval, on account of the Flysch of the Simmenthal. This observer rejects the mode of action called plutonic, and localizes the cause, finding adequate force in the expansion due to crystallization. Still the lateral displacement is connected with the upheaval. The actual Molasse boundary is not considered a shore of that period; the rocks sre said to be broken sharply at the junction. The author accounts for what he calls the *abnormal* projection of the boundary at the Stockhorn, and the absence of Nagelfluhe, by the greater lateral sliding of the mountain-mass at this spot. For the four shocks usually reckoned for the production of the Alps M. Brunner substitutes one long upheaval, commenced after the Lias, and continued uniformly until after the Molasse.

* Bull. Soc. Géol. France, vol. xii. 1854–55, p. 204.
† Sitzungsberichte der k. Akad. Wien, vol. xvi. 1855, p. 477.
‡ Neue Denkschriften, Zürich, vol. xv. 1857.

M. F. v. Hauer*, in his section of the eastern Alps, says that the first great upheaval, involving contortion, occurred after the Lias; and he seems throughout to attribute contortions and valley-formation to such agencies.

In his paper on the Tertiary rocks, M. Lory† uniformly attributes the contortions of the Molasse to the upheaval of the Alps.

M. Kaufmann's paper‡ on the Subalpine Molasse is the most detailed I have seen. He traces three axes of flexure throughout his entire area—a synclinal between two anticlinals. The inner anticlinal is a folded flexure; and thus the flanking belt of hills, at the base of the great range, is sometimes partly composed of inverted strata as in the Beichlen: the great hills of this zone (the Rigi and the Speer) are south of the inner anticlinal; and therefore the strata are in their normal order of superposition, as the contact-rocks must be throughout. M. Kaufmann, however, altogether avoids the actual junction; the inner rocks do not appear on any of the figured sections. The historical sketch given by this author is peculiar. A continental elevation is distinguished from that confined within the mountain-range. During that elevation great erosion of the Molasse area took place, leaving hills of Nagelfluhe in their present approximate position. The lateral pressure, subsequently induced by the mountain-upheaval, produced the lines of flexure along the lines of erosion, as lines of weakness. Although M. Kaufmann thus seems to invert the usually accepted order, he is in advance of most Alpine geologists in even recognizing the intimate connexion between contortion, denudation, and valley-formation. During the mountain-upheaval, it is considered that the Molasse area must have suffered depression, to help to account for the actual superposition at the contact. Like all the preceding writers, M. Kaufmann seems to think it necessary to account for the present irregularities of the line of boundary as due to disturbance—although no one offers any reason for assuming it to have been at any time straight, unless in so far as such an assumption is implied in the assumption of a great line of fissure.

M. de Mortillet§, after describing many facts implying how partial in extent and in influence great changes of level may be, conforms fully to the current opinion. The last great rising of the Alps is described as having taken place at the close of the Miocene period; this upheaval traced out the valleys as we see them, rock-basins and all. It was the last violent movement.

M. Favre‖ would seem to connect the origin of the Salève mountain with that of the main anticlinal in the Molasse.

In M. Gümbel's large work on the Bavarian Alps¶, notwithstanding the great labour expended, the stratigraphical question does

* Sitzungsberichte der k. Ak. Wien, 1857, vol. xxv. p. 253.
† Bull. Soc. Géol. France, 1857–58, vol. xv. p. 40, and vol. xvi. p. 823.
‡ Neue Denkschriften, Zürich, vol. xvii. 1860.
§ Bull. Soc. Géol. France, vol. xix. p. 849: 1861–62.
‖ Bull. Soc. Géol. France, vol xix. p. 928: 1861–62.
¶ Geol. Beschreibung des bayrischen Alpengebirges und seines Vorlandes. Gotha, 1861.

not seem to be placed upon a better footing. The diagram section figured on pp. 679 and 757 is irreconcileable with itself; the lowest beds of the series, next the main junction, as numbered and described, are shown at the top of what must be (according to the lines of stratification) a normal ascending section. There are other similar discrepancies in the same section. The evidence given (p. 694) that the lowest beds do occur next the junction is far from convincing. There is much variety shown in the actual sections taken at different points of the junction, inversion being by no means the rule. The irregularities which occur in the line of boundary, generally near a main valley, are explained in the same arbitrary manner as by M. Kaufmann and others—by the horizontal displacement and projection of the older rocks at these points of transverse fracture. The sequence of formations is represented to have gone on regularly up to the Cretaceous period, the younger Cretaceous rocks resting transversely upon all. The Nummulitic deposits stretched, up fiords, deep into the Alps, the coal-beds of Häring, in the Inn-Thal, showing that the limestone Alps were then as high as now. A little further rise of the coast defined the basin of the Molasse. The warm character of the Neogene flora precludes the conclusion that the Alps (? the central Alps) were as high as now. Hence this altitude must have been attained since: as collateral evidence of this "Katastrophe" the author points to the contortion of the Neogene strata. The similar preceding alterations of level can only be looked upon as precursors of this "Haupthebung." It is remarked that this period corresponds with that of great volcanic eruptions in other regions. The state of the Alps during the Molasse period is compared (p. 870) to that of the present Jura and Swartzwald; then came the "Hauptkatastrophe." Erosion and disintegration afterwards completed the present configuration. It would seem, however, that considerable depression can occur without any remarkable stratigraphical results, the inundations which produced the Loess, M. Gümbel supposes to have been caused by sudden sinking of the snow-clad mountains. Were not M. Gümbel's history full of anomalies, one might suppose that the events just indicated can scarcely have appeared to the author so violent as the language and, indeed, the alleged facts seem to require; for he makes the excellent suggestion (p. 854) that some shelves of débris, now found in the inner Alps separated from the present watercourses, may belong to the Molasse period. The fan-structure of the central masses is accounted for by the protrusion of the mountain-core. The prevailing inward dip in all the fringing mountains is attributed (p. 855) to the tendency of the strata to range themselves at right angles to the upward and outward pressure—an explanation which seems to me to lead to a result the very opposite of that required. To render possible the contortion in the Tertiary zone, M. Gümbel considers it necessary to suppose the resistance of a now departed mountain-ridge somewhere in the Bavarian plains.

Professor Ramsay, in his paper on the glacial origin of lakes*,

* Quart. Journ. Geol. Soc. Lond. 1862, vol. xviii. p. 185.

gives an ample refutation of the notion, universally adopted by continental geologists, of the fissuring by elevation as an origin for valleys, transverse or longitudinal; his argument applies by implication against accepting contortion as evidence of elevation. The contortion of the Miocene strata is, however, accepted as proof that, after the Miocene epoch, the rocks of the Alps were much disturbed, sufficiently so to alter the drainage-system in all its details. In the Molasse itself the inversion of the rocks of the Rigi is quoted as a measure of the action.

Sir Charles Lyell, in his 'Antiquity of Man' (p. 309), adopts generally the views which connect the disturbances of the Molasse with, and as proof of, the last series of movements to which the Alps owe their present form and internal structure, dissenting from those views so far as they include the production of the lake-basins. He combats, I think effectually, Professor Ramsay's theory of the formation of the great Alpine lakes by glacier erosion; while at the same time (in assigning unequal subsidence of large areas as the *main* cause of these lakes) he introduces glaciers as an almost essential adjunct, to prevent silting up *pari passu* with the subsidence. The absence of lakes in non-glacial mountain-regions is accounted for in that way. In appealing to the undisturbed, yet præglacial, lacustrine deposits on the lake of Zurich against the theory of Prof. Ramsay, Sir Charles Lyell seems to overlook that this evidence tells with as great force against the use he himself makes of glaciers in the production of those lakes; for the lake of Zurich must by his process of formation have attained its maximum extension and depth when the deposits of Utznach and Dürnten were formed, *i. e.* before the glacier-period.

The Molasse does not come within the range of Professor Theobald's recent work on the Grisons*; but the author would seem to allude to the contortions of those rocks when he says (p. 7) that only on the north did the upheaval of the Alps find an obstacle, in the earlier formed crystalline mass of the German Mittelgebirge.

In M. Heer's valuable work on the geology of Switzerland †, there is scarcely any tangible allusion to physical geology. The author seems to adopt the current opinions upon the last great upheaval of the Alps, subsequent to the Molasse period.

'Der Gebirgsbau der Alpen' ought to be an exact complement and suitable companion to 'Die Urwelt der Schweiz.' M. Desor's work ‡, however, in no real sense fulfils this expectation; there is not a single section in it, nor anything like a critical matter-of-fact discussion of Alpine rock-structure. The history of the Alps is divided into two great periods, before and after the last mountain-upheaval. From the early Prælias land the centre had progressively risen, but unequally and with oscillations. On the south the Pliocene deposits suffered the same disturbances as the Miocene; so the

* Geol. Beschreibung der N. O. Gebirge von Graubünden. Bonn, 1864.
† Die Urwelt der Schweiz. Zürich, 1865.
‡ Der Gebirgsbau der Alpen. Wiesbaden, 1865.

"Haupthebung," the last "Krisis," which was as great as all the others put together, must have been at the end of the Tertiary periods. M. Desor traces all the great features of the Alps to this time—folds, inversions, *combes*, and *cluses*, and the general uniformity of dips throughout the whole section. The Rigi and the Speer are mentioned as instances of inversion in the Molasse, on the authority, I believe, of M. Studer's more recent observations.

Such is the latest and most tragic history of the Alps. It fully confirms the statement with which I started, that a school of geology, obsolete elsewhere, still holds its ground in those mountain-regions.

Any general notice of the geology of the Alps must be altogether deficient without mention of the latest opinions of M. Studer, whose great work on the geology of Switzerland is the acknowledged authority. I have not had access to this book. My object, however, has only been to show, by sufficient references, what is the generally received view regarding one or two important features of Alpine geology. I have omitted no available source of information; the works of most of the best-known observers have been consulted; and, from the frequent allusion made by other writers to M. Studer, I am pretty confident that his views upon those points coincide more or less with what I have represented. He is, I believe, the authority for the inversion of the rocks in the Rigi and Speer.

The opinions to which I would draw attention, as universally applied to the Alps, are the abnormal (faulted) nature of the actual boundary of the Molasse with the rocks of the higher Alps, and the explanation of this, as well as of the contortion of the inner zone of Molasse, by the direct upheaval of the main mountain-mass. In almost all the works referred to there may be found passages to the effect that all the features of the Alps are the result of one long-continued action. These professions can be little more than nominal concessions to modern views; at least every special explanation and many of the alleged facts seem to me to be essentially inconsistent with such views.

III. Sketch of some Subhimalayan Sections.

There is a very striking similarity between the sections along the southern base of the Himalaya and the northern base of the Alps. One can scarcely doubt that the histories of the two regions have a corresponding agreement. I must refer to my memoir on the Subhimalayan rocks of North Western India * for a detailed description of the sections; I can here only point out some leading features. The clays, sands, and conglomerates of the Sivaliks are undistinguishable in hand specimens from those of the Molasse. In both regions the coarser deposits prevail towards the top. The distant hills on the south of the Gangetic plains form only nominal representatives of the ranges which bound the great valley of Switzerland on the north; and the ancient alluvium forming those plains conceals completely the southern extension of the Sivalik strata beyond the limits of a narrow zone fringing the mountains. Within

* Mem. Geol. Survey of India, vol. iii. pt. 2.

this zone the rocks always exhibit more or less of disturbance, very often to an extreme degree.

There are two well-defined groups in this Subhimalayan zone. Along their northern boundary the Upper Sivalik strata abut against lower beds of the same Subhimalayan (Tertiary) series, of the middle (or Nahun) group. These latter beds form a narrow band of variable thickness, but rarely, if ever, absent, separating the true Sivaliks (the strata which yielded the Fauna Sivalensis) from the much older rocks of the higher mountains. Sir Proby Cautley has identified the rocks of the Nahun band with the beds at the outer base of the Sivalik hills, where they seem to be regularly overlain by the younger Sivalik strata*. The collection of fossils from the older beds, which might have thrown such light upon this stratigraphical break, has been lost since its transmission to England; indeed I am told, by the distinguished donor, that this misfortune has befallen it since the consignment of the collection to the vaults of the British Museum †. Even without the palæontological facts, the relation I have described of the Sivalik and Nahun groups is remarkably analogous to that of the Neogene and Oligocene groups of the north-eastern Alps.

In one portion of the north-west Himalaya we find a remnant of a much older group of Tertiary rocks; the bottom beds are the well-known Nummulitic strata of Subathoo. They are overlain transitionally by sandstones of the regular Molasse type, only thoroughly indurated, like the Flysch sandstones of Appenzell. By position this group identifies itself with the rocks of the outer edge of high mountains, rather than with the true Subhimalaya, just as do the corresponding rocks in the Alps, thus completing the analogy of the sections with almost startling exactness.

The Subathoo group rests high up on a base of the slates forming the mountains, upon a denuded surface of which it had been deposited, both rocks being now seen folded in the same contortions. The younger groups of the Subhimalayan series (Sivaliks) only appear at the outer base of the mountains, and the junction is as apparently abnormal as anything seen in the Alps; the dip of the younger rocks is almost invariably towards the contact, the plane of which underlies to the north, thus producing actual, though not parallel, superposition of the older rocks. All the arguments as to prodigious faulting &c. that have been applied to the Alps would be just as applicable here.

A very brief inspection of the Sivalik rocks made me averse from the supposition of any great change in the features of the surface since the time of their formation. There is at once apparent a most

* Journ. Asiat. Soc. Bengal, vol. iii. 1834, p. 528.

† The more we see of these Sivalik rocks, the more does our admiration increase for the discoverers of the Fauna Sivalensis. I failed to find fossils either at Nahun or at the Kalawalla pass; and within this last year Captain Godwin-Austen, who has much experience as a collector, incited by my account of the difficulty and of the interest attaching thereto, spent some time at Nahun searching for fossils, but without the smallest success.

marked correspondence between the distribution of the accumulations of conglomerate and the position of the actual river-gorges of the mountains; even in front of some of the lesser streams, with very contracted drainage-basins, this limitation is well marked. Yet these conglomerate masses are often as thick and at as high angles as those on the Rigi and the Speer.

It was along the junction of the Sivaliks with the Nahun group that I found the sanction for the explanation I was disposed to apply to the main junction of the Subhimalaya with the older rocks of the high mountains. That line of contact of the two younger groups is mostly concealed along the inner slopes of those longitudinal valleys known as "dúns." For about twenty miles midway in the space between the Jumna and the Sutlej the Sivalik hills are confluent with those of the Nahun band; and the junction of the groups can here be followed without a check. The character of it is most constant, and uniformly of the type already noticed. The conglomerates dip at various angles, high and low, against the bottom beds of the Nahun band; they seem to go under, or to be buried in, the older rocks, the plane of contact actually underlying to the north. Here then, again, we have a *primâ facie* case of reverse faulting, of lower rocks slipping up over younger ones. A doubt of this is first raised by the fact that the conglomerates contain much débris of the Nahun rocks. There is, however, an actual section which seems to render impossible the supposition of any faulting whatever: on the same boundary, and within half a mile of a grand section of abnormal superposition, we find the same conglomerate beds dovetailed into a serrated steep denuded surface of the same Nahun beds; and, further on, the younger beds broadly overlap the older. The process of formation revealed by these sections is, that the Upper Sivaliks were deposited against a steep denuded edge of the older group, the present inverted plane of contact being due to subsequent lateral pressure, which has not otherwise displaced the original boundary by any vertical relative motion of the masses in contact.

In spite of the great unconformability I have just noticed along the inner boundary of the Nahun and Sivalik groups, it would seem, according to the identification made by Sir Proby Cautley, as already noticed, that these same groups at the base of the Sivalik section, some miles to the south, are in apparently unbroken sequence, both being now much disturbed. Such a fact would be most convincing proof of the exceeding gentleness and partiality of the process of disturbance. Should any doubt hang over this point of evidence owing to the unconfirmed and originally incompleted palæontological observations upon which it rests, there is sufficient independent proof of the same inference as to the nature of the disturbing process, in the permanence of Præsivalik stream-courses. If this were only observed in the case of the great gorges of the higher mountains one would scarcely be surprised. These tortuons gorges are manifestly the work of rivers; but one has to encroach deeply upon geological time for the accomplishment of such results. In

the case of those great features, moreover, one can imagine very considerable violence of disturbance to occur without causing any alteration. Neither of these pleas suggests itself in the case of such streams as the Guggur and the Batta, the springs of which are not further in than the first ridge of the mountains.

The most apparent instance of the feature under notice is found in the course of the Sutlej. This mighty torrent debouches upon the plains at a point where the zone of the Subhimalayan rocks has become greatly widened, owing to the retreat northwards of the mountain-range; thus, before it reaches the outermost zone of the Sivaliks, the Sutlej has run for many miles through comparatively low hills of soft rocks of Lower Sivalik or Nahun type. At Bibhor the river cuts the last of these inner ridges; and on the outer flanks, on both sides of the stream, there are massive beds of coarse conglomerate, of boulders such as only occur in the main river-channels. These beds are now raised to the vertical; and in both directions along the strike these conglomerates pass gradually, within a few miles, into the ordinary sandstones. The presumption from such a coincidence seems irresistible, that the Sutlej itself had deposited these banks of boulders on the spot where it still flows. Whatever view one may take of the precise form of the contortions which now exist in these strata, their magnitude is unquestionable; yet, from the circumstances just noticed, the conclusion would seem unavoidable that they were produced at the very surface, and so gradually that one can imagine the process inappreciable to contemporaneous observers, had any such existed at the time.

Although the same detailed evidence is not traceable with regard to the main junction (that of the Lower Sivaliks, or Nahun band, with the slaty rocks of the mountains), it is certainly most reasonable to apply to it the same interpretation as was proved in the less-obscure section of the more recent boundary, and because whatever features are seen in the former are common to both. I consider that the older rocks had attained their present relative elevation before the deposition of the Lower Sivaliks—that the present contact of these rocks is the original one, only thrown out of its normal slope by the yielding of the softer and less-weighted rocks to lateral pressure.

The longitudinal irregularities in both the lines of boundary described are as numerous and as abrupt as those noticed in the Alps. The coincidence between them and the great river-gorges is quite accidental, there being more exceptions than examples of such a rule. I could not observe a shadow of evidence for these steps in the boundary of the mountains being due to cross faults or transverse fissures. On the contrary, I have always found them connected with local variations of strike, or of composition of the rocks, such as predetermine the irregularities in every process of denudation. Thus observation here seems to coincide with general considerations of terrestrial physics in separating, or even opposing, the operations of elevation and of contortion, the latter being altogether subsequent. That the contorting force in the case before us came from the

mountain-region no one would question; and no cause seems so natural as the simple one of gravitation. However puny any mountain-range may be in comparison to the mass which supports it, no grain is without its effect in maintaining the equilibrium. The theory of M. de Beaumont affords a plausible expression for such a process as I would suggest—a tuberance (bossellement) is produced with a slowness due to the motive source upon which that theory is founded. This upheaval would be scarcely observable, and would produce no structural change, until a limit of resistance was reached, whereupon gravitation, which all along had been the proximate cause of the tuberance, would become partially localized as an agent of subsidence, involving contortion. Direct gravitation is supposed to be the breaking force, not any rupture analogous to that of the tension produced by the bending of a quasi-rigid mass. Such a process might repeat itself any number of times in the same region.

In this way one might arrive at the apparent paradox, that the structure of true mountains (those which are in an especial manner regions of disturbance), from core to base, is the immediate result and the record of subsidences. And, indeed, that commonest feature of mountain-structure (the convergence of dips to central lines) points directly to such a supposition. Any attempt I have seen to connect such a result directly with an elevatory force has been unsatisfactory to my mind.

A force such as has here been supposed to produce contortion along the outer zone of a mountain-range might not be simply a lateral force. The partial sinking of the central regions might generate an elevatory motion at the flanks. The mechanical result in this position would be variously apportioned to each of these forces according to the circumstances of resistance. The elevation which brought the Nahun belt under denudation may have been of this kind rather than connected with a general elevation of the whole mountain-region.

From the foregoing explanations it will be evident that I consider, first, the present contact of the Sivalik formation with the mountains to be the original one, modified only by pressure without relative vertical displacement; secondly, that the sinking of the mountain-mass is the proximate cause of the contortions of these Tertiary strata. The annexed diagram section is an attempt to exhibit, *with a minimum of contortion*, the explanation I would give of the observed features of Subhimalayan disturbance.

IV. Suggested Parallelism of the Alpine and Subhimalayan Sections.

Any attempt to apply circumstantially to the Subalpine sections the interpretation I have offered for those of the Subhimalayan region must be left to those who can visit the ground. Adaptations and modifications will be necessary, which can only be made out on the spot. There are manifest differences of orographical conditions in the two regions, that could not but entail corresponding modifications in the results of a process such as I have supposed; and we

are not yet in a position to say deductively what these should be. The descriptions I have been able to examine are so wanting in detail upon the crucial points of the section, that I can only make vague identifications of parallel features.

The great anticlinal throughout the zone of disturbance in the Molasse would seem to find its counterpart in the Sivalik Hills. Throughout the whole North-west Himalayas these flanking hills are connected with an anticlinal axis, which generally runs along their southern base, the southern limb of the flexure having been denuded and covered by detritus.

The remnant of bottom beds of the Molasse series, so frequently found along the main boundary, between the Nagelfluhe and the Secondary rocks of the mountains, may be the physical equivalent of the Nahun band. As far as I can make out, it is upon the presence of these remnants that the supposition of inversion of the younger rocks at the contact has been founded, and extended to such sections as those of the Rigi and the Speer; but if my conjecture be correct, this would be unnecessary and erroneous. The denudation o the Lower Sivaliks consequent upon elevation, which in the Subhimalayan region was arrested well short of the mountain-

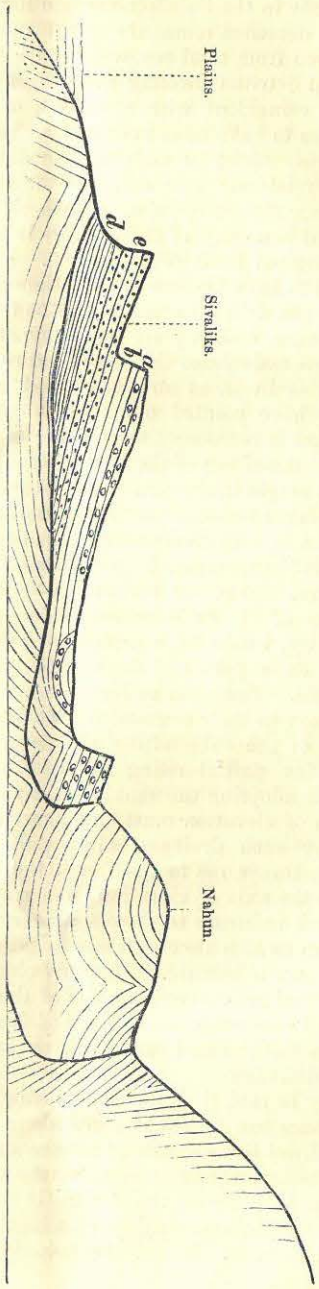

Diagram Section at the southern base of the North-western Himalayas.

slopes, may in the Subalpine region have proceeded until there were left only detached remnants of the upraised Lower Molasse, which were saved from total removal by the encroaching deposition of the torrential detritus forming the Upper Molasse. Subsequent compression coincident with a sinking of the mountain-mass, which also seems to have gone to greater lengths in the Alps than in the Himalayas, might in such a case obliterate any clue to such an original relation. The necessity for suggesting this interpretation is the more surprising, since almost all Alpine geologists agree that the actual boundary of the Molasse is approximately in the position of the original limit of deposition. None state explicitly what is supposed to have become of the original contact.

The much debated question of the formation of the great Alpine lakes at once finds a place in the hypothesis I am proposing. This hypothesis assimilates the main feature of the explanation given by Sir Charles Lyell, as already noticed, and is free from the discrepancy I have pointed out in that explanation. The presence of these lakes is corroborative evidence of the sinking of the mountain-mass and the rising of the fringing zone, of which more direct proof has been sought in the structural features. I think that the formation of these lakes was more or less coincident with the contortion of the Molasse, and with the concurrent partial elevation of the zone at the base of the mountains, both results being due to the depression of the central region. A period of continental elevation, such as the tuberance of M. de Beaumont's theory, succeeding to a period of tranquillity, would have arrested the deposition of the Molasse, and brought on a period of denudation, just as was supposed by M. Kaufmann. The great valleys then received their final clearing out, preparatory to their conversion into lake-basins. In due time depression of the culminating regions of elevation, and compression, with reflex partial rising of the border-zone would supervene. Although adopting the maxim that the original main drainage of any area of elevation must be transverse to the axis of that area, since any such drainage must *pari passu* develope secondary drainage, transverse to itself, and therefore longitudinal with reference to the axis of elevation, one may admit with M. Kaufmann some small influence to these secondary lines in guiding the lines of contortion (which are essentially longitudinal) when the compressing action began to operate. The chief objection to this mode of relation of the actual general coincidence of these features is, that the regularity and continuity of the lines of flexure seem incompatible with so very accidental and superficial an influence as that of secondary lines of drainage.

It may be said that the Himalayan parallel fails to support me here; there are no great lakes along the base of this range. Sir Charles Lyell has suggested that the absence of glaciers in the subtropical latitudes may account for the want in that position of lakes analogous to those of the Alps. It might have been known from the first that this removal of an admitted obstacle to his theory was of little avail; for alluvial flats holding the place of the lakes in the

main gorges of the mountains (for the prevention of which alluvial deposition glaciers were admitted as secondary though almost essential agencies in the hypothesis) would equally well attest the action of the principal agency appealed to. Alluvial flats of this nature do not exist in the Himalayas; the great rivers are torrential throughout their entire course to the plains. It is evident, however, that the production of such lakes is a very non-essential result of the whole process now under consideration, and contingent upon a number of circumstances, in degree and in kind. All other conditions being alike, if in one case the erosion of the valleys were much more complete than in the other, the same relative movement would produce lake-basins in that case, while there could be no such result where the fall of the main drainage was very steep. Or, the same amount of vertical movement, equally efficient for the structural results required, may, from unseen influences, be very differently distributed in two cases; the central subsidence might be localized at and about the centre, with little or no rise along the flanks. By some such plausible modification as this, the great lake-basins of the central Himalaya may be the true analogues of the fringing lakes of the Alps.

I quite admit the force of the difficulty which induced Sir Charles Lyell to introduce glacial action as a subsidiary agent in the formation of the great Alpine lakes. I, too, should have thought that the accumulation of torrential débris would have kept pace with the formation of the basin. If the objection is sound, it quite upsets the supposition I have made regarding the age of the Alpine lake-basins. It rests, however, on a purely *à-priori* judgment, and cannot outweigh a fair accumulation of evidence on the other side. If that judgment proves unfounded we shall have acquired a provisional limit and gauge for the rapidity of the crust movement*.

There is a well-known difficulty in Swiss geology that may, I think, be reduced by the supposition I have advanced as to the

* Some years ago Mr. H. F. Blanford applied this mode of explanation to some rock-basins in the Nilghiri Hills. See Mem. Geol. Survey of India, vol. i. pp. 241–243: 1859.

Although I have attempted to substitute another explanation for that given by Professor Ramsay of the formation of the great lake-basins of Switzerland, I fully assent to the power of glaciers to form rock-basins under certain conditions. An observation I made in Switzerland removed a mistaken *à-priori* opinion that had until then stood in my way. The observation must be patent to many, though I have not seen it described; but as the mistaken notion to which I refer seems to have still greater currency (it is the principal objection urged against Prof. Ramsay's views in a recent presidential address to the Geological Society), I may notice the observation. Supposing a rock-basin formed and filled with ice, it is often doubted if there could be enough of tractive force, or even of *vis a tergo*, to exercise a scooping-action within the basin; it is thought that the upper ice would flow on, leaving that in the basin almost undisturbed. The little lake of Lungern lies at the outlet from the fine amphitheatre cut in the flanks of the Brunig. The rock-barrier is so steep and narrow that it has been considered worth while to make a tunnel fifty feet below the rim, for the sake of the land gained at the delta by the partial drainage of the lake. The precipitou upward face of the rock-barrier is thus admirably exposed; and it displays numerous deep and regular grooves, the unmistakeable marks of the action in question.

period of formation of the basins of the great lakes, thus strengthening the validity of that supposition. It is the composition of the bunter Nagelfluhe. May not the unknown débris of this deposit have been derived from the portions of the valleys now depressed out of sight? This is surely a more likely conjecture than that of MM. Escher and Studer (as quoted in M. Heer's work, 'Die Urwelt der Schweiz'), of a ridge of these peculiar crystalline rocks along the north base of the Alps, the remains of which ridge have since disappeared down a fissure, and been further put out of sight by the lateral sliding of the limestone-mountains! If the great lake-valleys were still exposed to observation, if this phase of the process of disturbance had not extended to so much greater lengths in the Alps than in the Himalayas, we might find in this peculiar débris evidence, of the same kind as I have noticed in the Sivalik rocks, for the permanence of the Præmolasse streamcourses.

There are a few insignificant lakes along the outer fringe of the Himalayas that are evidently due to movements of the kind we are supposing, since the actual valleys were carved out. The Kundulu lake, on the road from Roopur to Belaspoor, is the most typical of this kind. The old lacustrine, or at least alluvial, area about Belaspoor itself and that about Haut, north of Subathoo, are of like character.

Although not attaching the same importance as has been given by several Alpine geologists to the subtropical character of the fauna and flora of the Molasse, as deciding the low elevation of the Alps in that period, compared with their present state, I may point out that the series of changes I am supposing would embrace such a position. Even the known distribution of land and sea in the Molasse period would go far to account for the required difference of climate. It is evident, however, that, at the commencement of the continental elevation which has been supposed to have interrupted the accumulation of the Molasse, the central mountains may have been lower than now. The word *continental* as applied to elevation implies only slow movement, a large area affected, and perhaps no *abrupt* linear limitation to that area, such as would be the "bossellement" in M. de Beaumont's theory. The last condition implies a very decided line of maximum elevation, which is all we require for the point under discussion.

If the view I have attempted to illustrate should not prove in any sufficient manner explanatory, even of the Subhimalayan sections, it will not have been useless to discuss a supposition that is fairly plausible, and which therefore should not have been so ignored as it has been, to the best of my knowledge, in discussions of Alpine sections and of mountain-formation in general.