

*Notes on the Geological Structure of the Chitichun region, by  
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of Vienna.*

Mr. Griesbach<sup>1</sup> has shown that the structure of the Chitichun area corresponds, roughly speaking, to a complicated synclinal, formed by Spiti shales and Gieumal sandstones and bordered on three sides by triassic folds, "namely, the range which runs from the Lahur to Chidamu on the west, the high peaks and ranges which form the Chitichun No. II (19,550 feet) and Dharma peaks on the south, and the long ridges, with fine precipitous cliffs, which extend from the Chanambaniali peaks (18,360 feet) to northwards, and shut off the Chitichun ground from the widely extended hilly area, chiefly formed by mesozoic rocks, which are seen to stretch to north-east and north towards the Sutlej river."

Although the bedding of the mesozoic strata comprising the Chitichun area is considerably disturbed and much crushing, especially in the Spiti shales, may be observed locally, they all form an apparently normal sequence, without any distinct unconformity or break between them.

*Jurassic beds.*—Between the mighty system of upper triassic limestones and dolomites (Griesbach's rhætic system), which are the Himálayan representatives of the Alpine "Dachsteinkalk" (in the sense

<sup>1</sup> Records, XXVI. pp. 19—25.

of the Austrian geologists) and the jurassic Spiti shales, the dark brown or Indian-red pisolites of the Kelloway are exposed in most of the sections which we were able to examine during our visit to this part of the Himálayas. The best exposures of these pisolites have been met with on the western slope of Chanambaniali. For these beds the name "Sulcacutus beds" has been recently proposed on account of their leading fossil, *Belemnites sulcacutus*, Suess, of the *bisulcati* group. They were regarded as lias by Griesbach in his preliminary notes, but the fossils, which have meanwhile been examined by Dr. F. Suess, are all dogger forms. According to Dr. Suess, the Sulcacutus beds are most probably representative of the European Kelloway. Of the Spiti shales and Gieumal sandstones Griesbach has given an excellent description, to which I have but little to add. The three divisions, which, according to Griesbach, can be distinguished among the Spiti shales, are not equally well represented in the Chitichun area. The upper horizon, for which the name Lochambel beds has been introduced, is most typically developed. It is near Lochambelkichak encamping ground (south-east of Chitichun No. 1) that the beds of this horizon are richest in fossils of the youngest jurassic type (stage of Berrias).

*Gieumal sandstones. Flysch.*—The overlying Gieumal sandstones are connected with the Spiti shales by a gradual passage. In the vicinity of the Kungribingri Pass (18,300 feet) their lowest beds actually alternate with Spiti shales, from which it results that the main bulk of the Gieumal sandstones must be cretaceous, although Stoliczka considered them to be of upper jurassic age. Lithologically this mighty formation represents a typical Flysch development, strongly recalling in its chief characters the Alpine or Carpathian flysch. A few traces which might be crushed belemnites, are the only organic remains which have been hitherto found in this system along the Kumaon-Tibet frontier.

*Diabase porphyrite.*—Both the Spiti shales and the Gieumal sandstones are intimately associated with intrusive igneous rocks in

the Chitichun area. Herr C. von John, Director of the chemical department of the K. K. Geologische Reichs-Anstalt in Vienna, who kindly examined the rock-specimens, which I collected near Sangcha Talla encamping ground, declares this igneous rock to be a diabase-porphyrite.

*"Klippen" or Crags.*—The younger mesozoic beds, which form the complicated synclinal of the Chitichun area, are capped here and there by massive limestones, which either seem to rest conformably on, or are imbedded in, the soft jurassic shales in the shape of detached blocks. Some of these masses of bright or reddish, often semi-crystalline limestone, are eroded into picturesque cliffs, or crags rising in sharp pinnacles and partly bordered by precipitous walls. By their material and outlines they differ remarkably from the dark, rather monotonous, undulating hills, composed of shales and sandstones, and thus form a very peculiar feature in the scenery of the country. These limestones do not rest normally on the mesozoic strata, but are partly of palæozoic, partly of triassic age, as has been proved by a careful examination of their fossil contents. It is their occurrence amidst much younger sediments and without apparent stratigraphical connection with the latter which makes the structure of the Chitichun area one of the most intricate and most remarkable in the Central Himálayas.

Mr. Griesbach in his preliminary note on this subject has called attention to the similarity of these limestone crags with like outcrops of older sediments (namely, of triassic and jurassic age) in the Alpine and Carpathian flysch, which have been described as *Klippen* in scientific literature. The correctness of this view has been doubted<sup>1</sup> but the doubts can no longer be maintained since the publication of the palæontological evidence.

The most northern of these peculiar limestone crags, which were examined by our expedition in 1892, are those situated between the Balchdhura and the Kiogarh-Chaldu pass (17,440 feet). Here the dividing ridge is composed of Gieumal sandstones and crowned by

<sup>1</sup> See foot note in Records, XXVI, p. 25.

a steep escarpment of limestones, which seem to overlie conformably the sandstones at their base. In 1879 Griesbach visited the Balchdhura and believed the limestone to be of upper-cretaceous age<sup>1</sup>, corresponding to Stoliczka's Chikim limestone, which in Spiti follows immediately above the Gieumal sandstone.<sup>2</sup>

We shared in this view, when passing along the southern slope of the range towards the head-waters of the Kiogadh river on the 12th and 13th of July, being likewise under the impression of an apparently normal position of the limestone cap above the underlying flysch. It was only after our discovery of the permo-carboniferous and triassic limestone crags near Chitichun encamping ground, that we began to doubt the correctness of our former opinion. We therefore resolved to revisit the Balchdhura on our trip from Laptal encamping ground to the Shalshal cliff, and succeeded in examining the most western of the limestone peaks which form the high range of mountains, extending northwards and eastwards into Tibetan ground, and culminating in the big rocky mass of Ghatamemin (18,700 feet).

This limestone peak overlooks the Balchdhura (17,590 feet) and is accessible from Sangcha Talla by a deep ravine, leading in an eastern direction. Its base is made up of Gieumal sandstones which show a very complicated dip and are penetrated by numerous veins of igneous rocks. In the upper portion of the mountain these igneous rocks and the tufa associated with them predominate. The limestone crag itself rests entirely on beds of a clearly igneous character, without coming into contact with the sandstone formation.

The highest crag forms a steep scarp and is likewise traversed by veins of a diabase-porphyrityte. The limestone is of a white to reddish-white or red colour, without any distinct stratification, semi-crystalline and partially altered, especially so where surrounded by intrusions of igneous rocks.

<sup>1</sup> Geology of the Central Himalayas, Mem. XXIII, p. 179, 1891.

<sup>2</sup> Mem. Geol. Surv. of India, VI, p. 113.

*Fossils.*—No fossils were found *in situ* in the limestone of the crag, but Griesbach was fortunate enough to find a loose block, full of sections of ammonites and bivalves, near the end of the ravine which descends towards Sangcha Talla encamping ground. It is a red marble, apparently detached from the main mass of the crag, and exactly like some of the famous red Hallstatt marbles from the Salzkammergut in Upper Austria and Styria. The block has yielded a few specimens of ammonites, belonging to the family of *Tropitidæ*. Dr. E. von Mojsisovics, who examined them, believes them to belong to the genus *Fovites* of middle or upper carnian age (Aonoides beds or Subbullatus beds). In the main region of the triassic belt of the Central Himálayas neither of these two horizons is developed in a similar (Hallstatt) development, although the Aonoides beds were met with in the Shalshal cliff section near Rimkin Paiar encamping ground and the Subbullatus beds were found by Mr. Griesbach in the Teragadh near Kalapani (Byans).<sup>1</sup>

From the presence of the genus *Fovites* in the limestone crag to the east of Sangcha Talla encamping ground it results, that the great mass of limestones between the Balchdhura and the Kiogarah-Chaldu pass cannot rest in normal position on the Gieumal sandstones as appears to superficial observation. This is an indisputable fact, but it remains, of course, very doubtful whether the entire mass of limestones is of upper triassic age, or is composed of sediments belonging to very different geological periods, like in the range of Chitichun No. I. Considering the considerable thickness of the limestone cap, I am rather inclined to decide in favour of the latter assumption. As we could not prolong our stay at Sangcha Talla, and had to abandon altogether the survey of the remaining part of these mountains, we must be content with the evidence that part of the limestones at least is of an upper triassic age, and stands in a similar structural relation to the Gieumal sandstones

<sup>1</sup> E. von Mojsisovics, Vorläufige Bemerkungen über die Cephalopoden Faunen der Himalaya Trias, Sitzungsb. K. Akad. Wiss. Wieu. Math Nat. Cl. CL., I. Abth., Mai 1892.

forming their base, as the limestone crags of Chitichun No. I, and near Lochambel-ki-chak encamping ground to the adjoining Spiti shales.

How far this mighty mass of limestone crags may extend to the north into Tibetan territory, we do not know. The other limestone crags of the Chitichun area are all of a considerably smaller size and in their strike exhibit a nearly semicircular arrangement. So far as we could get an idea of the grouping of these crags from our reconnaissance, they are arranged in three distinct rows or zones.

The first and most northern of these rows we only reconnoitred on our route from the Kiogarh-Chaldu pass (17,440 feet) to Lal Pahar encamping ground (on the western slope of Chitichun No. I). To this row of crags belong the top of Chaldu No. I (17,470 feet), and two lower cliffs of limestone, which face its eastern scarp. Mr. Middlemiss, who visited the Chaldu peak from Lochambel-ki-chak encamping ground, describes it as an isolated mass of a white semi-crystalline limestone with a north-eastern strike, apparently resting on Gieumal sandstones and on the igneous rocks associated with the latter. Lithologically it is perfectly like the limestone of Chitichun No. I, but has yielded no organic remains of permocarboniferous age.

The second or central row of crags is of much greater extent and contains by far the largest number of isolated blocks. It stretches from the prominent peak of Kungribingri (19,170 feet) towards the watershed of the Chaldu and Chitichun rivers. The first crag belonging to this central zone or row is situated to the south of the Kiogarh-Chitichun pass (17,960 feet). Although it was not visited, its outlines can be very distinctly traced from the top of Kingribingri, the bright coloured limestones standing out against the dark shales and sandstones as clearly as the Carpathian "Klippen" of jurassic limestones do against their mantle of eocene or cretaceous flysch. The very top of Kungribingri (19,170 feet) itself consists of a small block of white limestone, resting on greenish Gieumal sandstones, but as it has not yielded any fossils, I cannot say whether

it is in normal position, corresponding to Stoliczka's Chikkim limestone or not.

Another limestone crag was discovered in the immediate vicinity of Chitichun encamping ground, in the ravine descending from the Kiogarh Chitichun pass towards the Chitichun river. This mass, as well as a second block of much smaller size situated to the east of the former, is almost entirely imbedded in the Spiti shales, or in the lowest beds of the Gieumal formation, and has only been brought to the surface by the denudation of the surrounding softer materials.

Neither here nor anywhere in the Chitichun region can a distinct boundary between the Gieumal sandstones and the upper Spiti shales (Lochambel beds) be fixed, as the two formations pass gradually into each other. In the vicinity of Chitichun encamping ground, slabs of a greenish sandstone are frequently met with, overlying the slopes of the dark Spiti shales. It is therefore simply a matter of personal taste, whether these sandstones are considered as belonging to the one or to the other system

The next crag is situated near the low pass, west of the peak Chitichun No. I., on the route from the Kiogarh Chaldu pass to Chitichun encamping ground. A few sections of *Bryozoa* and corals were detected in the limestone, but no attention was paid to these very badly preserved organic traces, as at the time we visited this crag it was assumed to overlie normally the Spiti shales, by which the saddle leading over the range is formed. Close to this saddle a few loose blocks were found containing numerous though badly preserved ammonites of the genera *Monophyllites* and *Xenaspis* (?), pointing to a very low Muschelkalk horizon (Dinarian series).

*Chitichun crag.*—East of the abovementioned saddle rises the famous crag of Chitichun No. I (17,740 feet), with its rich permo-carboniferous fauna. It is rather difficult to say whether the limestone crag actually comes into contact with the Spiti shales or with the intrusive igneous rocks (diabase-porphyrites) and their tufa only, as the two are mixed up together so intimately, that a very detailed

examination of the ground is necessary to fix the boundary between them. The intrusive character of the igneous rocks has been proved by the following important observation, which I shall quote in Griesbach's own words :—

“The base of the south-eastern slope of Chitichun No. I is covered with a mass of débris, and there is therefore no actual contact seen with the Spiti shales. But north-east a low saddle leads across the range between the crags of Chitichun No. I and the one immediately next in succession. The saddle is seen to be formed of the basic igneous rock, which also runs as a vein up the side of the crag, whilst the crown of the latter, a small level space, is entirely composed of that rock. The latter is therefore proved to be of intrusive character penetrating in succession the Spiti shales and the crag in question.”

A distinct stratification has neither been observed in the limestone cap of Chitichun No. I, nor in any of the other crags, which I have personally visited. It is true that the limestone of Chitichun No. I appears to be bedded almost horizontally, especially if seen from the west or south-west, but the rock is crossed by so many planes of cleavage and thrust faults in nearly every direction, that it is extremely difficult to recognise its original stratification. So large indeed is the number of cleavage planes, that there is scarcely a fossil in our collection which is not traversed by one of them.

*Triassic crag.*—There is still another very remarkable crag immediately to the east of Chitichun No. I. It is about 130 feet in height and of a quite regular, conical shape. Its western, northern, and southern slopes are completely surrounded by intrusions of igneous rocks. Unfortunately there was no opportunity of examining its eastern slope. The surface of this cone is entirely made up of slabs of a yellow greyish limestone of a lithological character, which strongly recalls the topmost beds of the upper triassic limestones (Griesbach's rhætic system), corresponding to the Dachsteinkalk of the Austrian Alps.



The saddle north-east of Chitichun No. I, which is composed of intrusive igneous rocks, is joined by a long ridge, running along the Chaldu river in a north-eastern to northern direction. It is capped by masses of limestone, quite similar in their appearance to the crag of Chitichun No. I. They form the highest points of the ridge, and some of them exhibit quite picturesque outlines. That they are in reality only a continuation of the crag of Chitichun No. I, has been proved by an examination of the rocks of their most south-western promontory. But we could neither work out the details of their structure nor decide whether they form one continuous range or a row of smaller independent masses. It is however an indisputable fact, that their strike gradually passes from a north-eastern into a northern direction. The entire row or zone of crags, the centre of which is marked by the peak of Chitichun No. I, consequently describes a flat semi-circle with its convexity turned to S. E.

A third row of crags, considerably shorter however, is indicated by three small blocks to the west and north of Lochambel-ki-chak encamping ground, and by an outcrop of upper triassic limestones (Dachsteinkalk) in the Spiti shales west of the Chitichun river, and about 2 miles north of the last mentioned encamping ground. This latter outcrop may however turn out to be only an inlier of the upper-triassic limestones of the peak Chaldu No. II (17,110 feet), from which the overlying Spiti shales have been denuded.

*Permian fossils.*—Among the three small blocks to the west and north of Lochambel-ki-chak encamping ground, one has yielded *Productus semi-reticulatus*, and is therefore probably of the same age as the permocarboniferous limestone crag of Chitichun No. I. It is situated about half a mile to the north of the camping ground and is of sufficiently large size to exclude the probability of having rolled down from the eastern slope of Chitichun No. I. Half a mile further to the north, near the pass which leads into the valley of the Chaldu river, is a triassic crag with layers of shell-limestone, made up of *Monophyllites* and *Xenaspis* (?). The third block, situated in a narrow

ravine on the eastern slope of Chitichun No. I, to the west-north-west of Lochambel-ki-chak encamping ground, has yielded the interesting triassic fauna, which has been described in Pal. Indica, ser. XV, Vol. II.

*Hallstatt fossils.*—Like the rocks of upper triassic age, to the east of the Balchdhura, this crag differs widely from the normal triassic sediments in the main region of the Central Himálayas, and represents the Hallstatt facies in the Indian triassic province. Its fauna is composed of the following species of cephalopoda:—

- Orthoceras sp. ind.*  
*Danubites kansa*, Diener.  
 „ *ambika*, Diener.  
*Sibirites pandya*, Diener.  
*Aspidites kossmati*, Diener.  
*Monophyllites confucii*, Diener.  
 „ *pradyumna*, Diener.  
 „ *hara*, Diener.  
 „ *kingi*, Diener.  
 „ *pitamaha*, Diener.  
 „ *nov. sp. ind. ex. aff. sphaerophylla*, Hauer.  
*Xenaspis nov. sp. ind.*  
 „ *middlemissi*, Diener.  
*Procladiscites Yasoda*, Diener.  
*Gymnites ugra*, Diener.  
*Sturia mongolica*, Diener.

Since the publication of my Memoir on the Cephalopoda of the Himálayan Muschelkalk (Pal. Indica, ser. XV, vol. II. pt. 2), Waagen's<sup>1</sup> most important work on the ceratite formation of the Salt Range has been published, which has thrown new light on a number of geological and palæontological questions relating to the Indian trias. I had come to the conclusion that, judging from its general zoological character, the fauna of the triassic limestone of Chitichun can only be looked upon as a Muschelkalk fauna, but that the Muschelkalk types, which predominate in numbers, have all attained a stage of development pointing to a lower horizon than the main mass of the

<sup>1</sup> *W. Waagen*—Fossils from the Ceratite-Formation, Pal. Indica, ser. XIII., Salt Range Fossils, Vol. II, 1895.

Muschelkalk in the Central Himálayas (horizon of *Ptychites rugifer*). "The triassic limestones of Chitichun may therefore be considered as forming a lower division of the Indian Muschelkalk, corresponding probably to the horizon of *Sibirites prahlada* in the main region of the Himálayas"<sup>1</sup>

*Hydaspien stage of Waagen.*—It is only with some reserve that this view can be maintained, since Waagen has called attention to the geological importance of his "Hydaspien" stage, comprising the upper Ceratite limestone in the Salt Range, which he considers to be the lowest division of the "Dinarian" series.<sup>2</sup> The triassic limestones of Chitichun may eventually turn out to be homotaxial with the upper Ceratite limestone of the Punjab, not with the lower Muschelkalk (horizon of *Sibirites prahlada*) of the Central Himálayas. From the latter a small number of brachiopoda, but only a single ammonite, *Sibirites prahlada*, is known, and this is entirely different from any species of *Sibirites* described by Waagen from the upper Ceratite limestone. No direct comparison of the faunas of these two stratigraphical horizons is therefore possible.

From the upper Ceratite limestone of the Salt Range 41 ammonites have been described by Waagen among which 35 are *Trachyostraca* and 6 only *Leiostraca*. In the triassic fauna of Chitichun on the other hand, not less than 12 among 15 ammonites are *Leiostraca*. Thus a direct comparison of the two faunas is likewise difficult. Although identical species are not present, the occurrence of a species of *Aspidites* in the Chitichun fauna is in favour of its being possibly homotaxial with the upper Ceratite limestone. Nevertheless its bathrological position is as yet very uncertain. This uncertainty is still strengthened by the rather conflicting characters which the Chitichun fauna exhibits. The occurrence of geologically old types

<sup>1</sup> Pal. Indica, ser. XV, Himalayan Fossils, Vol. II, pt. 2, Cephalopoda of the Muschelkalk, p. 118.

<sup>2</sup> E. v. Mojsisovics, W. Waagen, C. Diener, Entwurf einer Gliederung der pelagischen Sedimente des Trias-Systems, Sitzungsber. K. Ak. Wiss. Wien, math. nat. Cl. Vol. CIV, Abth. 1, Dec. 1895, p. 1289.

(*Xenaspis*, *Gymnites ugra*) is counterbalanced by the presence of forms (*Procladiscites*, *Sturia*), which regarding their zoological character point to a higher stage of the Dinarian series.

Having described so far the structure of the Chitichun region, there remains the discussion of the difficult question whether the peculiar limestone-crags of this district do really correspond in their main characters to the structural features, known as "Klippen" in European geological literature. Before entering into this discussion a short analysis of the most remarkable types of Alpine and Carpathian Klippen must be given.

In the Carpathians and in the Alps of Switzerland the name "Klippen" was originally applied to isolated crags or outcrops, mostly of jurassic limestones, rising out of the surrounding flysch. The crags and the sandstones, in which these crags appear to be imbedded, lie, as a rule, quite unconformably to each other, but in many instances no unconformity can be observed between them.

Beyrich<sup>1</sup> was the first to prove the independence of the Carpathian Klippen of the surrounding belt of sandstones. E. von Mojsisovics<sup>2</sup> demonstrated the structural individuality of each separate crag. Paul<sup>3</sup> believed the different ranges of Klippen to correspond to anticlinal folds. Neumayr<sup>4</sup> gave the following definition of the Carpathian Klippen (more precisely of the Piennine chain).

"The Carpathian Klippen are the fragments and remains of a crushed anticlinal, which have been forced by pressure unconformably through and into younger, originally overlying, strata in the shape of blocks, or of upturned edges of strata shorn off from the original rocks *in situ*."

<sup>1</sup> E. Beyrich—Ueber die Entwicklung des Flötzgebirges in Schlesien, Karsten's Archiv XVIII, 1844, pp. 1-86.

<sup>2</sup> Verhandl. K. Geolog. Reichs-Anst. 1867, p. 213.

<sup>3</sup> C. M. Paul—Die nördliche Arva, Jahrb. Kk. Geol. Reichs-Anst. XVIII, 1868, pp. 201-247.

<sup>4</sup> M. Neumayr—Jahrb. Kk Geol. Reichs-Anst., XXI, 1871, p. 526.

Stache<sup>1</sup> however explains the mode of formation of the Carpathian Klippen in a very different manner. He considers them to be the fragments of a geologically older chain of mountains which, in latter geological periods, were unconformably overlaid by younger sediments, which are different from this older (infra-cretaceous) mountain range, both by their stratigraphical and structural conditions. The results of the recent detailed surveys of Uhlig<sup>2</sup> in the region north of the Tátra (Piennine chain) are in favour of Stache's view. According to Uhlig the Piennine Klippen, which are composed of triassic, jurassic and neocomian rocks, correspond to fragments of an older mountain chain, with a structure independent of the adjoining belt of sandstones, and are distinguished by the presence of littoral deposits of locally considerable thickness in their immediate vicinity.

In the western Alps chains of Klippen play likewise an important part in the structure of their north-western sedimentary belt. Among the Swiss geologists two theories prevail regarding the explanation of their mode of formation. These theories closely resemble those which have been proposed by Neumayr and Stache for the explanation of the Carpathian Klippen, and are similarly contradictory. One of them, advanced by Studer and Mösch, tries to explain the phenomena in question by the assumption of outcrops of crushed anticlinals. The other (Renevier<sup>3</sup>) prefers the assumption of a folding process, anterior to the deposition of the younger sandstones which have been deposited on the eroded surface of the fragments of an older mountain range.

Recently, however, a third hypothesis has been advanced by Bertrand and has been developed more fully by Maillard, Schardt,

<sup>1</sup> G. Stache—Die Geologischen Verhältnisse der Umgebung von Unghvár in Ungarn, Jahrb. Kk. Geol. Reichs-Anst., XXI., 1871, 405.

<sup>2</sup> V. Uhlig.—Ergebnisse geologischer Aufnahmen in den westgalizischen Karpathen, 2. Theil, Jahrb. Kk. Geol. Reichs-Anst. 1890, XL, pp. 559-824.

<sup>3</sup> E. Renevier, Matériaux pour la carte géologique de la Suisse, livraison XVI, Berne, 1890, pp. 112, 128, 133, 189, 457.

Lugeon,<sup>1</sup> Kilian, Haug, and other French geologists to explain the formation of a number of Klippen in the Provence and in the Western Alps.

The Klippen, to which this explanation applies, are considered neither as outcrops, shorn off from a crushed anticlinal (Neumayr, Studer), nor as fragments of an older mountain range (Stache, Uhlig, Renevier), but as the last isolated relics of enormous recumbent folds<sup>2</sup> (*plis couchés*) or overthrusts. In this way, for instance, the presence of a triassic crag in the cretaceous basin of Le Beausset is explained by Bertrand.<sup>3</sup> He proved this crag not to be an outcrop of older rocks, but to rest on the younger cretaceous strata, which on every side dip below the triassic beds and are separated from the latter by a quaquaversal thrust plane. The term "*lambeaux de recouvrement*" has been introduced to designate crags of a similar structure, the origin of which widely differs from that of the Carpathian Klippen. In the cretaceous coal basin of Fuveau the superposition of the triassic (Muschelkalk and Keuper) crags on the cretaceous strata has been actually proved by the construction of a tunnel, which traversed the cretaceous rocks underneath the triassic "*lambeau de recouvrement*."

A similar explanation has been given by Kilian and Haug for a number of crags in the Ubaye region.<sup>4</sup> But the structure of these crags seems to be altogether different from that of the Carpathian Klippen. The Ubaye crags consist of deposits of the so-called Briançonnais facies resting on Dauphiné facies, and their mode of

<sup>1</sup> *M. Lugeon*, La région de la Brèche du Chablais, Bull. des services de la carte géologique de la France, VII, No. 49, Paris 1896.

<sup>2</sup> *B. Willis*.—The mechanics of Appalachian structure, XIII Annual Report of the U. S. Geological Survey, p. 221.

<sup>3</sup> *M. Bertrand*.—Coupes de la chaîne de Ste. Beaulieu, Bull. Soc. Geol. sér. iii, XIII, 1885, p. 115, and: Îlot triasique du Beausset, analogie avec le bassin houiller franco-belge et avec les Alpes de Glaris, *ibid* XV, 1886-87, p. 667-702.

<sup>4</sup> *B. Haug*.—Les chaînes subalpines entre Gap et Digne, Bull. des services de la carte géologique de la France, III, 1891-92, No. 21; *W. Kilian* and *E. Haug*, Esquisse de la structure géologique des environs de Barcelonnette (Basses-Alpes), Travaux du laboratoire de géologie de la faculté des sciences de Grenoble, 1894-95, III, 2, fasc. p. 6.

origin is clearly indicated, either the crest (*charnière*), or the connection with the arch limb or roof<sup>1</sup> of the ancient recumbent fold having been partially preserved.

I shall not enter into the controversy on the intricate structure of the Chablais district in Savoy, but shall close this review of the Alpine Klippen and "*lambeaux de recouvrement*" with a short description of the crags in the Helvetian region between the lakes of Brienz and Walenstadt, which offer some very remarkable analogies with our Tibetan limestone crags. This region has been studied in detail by Kaufmann, Möscher, Stutz, and quite recently by C. Schmidt Steinmann and Quereau.<sup>2</sup> I shall follow the views as exposed by the latter author.

The crags under consideration are the following:—Gyswilerstöcke, Stanserhorn, Buochserhorn, Mythen, Zuckenalp, Iberger Klippen (Grosse and Kleine Schyn, Roggenstock). The area where these crags are situated is composed of rocks, which are all developed in the Helvetian facies, the predominating mode of development in the northern sedimentary belt of the Swiss Alps. The sequence of beds in the crags themselves is entirely different. It has been designated as Vindelician facies by Steinmann and Quereau, and it is much more closely related to the Austrian (Tyrolese) than to the Helvetian development of Alpine rocks. All the crags rest on the tertiary flysch, the youngest member of the Helvetian sequence, and in their occurrence are confined to synclinal depressions in the strike of the folds, making exception, however, of the two crags of Roggenstock and Mördergrub, which are placed on a recumbent anticlinal fold of the Helvetian sequence. Kaufmann and Möscher believed the crags to be anticlinal outcrops, forced and squeezed through the originally overlying sandstones, but from more recent investigations they seem actually to rest on the underlying sandstones, the folds and flexures

<sup>1</sup> *B. Willis.—loc. cit.*, p. 229, 221.

<sup>2</sup> *Quereau*, Die Klippenregion von Iberg, Beiträge zur geologischen Karte der Schweiz, 33 Lieferung.

of which pass underneath them quite unchecked in their development or direction. In the crags of Iberg the rocks are completely squeezed and crossed so intensely by thrust planes that the true stratification can be made out but exceptionally. In the Roggenstock crag the sequence of beds is totally inverted as has been shown by Quereau. Every single crag seems to be separated from the underlying flysch by a quaquaversal thrustplane, and may consequently be considered as a relic of an ancient recumbent fold, the larger portion of which has been carried off by subsequent denudation. These crags, like those of le Beausset or of the Ubaye district ought therefore rather to be classed among the *lambeaux de recouvrement* (Bertrand), than among the true Klippen, of which those of the Piennine chain must be regarded as the prototype.

The Tibetan crags of the Chitichun area form a special type of structural features, which differ both from the Piennine Klippen and from the Alpine "*lambeaux de recouvrement*" of the Ubaye or Iberg type. They are distinguished by five peculiar characters, which must be taken into consideration by any theory that may be advanced for the explanation of their origin. These five characters are the following :—

1. The difference of the rocks, both in the crags of Chitichun and in the main region of the sedimentary belt of the Central Himálayas.
2. The almost semicircular direction of their strike, which is arranged diagonally to the direction of the Himálayan folds outside the Chitichun area.
3. Their occurrence within a synclinal region, consisting of Spiti shales and Gieumal sandstones.
4. Their intimate association with intrusive igneous (basic) rocks of cretaceous or tertiary age.
5. The absence of any distinct littoral deposits in their vicinity.

These points will be separately taken into consideration.



1.—In the Tibetan crags of the Chitichun region the presence of the following rocks has been established :—

- (a) White or reddish limestones of permian (permo-carboniferous) age, with a rich fauna closely allied to the faunas of the Virgal and Kálábagh beds (middle *Productus* limestone) of the Salt Range and of the Artinski horizon of Russia.
- (b) Red limestone with cephalopoda of muschelkalk age, pointing to one of the lower horizons of the Dinarian series.
- (c) Red limestone with cephalopoda of upper triassic (Carnian) age (*subbullatus* or *aonoides* beds).

The series (b) and (c) represent the Hallstatt development of rocks in the Indian triassic province.

- (d) Upper triassic (?), unfossiliferous limestone, corresponding in its stratigraphical position probably to the Dachsteinkalk of the Austrian Alps and to Griesbach's "rhætic system" in the Himálayas.

Among these rocks only the last-mentioned is developed with similar characters in the Chitichun crags and in the main region of the sedimentary belt of the Central Himálayas. The Hallstatt development is not known in the latter region, where the triassic beds have all been deposited as normal sediments, spread equally over a large area. Nor have any equivalents of the permo-carboniferous limestone of Chitichun No. I been discovered as yet. The faunistic relations to the *Productus* limestone of the Salt Range are remarkably closer than to any member of the palæozoic series in the main region of the Himálayas of Kumaon and Gurhwal.

2.—The structural relations between the rows or zones of our Tibetan crags and the principal Himálayan folds may partly be seen from Griesbach's maps (*Memoirs* XXIII, 1891, and *Records*, XXVI, pt. I., 1893).

In the vicinity of the Niti Pass and in the district of Rimkín Paiar, the folds and thrust-faults (Painkhánda fault) strike almost directly north-west to south-east. In the frontier part of Painkhánda, Johár and Hundes they approach more nearly to a north to south direction. This meridional direction is most clearly indicated in the strike of the narrow synclinal of Spiti shales from Laptal to the Kiangur Pass with its continuation into the permo-triassic synclinal of the Utadhura, in the parallel anticlinal of the Lahur, with the adjoining synclinal of Kungribingri, and in the broad anticlinal of the Chanambaniali range. In the Dharma ranges, in Eastern Johár and Byant, the folds of the Himálayan system have again a north-west to south-east strike, as in Painkhánda.

The strike of the chain of crags, to which Chitichun No. I belongs, is quite independent of the direction of the Himálayan folds. This chain runs obliquely across the fold of upper-triassic limestones, which gradually rises from out of the Chitichun synclinal, in the peak Chitichun No. II, 19,550 feet, and transversely across the narrow synclinal of Dharma, which is enclosed between the anticlinal folds of Chitichun No. II and Chanambaniali.

The independence of this Tibetan chain of crags from the neighbouring folds of the Himálayan system is one of the chief characters by which these crags differ from the Carpathian Klippen of the Piennine type. In the Piennine chain the strike of every single row of Klippen almost invariably follows the direction of the zone of folds, of which this chain forms a part. A deviation from the normal direction of the folds is a great exception. The only instance on a larger scale, which has been noticed by Uhlig<sup>1</sup> are the Klippen of Falstin, which for a distance of 2 kilometres strike transversely across the direction of the entire chain. But this instance scarcely allows any comparison with the structural independence of the

<sup>1</sup> V. Uhlig.- Ergebnisse Geologischer Aufnahmen in den westgalizischen Karpathen, II. Theil. Der Pienninische Klippenzug, Jahrb. Kk. Geol. Reichs-Anst. Wien. XL., 1890, p. 797.

Tibetan crags from the Himálayan folds, the independent strike of the chain of crags to which Chitichun No. I belongs, having been ascertained for a distance of 13 km.

3.—A certain analogy of the Tibetan crags with those of the Iberg type in the Helvetian region between the lakes of Brienz and Walenstadt cannot be denied. Like the latter crags they are confined to a synclinal area. The crags of the Chitichun region rest on a synclinal of Spiti shales and Gieumal sandstones, fringed on three sides by triassic anticlinals. The Swiss crags rest in exactly the same manner on a synclinal of eocene flysch, forming a sort of trough between an outer (Pilatus-Autrig) and an inner range (Brienzer Grat-Brisen-Bauenstöcke-Räderten) of anticlinal folds.

4.—A feature, which is quite peculiar to the Tibetan crags and has as yet not been discovered in any of the hitherto known chains of Klippen or *lambeaux de recouvrement*, is their intimate association with intrusive igneous rocks. The local occurrence of eruptive materials within the zone of Carpathian Klippen is of a very slight importance only, if compared with the predominant part taken by intrusive igneous rocks (diabase-porphyrites) in the structure of the Chitichun area.

In the preceding description it has been demonstrated that the largest of our Tibetan crags are nearly imbedded in eruptive materials, that neither in the crag east of Sangcha Talla encamping ground nor in Chitichun No. I, a direct contact of the limestone crag with the apparently underlying sandstones or shales has been observed, but that an intermediate layer of igneous rocks and of their tufa is inserted between the two formations. The igneous rocks cannot be of older than at least cretaceous age, having penetrated both the shales and sandstones and the crags in succession. Nor can the formation of the crags as structural features be younger than the eruption of the diabase-porphyrites which must have intruded them *in situ*, at the place where they are at present situated.

5.—There is no indication of any deposits of a littoral character in

the Spiti shales, which surround the Tibetan crags. The condition of the sediments remains unaltered over a large area, and is not influenced in any distinct way by the vicinity of the crags. The nature of the Spiti shales themselves as well as of their organic remains prove, that they must not be considered either as a pelagic nor as a littoral formation. Professor Uhlig, who is working out the fauna of the Spiti shales, has kindly forwarded the following notes on this subject :—

“The Spiti shales are certainly not littoral sediment, as for instance is the Carpathian ‘Klippenhülle,’ *i.e.*, the complex of rocks in the immediate vicinity of the Carpathian Klippen (red clay, sandstones, and conglomerates with *Inoceramus*). With regard to their lithological character, the Spiti shales are undoubtedly very similar to the ‘Terrain a géodes’ (Dogger) of the Caucasus and to the Wernsdorf and upper Teschen beds of Silesia. In the latter beds the iron occurs in layers, but is not concentrated in concretions. In the Wernsdorf beds remains of terrestrial plants are frequently met with; their presence in connexion with the clastic condition of the sediments seems to prove that the latter are not truly pelagic deposits. The same reasoning might be applied to the origin of the Spiti shales. In this respect the fact is of some importance, that the state of preservation of the very numerous ammonites completely excludes the possibility of their having been rolled or abraded near an ancient coast-line. As in the Wernsdorf beds, specimens with entirely preserved mouthborders (peristomes) are not at all rare. Their state of preservation is indeed so perfect that they cannot be supposed to have been rolled or damaged in any way. The Spiti shales ought therefore to be considered as sediments, which, having neither been deposited in the vicinity of the ancient coast-line nor in the open sea, are certainly not littoral, though not strictly thalassic.”

The difference in the stratigraphical sequence between the main region of the sedimentary belt of the Central Himálayas and the Tibetan crags of the Chitichun area is equally consistent with an

explanation of the latter as true Klippen (in a structural sense), or as *lambeaux de recouvrement*. As has been pointed out by Griesbach, this change of the lithological character of the rocks in these two separate regions can easily be accounted for by the appurtenance of the crags to a sedimentary zone which was more distant from the ancient coast-line of the Gondwana continent (peninsular area of India) during the permian and triassic epochs.<sup>1</sup> There is consequently nothing astonishing in the fact, that in the Chitichun area a change in the development of sediments is met with, both palæontologically and lithologically.

As a direct structural connection between the Tibetan crags and the neighbouring folds of the Himálayan system has not been observed, these crags cannot be explained as the fragments of crushed anticlinals. The theory advanced by Paul and developed more fully by Neumayr for the explanation of the origin of the Carpathian Klippen of the Piennine type is therefore not admissible. Nor are we justified in considering the crags of Chitichun as the relics of an older mountain range, as the Piennine Klippen to the north of the Tátra have been proved to be by Stache and Uhlig, seeing that littoral deposits of the character of the Carpathian "Klippenhülle" are absent in their vicinity. In the Spiti shales of the vicinity of Chitichun No. I at least, which was more closely examined during our visit to this part of the Himálayas, we failed to discover any similar deposits pointing to the existence of a jurassic coast-line within the Chitichun region.

Regarding the differences which exist between the Tibetan crags and the Carpathian Klippen of the Piennine type, the question might

<sup>1</sup> The difference in the development of the upper-triassic strata of the Himálayas and the Salt Range is explained in a similar manner. The geographical position of the Salt Range is an intermediate one between the Gondwana continent in the south and the pelagic area of the Himálayan system in the north. Waagen and E. v. Mojsisovics justly compared its position to that of the German triassic basin between the Atlantic continent and the Alpine region (*E. v. Mojsisovics*, Beiträge zur Kenntniss der obertriadischen Cephalopoden-Faunen des Himálaya, Denkschr. K. Akad. Wiss. Wien. math. nat. Cl. LXIII., 1896, p. 689).

be raised if these crags ought not rather to be considered *lambeaux de recouvrement* of an origin similar to that of a good number of so-called Klippen in the Western Alps.

There are several arguments of no slight importance, which seem to be in favour of such a view.

Like the Alpine *lambeaux de recouvrement* the Tibetan crags are confined to a synclinal area, and apparently rest on geologically younger strata. I should not, however, like to insist on the latter argument, as I am too well aware of the difficulty of deciding, whether in similar cases one has to do with a real superposition or with outcrops of older rocks.<sup>1</sup> Nor must it be forgotten that some of these Tibetan crags appear to have been perfectly imbedded in the soft Spiti shales of the igneous materials associated with them, and to have been laid bare by subsequent denudation only. A stronger argument in favour of an explanation of the Tibetan crags of the Chitichun area as *lambeaux de recouvrement* is their structural independence of the Himálayan folds. This peculiar feature of theirs might be easily accounted for by the theory advanced by Bertrand, Schardt, Quereau and Lugeon for the explanation of the majority of the so-called Klippen of Switzerland and Savoy.

Nevertheless I believe that the latter hypothesis must also be dismissed on account of the very grave objections which might be urged against it. The objection against this explanation of the Tibetan crags as *lambeaux de recouvrement* is two-fold.

Supposing these crags to be really the relics of an enormous recumbent fold, the mountain range, part of which has been carried across the Himálayan system into the Chitichun area by means of this hypothetical fold, must exist somewhere in the neighbourhood of the latter region. But nowhere in Southern Hundés has a large belt of sedimentary strata of the Chitichun development been discovered.

<sup>1</sup> *Vide* the triassic crags of Beausset and Fuveau, considered formerly—and not only by casual observers—as outcrops; or the controversy, which is still going on between Heim and Vacek on the structural condition of the Verrucano-caps in the Alps of Glarus.

Against this evidence, it is true, not only our very superficial knowledge of the geology of Southern Hundés may be urged, but the probability of the existence of a sedimentary zone north of the Kailas mountains is supported by the following arguments.

Thanks to the geological reconnaissances of Godwin-Austen, Stoliczka and Lydekker the structure of the Western Himálayas has been made pretty well known. On the important papers of these authors the masterly description of the mountain-system of Kashmir and Ladakh by Eduard Suess (*Das Antlitz der Erde*, I Bd., pp. 559-565) has been based. He proposes the following structural division of the Western Himálayas:<sup>1</sup>—

- a. Sub-Himálayas (tertiary, with outcrops of older rocks).
- b. Pir Panjal (anticlinal of crystalline and metamorphic rocks).
- c. Synclinal of Kashmir (mesozoic and palæozoic).
- d. Zaskar (crystalline zone, corresponding to the main axis of the Central Himálayas).
- e. Synclinal of Spiti (palæozoic and mesozoic).
- f. Eocene zone of Leh (Upper Indus Valley).
- g. Crystalline zone of the Ladakh Range.
- h. Sedimentary belt of Baltistan (upper palæozoic and mesozoic).
- i. Gneissic zone of the Mustagh Range (Karakorum).

Whilst the outer crystalline zone of the Pir Panjal and the synclinal sedimentary belt of Kashmir come to an end before reaching the Sulej river, both the crystalline zone of the Zaskar and the sedimentary belt of Spiti find their continuation in the Central Himálayas of Kumaon and Gurhwal. To the crystalline mass of the Zaskar correspond the enormous gneissic masses of the Kedarnáth peaks, of the Nanda Devi (25,660 feet) and Nampa. The sedimentary belt on the northern slope of these crystalline masses, which has been followed by Griesbach from the Hop Gádh to Kalapani for a distance of 130 miles (210 km.), is a direct continuation of the

<sup>1</sup> *Vide also Godwin-Austen.*—The mountain-systems of the Himálaya and neighbouring ranges of India, *Proceedings of the Royal Geograph. Soc.*, London, new ser. V, 1883, p. 61 o VI, 1884, p. 83.

mesozoic synclinal of Spiti. This sedimentary zone of fossiliferous deposits, ranging from the silurian into the cretaceous formation, is one of the most important features in the structure of the Himálayas. In the district of Chitichun it is intimately connected with the tertiary belt of the Upper Indus Valley in Ladakh, our Tibetan crags forming part of these two united zones (*e* and *f* of the foregoing scheme).

Having been able to follow the sedimentary belt of Spiti as an almost uninterrupted zone from the Suru river in Kargil to the frontier of Nepal and Byans, we must consequently look on the crystalline mountain ranges to the north of this zone as a structural continuation of the gneissic Ladakh range. The Kailas mountains, the southern slopes of which have been reconnoitred by Strachey, belong to this crystalline zone of Ladakh. None of the fossiliferous beds of the Bhot Mahals of Johár and Painkhánda have been found, either in the Kailas range or in the vicinity of the Mánásarowar lakes. Nor are we justified in expecting their discovery so far as we may judge from the structural analogies with the Western Himálayas. If any sedimentary zone exists beyond the valley of the Sutlej river in Hundés, we must suppose it to form a continuation of the sedimentary belt of Baltistan. The regularity in the arrangement of the structural zones in the Western Himálayas is a strong argument in favour of this supposed continuation of the palæo-mesozoic belt of Baltistan into Hundés. But this sedimentary belt must by all accounts be looked for on the northern slopes of the Kailas range.<sup>1</sup>

This problematic continuation of the zone of Baltistan to the north of the Kailas mountains is the only possible source of the hypothetical *lambeaux de recouvrement* in the Chitichun area.<sup>2</sup> An

<sup>1</sup> The existence of a sedimentary synclinal along the northern slopes of the crystalline anticlinal of the Kailas range has also been advocated by Griesbach (Mem. Geol. Survey Ind. Vol. XXIII, p. 40).

<sup>2</sup> I need scarcely dwell on the fact, that the few fossils, which were collected in the sedimentary belt of Baltistan near Shigar by Godwin-Austen, are certainly not sufficient to prove an identity of the development of sedimentary strata in Baltistan and in the Chitichun area.



advocate of this hypothesis must admit the existence of an ancient recumbent fold, by which part of the abovementioned sedimentary zone has been carried across the crystalline Kailas range into the Chitichun area. Now the shortest distance between the crest of the Kailas range (north of Tirthapuri) to Chitichun No. I is nearly 50 miles (80 km.). It would be difficult to explain, I believe, the mode of formation of such enormous recumbent folds, in comparison to which any fold, which has hitherto been actually observed, is ridiculously insignificant. I am well aware that several geologists, like Schardt or Lugeon, suppose the region of the "Brèche du Chablais" in Savoy to have been formed by a recumbent fold of similar dimensions, but I humbly confess my inability to understand the mechanics of an overthrust of entire structural zones for a distance of 50 miles.

The second objection, which to me appears to be still more cogent, is based on the intimate association of the Tibetan crags with intrusive igneous rocks, which penetrate both the crags and the geologically younger shales and sandstones in their proximity. The localisation of the igneous rocks to the crags along their entire line of strike seems to prove the coincidence of the eruptions with the structural movements, by which the crags themselves have been brought into their present position. This fact excludes any mode of explanation, by which the crags are assumed to have been brought into their present position from some distance, by recumbent folds or overthrusts, but naturally involves the assumption, that they have been brought to the surface from underneath, either as fragments of a squeezed fold, or by faulting.

The independence of the strike of the crags from the folds of the Himálayan system in the Chitichun area is opposed to the existence of a squeezed fold. Thus the explanation, given by Griesbach in his preliminary notes (Records of the Geological Survey of India, Vol. XXIV, p. 24) remains the most plausible. He explains

the occurrence of the crags in association with the diabase porphyrites in the following manner :—

“ We have seen, that this limestone (which forms Chitichun No. I and the neighbouring crags) lies apparently on Gieumal beds in one section and on Spiti shales in another ; further that the crags are accompanied more or less along their entire line of strike by igneous intrusive rocks, and in one instance at least the latter penetrates the permocarboniferous limestone, which is partially converted into a semi-crystalline limestone.

“ I advance therefore the theory that these older rocks have been brought to the surface by faulting. The latter is not directly visible, which, indeed, is rarely the case in a complex of soft shales, such as the jurassic beds are in this region, but a fault may be inferred not only from the existence of palæozoic rocks above jurassic, but also from the fact, that the former rest on different divisions of the latter in adjoining sections.<sup>1</sup> The assumption of a fault explains also the presence of intrusive rocks, which may have most probably intruded along a line of fissure.”

According to Griesbach these Chitichun faults may belong to the system of dislocations, which affects the Hundés plain in the vicinity of the Mánásarowar lakes and has enabled the basic rocks of Eastern Hundés to intrude. This system of dislocation is however purely hypothetical, being based only on Strachey's reconnaissances, which though very meritorious in many respects, are of no value for a discussion of the complicated question of our Tibetan crags.

If I should be asked an explanation of the origin of these crags, I could give no better than the above quoted, which has been advanced by Griesbach, at least for the present moment, although positive proofs of the supposed faults are yet absent. After all, this opinion may yield to reconsideration, when the details of the struc-

<sup>1</sup> This fact, however, is equally well consistent with the hypothesis of a fault or of a recumbent fold or overthrust.

ture of the Chitichun area and adjoining portions of Hundés have been worked out more fully by a new exploration of this exceedingly interesting country. I scarcely need say that it would be of special interest and well worthy the expenditure of money and time to further explore a territory exhibiting such peculiar structure. For the present we must be satisfied with the discovery of the latter which had not previously been recognised in India, but must leave its thorough explanation to our successors.