# The Role of Erosion in Mountain Building

by **J. V. Harrison.**

1. The impression left in one's mind after reading many accounts of orogenesis is that lateral compression alone need be invoked to explain mountain building and orogenic structures. It is at once admitted that it is and must be the principal agent concerned; but other factors enter into play which produce effects sometimes of very great importance. For instance, it is commonplace knowledge that after folding, the processes of destruction are usually revivified and masses of formations are swept away by erosion. Situations are thereby developed which may later essentially modify the structures, and will do so if, at a later date, further compression takes place. This will produce a more irregular set of wrinkles superimposed on or breaking down the pre-existing weathered-out folds than a single shortening of the crust can set up in previously unfolded layers of strata. Many mountain ranges known at present have been built up by two or more movements widely spaced in time and in the intervening periods extensive erosion is known to have taken place. This is a stage in the story which, although it may not have been lost sight of by many authors, is one which has not been always sufficiently emphasised, nor its importance appreciated in the course of analysis of orogenic processes. Several years spent in field work and geological mapping amidst the well exposed barren sub-tropical Zagros mountains have led the writer to conclude that many complex structures occuring in that region are the result of a second or third application of lateral compression acting upon a strongly eroded old land surface directly dependant for its topography upon the first compression. It is perhaps not unreasonable to assume, that if this interpretation is justifiable here, similar results are likely to have resulted from similar causes in other parts of the world which are now

more difficult to comprehend because exposures are imperfect and a clear comprehensive view more difficult to obtain.

2. The obvious effect of erosion is the sculpturing of the earth's surface. The result is greatly influenced by the rock structures lying below. In the earlier stages of the cycle they are etched out as the skeleton of a dead animal is revealed through the removal of its skin and flesh. In a large part of south western Iran this juvenile stage is now well expressed in the landscape, for the rock folds directly control the broad lines of the hills and valleys. An almost diagrammatic reflection of the structure can be seen in the topography by walking through the land and climbing some of its peaks. The anticlines form the ranges, and the synclines the smooth sweeping valleys between them. There are of course some examples of residual synclinal ridges occasionally remaining as perched canoe-shaped hills in place of the open unlittered synclinal valley. The prospect is precisely what one would expect as the outcome of a single compression acting upon a pliable medium retaining approximately uniform mechanical characters over a considerable area. Because this area is part of a spherical and not a plane surface, the waves produced are not indefinitely prolonged along the trend at right angles to the direction of the pressure but terminate individually so that they stand as strongly elongated domes en échelon. If it be borne in mind that this stage occurred it will be easier to picture what may happen when once again compression occurs. Certain features seen in more complicated chains in which even nappes are present passed through this stage which provided an irregular sheet, both form and strength being variable from point to point ready to respond unevenly to the new strain.

3. In the garland of ranges comprising the Zagros Arc as a whole, much more complicated topography and structures than those referred to above occur locally, mainly to the north-east of the system. Three groups of mountains have been distinguished; those which have suffered only one principal folding in the Pliocene; those which have been effected by two major compressions one in the Upper Cretaceous and one in the Pliocene; and those which in addition underwent strong corrugation in

the late Triassic or early Jurassic. The last chain is rather poorly preserved and its relics are somewhat fragmentary although in places its topographical effect is bold. It has not been extensively surveyed and for the present purpose its forms and structures need not be considered further. The intermediate twice shortened system is upstanding over a long distance along the strike building chains of scenic mountains whose diverse land-forms reflect their varying constitution. The first and youngest group is most extensive and best preserved, besides which it has been well reconnoitered and mapped. Its history is now known in some detail and it has emerged that minor warping affected the area in Upper Cretaceous, Oligocene, and Miocene times before the potent Pliocene orogenesis took place. These earlier warpings account for certain departures from complete regularity but do not seriously modify the story, on account of the pre-eminence of the Pliocene diastrophism. There has also been post-Pliocene activity but it was small in comparison with the Pliocene movements. Each minor disturbance was strongest in the north-east and was followed by some erosion in that direction, which gave rise to rather variable shallow water deposits passing south-westwards into reef limestones and these in turn into marls and silts.

4. This youngest component of the Zagros builds up the south-western strip about 60 to 80 miles wide. It is hilly south-westwards and mountainous north-eastwards. In general the structures in the former part are almost symmetrical elongated domes, and in the latter part are both asymmetrical and occasionally thrust-faulted elongated structures. On the extreme south-west the crest of the domes considered in respect to the Miocene Limestone stand only at about sea level with troughs depressed far below that datum line. They are covered by younger formations but the next belt north-eastwards is one in which the Miocene Limestone exerts a controlling influence upon the topography. The troughs are sometimes empty and sometimes partially filled by the younger beds. The summits of the anticlines range from about 2000 feet to as much as 8000 feet above sea level. In the next strip the Miocene Limestone no longer builds the mountain tops but is present as a girdle forming subsidiary features around the domes which through erosion

now expose Eocene or Cretaceous Limestones in their upper part. At an earlier stage however the Miocene Limestone formed a complete cover to the domes which then must have reached altitudes approaching 18000 feet because the present crests with the Lower Cretaceous Limestone in control now rise to 13000 feet and between it and the Miocene some 5000 feet of strata are interposed. From the first Miocene range to the highest north-easterly chains there is a gradual increase in stature of the whale-back mountains but abnormal monster folds rise sporadically above their graded fellows in the heart of the country. They are exceptions to the normal suite which has long been described by travellers journeying inland from the Persian Gulf as the "Iranian Staircae".

5. The next division bordering the array of smooth and generally symmetrical mountains on the north-eastern side is composed of a few ranges of saw-toothed peaks with gentle north-eastern slopes and precipitous south-western faces overlooking deep strike valleys. Traced to their plunging ends the sierras terminate in smooth noses where the beds are found to swing round without a break. These originally simple structures have snapped in the more central part but not at their ends. In parts of the valleys in front of them thick conglomerates have been deposited after considerable erosion had first occurred and the north-eastern edge of these gravels are steeply folded whereas the bulk of the formation lies flat. This evidence suggests that the faulting has been augmented in the latest movements after the main compression was over. These sierras are fine mountains with peaks reaching about 15000 feet above sea level with a present day relief of the order of 8000 feet. As a generalisation it may be taken that the vertical amplitude of the folds comprising the mountains from the coastal plain to the sierras, measured with respect to any one bed is usually between 8000 and 12000 feet, but exceptionally a billow may have reached a height of 18000 feet above its trough.

6. The development of the present landscape seems to have been in progress since the Lower Miocene warping. This was accompanied at first by the deposition of a series of chemical and detrital deposits and later by the laying down

of wholly detrital coarser sediments which had a tendency to overlap earlier members of the suite. This ended with the emergence of a plain tilted gently south-westwards and diversified by the occurrence of a few minor swellings which marked the site of future ranges. The watershed probably lay about 120 miles from the coastal and Tigris plain and was determined in certain districts by the mountains of the Upper Cretaceous ranges. These were the limit to which rivers draining south-westwards attained at their inception, when they built up a normal pattern of tributaries between the sea and the divide, apart from those consequent upon the infrequent irregular swellings rising from the plain. These hills at the same time deflected the principal rivers to their extremities. With the main compression tilting of the plane rapidly ensued, but the streams were able to keep to their courses and cut through the obstacles which protruded as the orogenesis continued and the original plain was destroyed. In the terms of the present sea level the water shed rose to a height of more than 15000 feet whilst the drainage, true to its primary alignment sank vertically. Structures not represented at all on the original surface of emergence but rising to more than 10.000 feet above sea level at the present day were cut across at the point of their greatest elevation when they must have been covered by at least 5000 feet of strata since removed. Others are found with a gorge incised on their shoulder, making it clear that the slopes from this to the structural saddle now exposed had no expression upon the surface when the drainage was initiated. With the concomitant removal of the less resistant detrital formation in the synclines all trace of this early surface which is so easily inferred from the entrenched drainage was removed. The scouring of the troughs led to the growth of secondary tributary systems formed from the run off shed by the newly exposed structure controlled surfaces. Further erosion brought about the unveiling of the inner structure of the whale-back mountains, stripping them stage by stage until the succession of more resistant limestones and the less robust marlstones stood revealed. There are limestones of Lower Miocene, Oligocene, Eocene, Maastrichtian, Middle Cretaceous (Cenomanian) and Lower Cretaceous ages, all of which are not all developed in any one section but occasionally take control of the shapes of the existing mountains and often weather out as ridges above the intercalated marlstone groups which occur in the Eocene, Upper Cretaceous and Aptian.

7. An immense volume and weight of material has been removed in a short time from this mountain system. A little of it has been redeposited during the cycle forming gravel fans where over-loaded streams debouched occasionally within the mountains, or more often near the south-western marginal hills, but the bulk of it has been carried off to the sea and forms part of the great sheet of alluvium through which the Tigris, Euphrates, Kerkha and Karun Rivers meander to spill themselves in the waters of the Persian Gulf. It is probably not an over estimate to place the amount of the strata removed along the length of the south-western unit of the Zagros Mountains as some 5000 feet thick across a belt 50 miles wide. As in the Himalaya the rivers now usually rise on the slopes of a water shed in an area of extensive fluvatile plains at a considerably lower altitude than the ranges they cut through to reach the sea, so that besides the uplift due to compression there is a strong probability that isostatic adjustment during and after the removal of this load has also entailed strong uplift. The case has recently been argued by L. R. Wager for the Himalaya (Geogr. Journ., Vol. LXXXIX, pp. 239—249, 1937).

8. Such has been the evolution from the Miocene to the present day, of the part of the Zagros Group in which the simple ranges abound. The mountain forms express the geological structures displayed in the robuster formations in the stratigraphical column. The whole zone is now deeply dissected and the synclines swept clear of detritus. The main drainage is superimposed and its secondary features alone depend directly upon the structure, for instance the high broken folds have usually a stream course developed along or near the trace of their fault plane. Maximum relief reaches the order of 10.000 feet.

9. Amongst this welter of mountains dependant primarily upon structures due to simple compression rare secondary structures produced by the action of gravity are to be found. The massive limestone bodies, especially that of the Lower

Miocene whose dip slopes build up so much of the landscape, have proved mechanically unequal to the strain imposed upon them of bearing up their own weight after the differential stripping they have undergone and have collapsed. This collapse has not been a sudden affair but a subsidence taking place slowly, in many cases by flexure without disruption of the beds. The simplest effect occurs upon the lower part of a long dip slope. The strata moving down dip under the influence of the weight above have wrinkled into a cascade. Such an effect is produced at the foot when a sheet of velvet slips down a chair back. The upper part remains smooth, the basal part is corrugated into a group of wrinkles. High simple domes have presented a situation in which the strain in the superficial formation has found relief by movement. The upper part has slipped down the under-lying sheets and driven the flank outwards so that instead of the original flowing curved section a cusp is developed and the section is an angular one simulating in shape the roof and wall of a house. This 'knee" effect is often seen and is the most abundant structure resulting from such gravity collapse. Q. J. G. S., Vol. XCII pp. 91—102, 1936, Ref. Geol. Mag., (XX), pp. 529, 1934. By far the most sensational form however is the "flap" in which a formation of limestone 1000 feet thick has turned right over upon itself for some distance along the strike. Its form is that of the hood of a cloak which in its ideal condition will cover the head of the wearer and present a view of the outside of the cloth alone; but when not in use and has collapsed it hangs back on the shoulders displaying the lining, the lower side of the sheet, whilst the outside of the hood is in contact with the outside of the cloak. A flap in the Miocene Limestone has been surveyed which is 7 miles long and 2½ miles wide. Such effects, and admittedly they are rare phenomena, are only small affairs when compared to the features due to compression, for single domes reach a length of 40 miles in the Zagros, but they do appear with surprising frequency amongst simply folded naked limestone hills of ample vertical relief. The important point at the moment is that they provide evidence of bending without breaking in so-called competent formations at the earth's surface and at ordinary temperatures. It comes as a surprise also that apparently massive limestone enjoys such remarkable flexibility, for this group of limestones 1000 feet thick is bent back through 180° and the diameter of the circle, of which the hinge is part, amounts to only 3000 feet. The structure which must result when a syncline containing a flap is shut up under subsequent pressure would be so strange that it would lead to the drawing of more fantastic diagrams than usual to account for the partially exposed facts which supply the all too meagre basis of many attempts at synthesis.

10. It has already been mentioned that minor movements succeeded the main folding. In one case near Chulbar (lat. 32° 20'; long. 49° 25') the plunging ends of two domes covered by Miocene Limestone oppose each other and between them lies a saddle. These were swept clear of the detrital deposits as was the syncline between them and the larger anticline on the north-east. After this evacuation the renewal of pressure caused a shortening which has closed the synclines and caused the north-eastern fold to break on its south-western side where it has moved forward somewhat over the saddle, so that a part of it now lies recumbent upon the nose of the fold in front. In this case the topography has been the controlling factor in the structure produced by the final compression, and so a freak structure, a partial recumbent fold, engendered by compression plus erosion exists within the simple mountains.

11. The country west of the Indus on the borders of India and Baluchistan is in almost the same condition as the Zagros Mountains at the present time. As climatical conditions are similar exposures are good. Parts of the Taurus recall fragments of the Iranian ranges. The Jura Mountains in France and Switzerland supply the classical example of such a stage in mountain building, although exposures are poor in the Jura compared with the state of affairs amongst their Asiatic brethren. It seems probable from a study of the diagrams and plates illustrating the work of Heim and Buxtorf that there may be secondary gravity effects superimposed upon the simple structures just as there are in the Zagros. Early structural sketches given by observers, as yet uninfluenced by the conventions which now distort so many sections from Alpine regions, Ref. W. G. Collingwood The Limestone Alps of Savoy, 1884 bear out this

statement. On the other hand the exposures are so imperfect and the general view so often obscured by forests that the secondary effects are much more difficult to recognise. Behind the Huasteca in eastern Mexico and also in parts of Tabasco and Chiapas up to the frontier of Guatemala the landforms suggest that the ranges belong to a system of this same type of folding. Again between Cúcuta and Bogatá in Colombia and in the High Andes of Peru in the Aroya neighbourhood, the landscape, although more complicated on account of igneous manifestations, reveals forms closely dependent upon structures of rather simple type.

12. At the present time in several parts of the world beds which have been thrown into folds by one principal compression acting upon a packet of strata have been eroded in such a way that one or more competent formations have been weathered out until land forms and geological structures are closely related. This regular folding is probably the result of "unsticking" at some horizon where a lubricant is present. The Trias in the Jura is the best known example, while in the Zagros Garland Messrs. N. L. Falcon and K. W. Gray first attributed to the Cambrian salt a similar rôle. However they may have arisen a series of great rock billows now stand on the surface of the earth and will suffer abuse if any further crustal shortening should obtain. In this event two possibilities seem to be offered. Firstly the shortening may effect the surface only in a superficial way so that the ranges in being are pressed together, and the whole crust moves independently of the basement over a lubricant. Secondly the shortening may act upon a thicker body and splintering of the basement take place to allow for the shortening. Adhering to these blocks fragments of the earlier folds may be preserved intact. In the first place the pattern produced will allow of analysis which should reveal some features of the earlier topography, and the crumpling occur without any induced vulcanicity. It is true the relics may have become very distorted, but in most cases complete obliteration of the half-way stage will not have occurred. In the second case isolated parts of the superficial ornamentation may have been carried unharmed upon a block of basement and yet lie in contact with a part from which it has been completely removed.

It is in this case that intrusion tectonics will be noticeable and that alternations of rocks exhibiting strongly different grades of metamorphism may be found, together with contemporaneous igneous rocks.

13. The Upper Cretaceous was a period of restlessness in the Zagros Mountains. Until the Cenomanian the calcareous deposits in the south-western part of the geosyncline, a part of Tethys, followed one another without much variety in composition. In the north-east things were less constant and arenaceous formations occurred between the calcareous ones which alone are developed south-westwards. In the Senonian movements became vigorous, and in places a sheet of material was driven from a basin to the north-east across scarcely folded country south-westwards. Later as the compression continued it found expression by setting up a series of folds of similar nature to those due to the Pliocene disturbance which have just been described. They were produced and reached an amplitude of more than 7000 feet in a short interval of time, because by the Maastrichtian they were already suffering vigorous erosion, and the contents of the synclines, in general less resistant material than the limestone of the anticlines, was being carried south-westward into the sea. It built up a great off-shore deposit of coarse detritus with which sporadic limestone reefs are interbedded. Some twenty miles from the coast these were more numerous and formed a fringing reef. Beyond it the sands and grits were not carried so that seawards only oozes and fine silts were laid down. The cover of the folded country and the filling of the synclines was Upper Cretaceous marl below and thin-bedded red and grey chert above associated with variable amounts of igneous rock, chiefly basic pillow lavas. The preponderance of chert in the conglomerates, almost to the exclusion of the other rocks, is due to its hardness and resistance in boulders whereas the marl is easily broken up in contact with such harsh bed fellows and the basic igneous rocks readily weather chemically, besides being easily ground down by the ball-mill action of the moving chert lumps. Igneous pebbles are extremely rare and marl pebbles unknown. The chert occurs as coarse conglomerate near the old shore-line with boulders up to 3 feet in diameter and these diminish in size outwards. The grits attain a thickness

of 9000 feet and possibly more in the fore-deep on the south-western side of the range. The thickness tails off rapidly as the distance from the old coastline increases.

14. That a large body of material had been removed from the recently erected mountains in late Upper Cretaceous time is clear. The controlling limestone had hardly been attacked by erosion, however, as the deposits of this incident are singularly free from limestone pebbles. It is inferred therefore that a topography like that now prevailing in the south-western Zagros had developed. The Middle Cretaceous Limestone instead of Miocene Limestone was in control of the scenery which closely reflected the structure. The synclines had been emptied of all but a meagre relic of their filling for an Eocene chert conglomerate and nummulitic calcareous grit lies, sometimes with strong angular unconformity, on the limestone in some of the synclinal zones, sometimes upon shreds of the bedded chert and igneous rock which still remain locally upon the Middle Cretaceous Limestone. A considerable thickness of Miocene silt sand and marl also collected later. There are other synclines which seem to have escaped flooding. In the north-east the erosion of the chert and igneous rocks had not been extensive because immediately upon the back of the limestone ranges at one place the chert and its associates reach a considerable altitude and both have been covered transgressively by the Eocene beds which at the base are coarsely conglomeratic. The evidence points to a group of ranges in which the synclines in the main had been swept all but clear at one stage. Then some of them were partly filled by Kainozoic sediments. In some, however, no sign of later beds having been deposited is to be seen although it is possible that they once were laid down only to be removed before the Pliocene compression had achieved conspicuous results.

15. The course of these Upper Cretaceous mountains cannot be easily mistaken. The comparatively orderly and tidy landscape of even folds or regular saw-teeth ridges is not found here. The ranges are razor-edges or else mis-shapen with strange exotic peaks and are irregularly littered with blocks. Persistent dip slopes are sought in vain, indeed, only sporadically can any dip be detected at all. Everywhere the Middle Cretaceous

Limestone has been crushed, the development of a mesh of irregular joints throughout, together with local abundance of calcite veins being unimpeachable evidence. The structures found in this Crush Zone are all rather complicated. In Chaharmahal (Lat. $32^0$ N; Long. $51^0$ E.) the crushed and veined limestone is thrust over coarse conglomerates which rest upon Miocene marls and limestones. It ties down the later movements as being post Miocene in age. The range east of Simarun (Lat. $31^0 50'$; Long. $51^0 20'$) tells the same story. Fragments of bedded chert and shreds of igneous rock are nipped between the limestone and the conglomerate in this district and indicate part of a synclinal filling trapped as the dome north east of it was driven forward. North-eastwards, or behind the thrust plane sharp ridges of limestone project above the average level with shattered zones between them to mark the course of former synclines. In places where such strong thrust faulting does not occur a suite of razor-back structures arranged en échelon is sometimes found. The individual hills are nearly elliptical in plan although their noses seem to be pinched. Dips cannot usually be distinguished everywhere in these ill-treated domes which are the simplest structures produced by the two compressions. They are recognisably simple smooth domes pinched up, the axes moved together and the synclines ruined beyond belief. In these features it is notable that the greatest approach to regularity in the dip is provided by the shoulders. The lower slopes have suffered most distressfully in the second disturbance. A further stage is portrayed in ranges north and north-east of Kermanshah (Lat. $34^0 20'$; Long. $47^0$) where the earlier anticlines are so strongly crushed together that the synclines appear only as notches traversing the irregularly shaped mountains, or as thin bands of chert nipped between limestone massifs. They would defy interpretation but for the gradation from the simple cases described above.

16. In some regions Kainozoic beds are fairly thick and preserved in the bottom of certain of the troughs. Near Harsin (Lat. $34^0 20'$; Long. $47^0 35'$) one range of Cretaceous Limestone has dips of $70^0 — 80^0$ on its flanks, whilst the Eocene in contact with it dips at $25^0$. This provides a measure of the later folding in this neighbourhood where the syncline has

been closed sufficiently to tilt the later deposits to 25°. The nose in the same structure as presented by the Middle Cretaceous Limestone exhibits distortion and crushing to the complete annihilation of dips. The synclinal filling tends to keep the dips in the Cretaceous within a simpler pattern. A series of folds in which the synclines are relatively simple occur to the west of Burujird (Lat. 33° 55'; Long. 48° 50'). The synclines contain, upon the Middle Cretaceous Limestone, fragments of bedded chert and pillow lava covered by Eocene conglomerates and nummulitic grits with Miocene marls and grits above them. In all, approximately 6000 feet of beds are preserved and are moderately folded. The limestone rises as much as 4000 feet above the now planed off Kainozoic beds. Where streams have exposed the limestone deeply it is seen to be relatively well behaved, but in the higher parts of the mountains it is much more troubled. Thrust faults have developed which have enabled the protruding limestone to move across the edge of the syncline on both sides, so that the filling of the trough has acted as a massif, and the thrust faults hade away from its margin on both sides. In the next syncline to the north the filling is scantier and the northerly fold has been pressed against the flanks of the southerly one, thereby shutting up the syncline in which both chert and Kainozoic beds testify to the earlier state of affairs when the syncline was open and only partially filled. The strong jointing in the Cretaceous limestones of these ranges has already been noted and it occurs here in contact with normally jointed Kainozoic beds — as if beds of different metamorphic states were in contact. It may be noted that in the Pliocene ranges the order of jointing is the same in the Miocene as in the lower systems down to the Permian.

17. Before leaving the consideration of this crush zone, the effect near Burujird (Lat. 33° 55'; Long. 48° 50') of a fold bringing up Cambrian, Permian, Trias and Jura must be recorded. This structure was a more substantial feature than its neighbours. Its flanks are strongly crushed and faulted, but its core seems to have been sufficiently robust to transmit the pressure without having been crushed itself. The Cretaceous on its northern side is crushed to a breccia in places whilst on the southern side it is strongly imbricated. Evidently, if

the mechanical strength of a projecting structure is sufficiently great it can withstand the destruction falling upon weaker units, but in such a case its outer layers suffer intensely from the strain.

18. In the Pliocene ranges the development of the saw-tooth chains to the north-east has been recorded. In the Cretaceous Mountains it appears as if similar structures were occasionally developed. For instance in Dul Gharib (Lat. 31° 55'; Long. 51° 25') a series of sheets of Cretaceous limestone in better preservation north-eastwards have been found piled up with very crushed Cretaceous limestones associated with reef Eocene and Miocene limestones and post-Miocene conglomerates south-westwards. The crushed south western part was a series of anticlines of Cretaceous limestone with partially filled synclines before the Pliocene compression, whilst the north-eastern part which has suffered little internal distortion was a dip slope and scarp feature. The imbrication seems to have been controlled by the former topography. The saw-tooth shaped mountain moved forward easily; whilst the whale-backed ranges moved with difficulty and were crowded together and crushed.

19. The only igneous rocks which have suffered deformation during the sequence of events are pillow lavas and basic igneous rocks which were present before the main force of the earlier movement was felt. Along the total length of these mountains no flows or intrusions have been found which took up their position between the Upper Cretaceous and the Pliocene. Nor have there been any post-Pliocene igneous activities within the belt. It is considered probable, therefore, that all the shortening visible at the surface, and it is considerable, has been accommodated by slipping over some layer of lubricant which for much of the Zagros Garland is afforded by the saliferous Lower Cambrian. Igneous activity in the Upper Cretaceous and Eocene, which was doubtless connected with this history, is abundant some miles further north-east where tuffs and lavas are cut by dykes, sills and bosses, all the rocks being relatively acid. In the same region post-Pliocene vulcanicity has given rise to a series of young cones and sheets of scoraceous basic lava which have only been warped and not at all affected by compression.

20. In other parts of the world whenever a thick detrital deposit lies within an intermontane valley and is strongly folded it at once raises a suspicion that the chain in which it occurs may have had a complex history. Where an unconformity occurs between such a body and its neighbours there is evidence of two movements having taken place, and of the pre-detritus land forms having suffered deformation in the diastrophism which folded the detrital deposits. Thus it is that the district of Chur on the Rhine Valley comes to mind where abundance of flysch is preserved, most of it involved in folding of a complicated type and intricately associated with older rocks. The task of interpreting the history is rendered enormously difficult here on account of the indifferent exposures, the surface slipping, and the physical difficulty provided by the steep slopes to the pursuance of geological research, but simplification would probably follow a clearer picture of the pre-flysch topography and the structures controlling it. This stage is better understood in the zone of the Helvetic calcareous nappes, but even there it is doubtful whether enough has been made of the weathering and sweeping out of valleys before the later closing up set up the system of bewildering recumbent and thrust-faulted folds now displayed. Certain of the structures around Zermatt which seem quite inexplicable at the present time call for re-study with the object of determining whether surface configuration at an earlier period cannot be invoked to simplify the history of their formation.

21. The evidence from the northern parts of Venezuela and Trinidad is only partially collected, but a thick series of post Cretaceous sediments exist there on the southern side of limestones, which are in part Cretaceous. These limestones are folded in a complex fashion and in comparison with their superior mechanical strength they have gone to much greater extremes of crumpling than have many areas covered by the weak later sediments. Unconformity exists in places and the build of this region suggests folding of the Cretaceous, strong erosion and deposition in the fore deep of such deposits, as the flysch at San Juan de los Morros for example, followed by a second compression when the first group of folds was broken up and tortured to produce such fine schuppen structures as are weathered out in spikes and cockscombs after which the

neighbourhood is named. The first movement was pre-Upper Eocene and the second late Miocene or Pliocene. The schuppen represent fragments of the earlier anticlines.

22. Hitherto consideration has been given to the simpler case in which a strong robust group of beds has been etched out to control the topography and in which the anticlinal structures are upstanding. Where the beds are loose and friable first effect of erosion is to bring out the basins as mountains and reduce the anticlines to lowlands. Baluchistan is such a country in part and there strong compression affected the beds after the Oligocene and again in the Pliocene. The post Oligocene synclines were upstanding in the Pliocene and whilst they display strong folding and local distortions their behaviour is simple compared to the anticlinal parts. This seems to be due to the comparative immunity these upraised zones enjoyed during the rigours of the Pliocene shortening.

23. The object of this paper has been to bring forward a plea for the recognition of erosion as a factor in the building of mountain structures. A surface with rock billows and troughs sculptured upon it is bound to fold up unevenly under the influence of a strong uniform stress. The subject has been dealt with by others before and much has been made of wrinkles as a result of folding under little load. In the present case more has been said about the closing up of synclines as the common source of major complication, and it has been described how quite smooth anomalous flexures can result at the surface in beds which would normally be described as competent. The discussion has been built up on observations in the Zagros Mountains where three movements have occurred but have left strips of magnificently exposed mountains, the result of three, two and one compressions respectively. After a full description of the simple forms in the once-folded belt the forms found in the twice-folded belt have been analysed and in the simpler cases it has been easy to recognise relics of the once-folded ranges distorted by the second folding. Pains have been taken to stress the capacity which an empty syncline has for leading to structural complications under later pressure, and the suggestion is made that an appreciation of their earlier distribution may help to simplify the history of the building of complicated mountain zones in other parts of the world.

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