## DISCUSSION

*This section is intended to provide a forum for the discussion of papers published in our Journal by those working in similar fields of investigation and research. Such a discussion is expected to be of value not only to the actual workers in the concerned field, but also to a wider circle of readers interested in the progress of geological studies.*—Editor.

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Paper 'ON THE KROL NAPPE HYPOTHESIS' by A. Ranga Rao, published in the Journal (Vol. 9, No. 2, pp. 153-158 December 1968).

*Comments by J. B. Auden (43, Thurloe Square, London)*

*Introduction:* In a recent paper on the Krol Nappe hypothesis, Ranga Rao has concluded that the rocks of the Krol belt are not allochthonous but autochthonous, and that the outcrops of Nummulitics in the Solan area do not belong to different tectonic units.

It is 31-42 years since I mapped in the region between Solan and Lansdowne, and 36 years since my publication appeared which suggested that the rocks of the Krol belt occur as a nappe. Both time, and the subsequent occupation with other aspects of geology in several countries, have tended to dim my memory of many of the critical localities and geological problems. Moreover, I have been out of touch with the results of much recent work undertaken in the Himalaya by the Geological Survey of India, the Oil and Natural Gas Commission, and academic institutions; and I must be unaware of many recent vital investigations which have a bearing on this problem. I hope, notwithstanding these deficiencies, that I may be permitted to reply to some of Ranga Rao's criticisms. In this note, the term *Blaini* refers to what were originally mapped separately as Blaini and Infra-Krol.

The problem of the present relationship between the Nummulitics and the adjacent rocks may be studied from two points of view:

1. The nature of the formations which are now found below and above the Nummulitics.
2. The study of the floor of the Nummulitic sea in the region.

*Nature of the formations above and below the Nummulitics:* If I have understood Ranga Rao correctly, he considers that the Nummulitics of the Himalayan foothills were deposited over a strongly eroded sequence of pre-Tertiary rocks that has since remained autochthonous throughout the Tertiary orogenesis, with a late Cretaceous topography that has survived intact.

In Table I an attempt has been made to show the relationship between the Nummulitics and the contiguous formations which lie above and below the Eocene. It is seen that in every exposure the Nummulitics have a floor and top of different geological formations.

If the Nummulitics had been deposited in deeply incised embayments of the Krol and older rocks, and the whole complex had been subsequently folded and submitted to minor reversed faulting, it would have been expected that the Nummulitics would generally have the same formation above and below as that against which it had originally been deposited. Yet there is almost invariably a striking

TABLE I

RELATIONSHIP OF THE NUMMULITICS IN THE OUTER HIMALAYA

--x--x--x--x-- = Inferred Thrust Plane

| (1) KOTLI RIASI | (2) KAKARA | (3) SHALI | (4) SOLAN | (5) CHANDNA RAO | (6) DABRA SAYASU | (7) DADAHU | (8) TONS RIVER | (9) MAUN & GANGA | (10) DOGADDA | (11) DAILEKH |
|---|---|---|---|---|---|---|---|---|---|---|
| 33°32' 74°00'<br>33°08' 74°45' | 31°03' 77°01' | 31°10':77°17'<br>31°13':77°21 | 30°56':77°04' | 30°13':78°18' | 30°40':77°48'<br>30°42':77°44' | 30°36':77°26' | 30°32':77°49' | 30°04':78°21'<br>30°04':78°30' | 29°48':78°37' | 28°52':81°40' |
| D N WADIA | SRIKANTIA BHARGAVA | W. D. WEST | | | | | | | | |
| | | | | | | | | CHANDPUR<br>BIJNI | CHANDPUR<br>BIJNI | DAILEKH METAMORPHICS |
| | | | | | | | | -x-x-x-x-x- | -x-x-x-x-x- | -x-x-x-x-x- |
| | | | | | | | | NUMMULITIC | NUMMULITIC | Concealed Gas-bearing rocks presumed to be |
| | | | | TAL | TAL | TAL | TAL | TAL | (Krol Unit locally eliminated by overthrust) | |
| | | | KROL | KROL | KROL | KROL | KROL | KROL | | NUMMULITIC |
| | BLAINI | | BLAINI | BLAINI | BLAINI | BLAINI | BLAINI | BLAINI | | |
| | | | | NAGHTAT | NAGHTAT | | NAGHTAT | | | OUTCROPS OF COAL- |
| | | | | CHANDPUR | CHANDPUR | | CHANDPUR | (Chandpur & | | BEARING EOCENE |
| NUMMULITIC & PRE-TERTIARI | | CHAIL | | | MANDHALI | | MANDHALI | Bijni rest | | 17 Km. S.W. of |
| | | | | | | | | directly on | | DAILEKH BELOW |
| -x-x-x-x- | -x-x-x-x- | -x-x-x-x-x | -x-x-x-x-x | -x-x-x-x | S-x-x-x-x- | 20°N.-x-x-x-x- | 14N.-x-x-x-x- | Tal at Banali | | KARNALI THRUST |
| MURREE NUMMULITIC with coal & bauxite | NUMMULITIC | DAGSHAI NUMMULITIC | NUMMULITIC | NUMMULITIC | NUMMULITIC | NUMMULITIC | DAGSHAI + INFERRED NUMMULITICS | 30°18':78°17') | | |
| SIRBAN LIME-STONE | SIMLA SLATES | MADHAN SLATES | SIMLA SLATES | SIMLA SLATES | | -x-x-x-x | -x-x-x-x | | -x-x-x-x- | -x-x-x-x- |
| -x-x-x-x- | | SHALI SERIES | | | SIMLA SLATES | LOWER SIWALIK | LOWER SIWALIK | | LOWER SIWALIK | LOWER SIWALIKS |
| LOWER & MIDDLE SIWALIKS | | | | | | | | | | |

contrast between the formations which underlie and overlie the Nummulitics, and it is not easy to imagine that in every case the Nummulitics just happened to lie over the contact between dissimilar formations, one of which remained underneath during orogenesis, while the other formation was translated over the Nummulitics by minor reversed faulting.

In the case of the Shali and Maun-Ganga exposures (numbers 3 and 9 of the table) mapping and the geometry of the formations clearly indicate that the rocks which lie upon the Nummulitics have been carried on a major thrust plane, which cannot be interpreted as the result of merely local reversed faulting of beds which formerly had lain below the Eocene. It must be accepted, therefore, that the Chail rocks of Shali, and the Chandpur rocks of the Lansdowne zone, belong to important nappes. At Shali, the Chail nappe rests upon Nummulitics which in turn lie upon para-autochthonous Shali limestone (regarded as equivalent to the Sirban). In the Lansdowne zone the Garhwal nappe lies upon Nummulitics which in turn rest upon the Tal-Krol-Blaini unit. The Garhwal nappe extends to the Satengal and Banali outliers; but there the Nummulitic is absent, and the metamorphic rocks rest directly upon the Tal. Whatever doubts may exist in the understanding of the exposures around Solan, it would surely be difficult to adopt this explanation for the Nummulitics which crop out near Narendranagar, (No. 5 of the Table). Two inliers at the base of the Tal-Krol-Blaini unit are exposed, along the Bhidalna Rao (30°16′ : 78°14′) and Chandna Rao (30°13′ ; 78°18′), where the Nummulitics rest upon autochthonous Simla Slates and are overlain by the Blaini-Krol-Tal sequence. In my opinion, the Nummulitics are separated from this sequence by a thrust plane and not by a locally inverted contact of a former sedimentation floor.

Only 12 km to the south-east of the Chandna Rao inlier, across the Ganga, the Nummulitics rest upon the complete Blaini-Krol-Tal sequence, which is 2,000m in thickness in the Mahadeo Chatti area. While it is accepted, as discussed below, that the Nummulitics have overstepped the Tal beds on to the Krol in the region between Dadahu and Bagar, the relationships of the formations between Narendranagar and Lansdowne would make such a violent erosin of 2,000m rocks most improbable. The alternative explanation is that the Nummulitics as now exposed after orogenesis rest upon different tectonic units, and have been brought into close proximity by overthrusting from originally distant and separated sedimentation areas.

The exposures ESE of Dadahu are also relevant to this problem, (Nos. 7 and 8 of the Table). The Nummulitics there are thrust upon Lower Siwaliks and continue eastwards in that disposition to longitude 77°42′. Further east, in the Tons-Kalis area, the Nummulitics are not seen, but sheared chocolate-coloured shales and sandstones of Dagshai type are present which are also thrust upon the Lower Siwaliks*. Upon the Nummulitics near Dadahu is found the Blaini-Krol-Tal complex, at 2000 feet elevation on the Giri river and extending to higher elevations south of hill 4217 (30°34′ : 77°28′), wilh a height difference of 600 metres across a dip section of 1700 m., the angle of north-dipping thrust being 20° (Auden 1942, plate V). In the Acchaun-Byas section the thrust plane has a dip of 23°. In the Tons river section the angle of thrust is 14°, northwards.

In the Dadahu-Tons area, therefore, the Nummulitics are definitely not autoch-

* I had originally regarded these beds as belonging to the Siwaliks (1934; p. 434) but subsequent work indicated that Pilgrim had been correct in assigning these beds to the Dagshai, and they are shown thus in my 1942 paper, plate VII.

thonous, since, they are thrust upon Lower Siwaliks. The Nummulitics, together with Dagshai (Murree), are separated from the overlying Krol unit by a regional overthrust, clearly involving movement with a large horizontal component. This overthrust does not necessarily imply, taken in isolation from regional considerations, that the rocks of the Krol unit occur as a rootless nappe. Viewed in conjunction, however, with the regional mapping, and with the occurrences of Nummulitics at Sayasu and Dabra on the north side of the Krol syncline, there would appear to be strong grounds for postulating the existence of the Krol nappe (No. 6 of the Table).

The occurrences along the Giri and Tons river are comparable to those in the Kotli and Riasi inliers which lie 400-500 km to the north-west. There Nummulitics and Murree beds rest upon para-autochthonous Sirban limestone and dolomite, which is thrust over Middle Siwaliks. The whole unit of the inliers is itself overthrust by Nummulitic and pre-Tertiary rocks, as has been mapped by Wadia as a regional thrust plane extending for 300 km (1934 and 1938). The Sirban dolomite and limestone becomes broken up further to the south-east by intense shearing into irregular lenticular masses of carbonate rock, which is sometimes stromatoidal, associated with green and purple slates of Murree-Dagshai type, in places wedged between the Siwaliks and the Krol unit. This is well seen at Sataun on the Giri river (30°33′ : 77°38′ : *Rec. Geol. Surv. Ind.*, 77, pp. 516-517, 1955). The outcrops at Malla (30°46′ : 76°59′) near Kalka are more isolated from the pre-Tertiary units, being confined within the Siwaliks,

Finally, mention may be made of the Eocene coal bearing rocks of the Dang series in central Nepal (No. 11 of Table). These rocks are not autochthonous, since they have been thrust over the Siwaliks. Almost without question they occur, totally concealed and overlain by metamorphics, in the Dailekh area (28°51′ : 81°40′), where gas seepages occur from anticlines in the metamorphics, The gas occurrences are 17 km from the actual outcrops of Dang beds, and the inference is that the Dang series occurs at shallow depth in the core of the Dailekh anticline, lying below the great Karnali overthrust of altered pre-Tertiary rocks.

*The floor of the Nummulitic sea:* Ranga Rao implies that the Nummulitics were deposited in embayments within the older rocks. This is indeed the explanation that was put forward by H. B. Medlicott 106 years ago. Medlicott wrote:

> "... had the nummulitic beds been originally deposited upon an undenuded surface of the Krol group, the faulting necessary to account for their present relative position would be inconceivable,—long narrow trough-faults with a throw of 2 or 3,000 feet on either side." (1864, p. 76).

Medlicott had realised the difficulty, because the present height difference between the Krol hill summit and the Blaini valley is of the order of 750 m. He is correct in showing that major vertical trough faults are absent. His alternative explanation implies that very deep erosion took place in the probably Permo-Trias Blaini-Krol rocks, into the valleys of which topography the Nummulitic sea entered as embayments.

Certainly, some of the exposures in the Solan area are poor and difficult to decipher. Reference to pp. 435-438 of my 1934 paper will show that considerable uncertainty existed about the interpretation of the outcrops between Solan and Subathu. Since I was last in that area in 1931, I understand that the Geological Survey of India has now located further outcrops of Nummulitics in the area between

Solan brewery and Kandaghat, lying apparently below the Krol-Blaini rocks and north of the Krol syncline.

If the Nummulitics are regarded as outliers in the Blaini rocks near Solan, it follows that deep valley erosion must have taken place in the Blaini-Krol rocks at the end of the Mesozoic, with the Nummulitics occurring as wedge-like valley deposits flanked by high slopes of the Blaini-Krol sequence. This markedly eroded topography must have survived intact throughout the whole period of mid-Tertiary orogenesis. In my view, the Krol rocks, now left as outliers on Krol and Pachmanda hills, were once continuous over the present Blaini valley until Quaternary erosion carved out this valley down to expose the underlying Nummulitics, leaving the isolated masses of these hills as witness of the former super-imposed tectonic unit.

It is evident that no deep late-Mesozoic erosion, of the type postulated by Medlicott and Ranga Rao, took place in the rocks of the Krol Belt east of longitude 77°25′ E., because undenuded Lower and Upper Tal rocks (now established I understand to be of Jurassic-Cretaceous age, as had been formerly assumed) occur over the 150 km between Dadahu and Lansdowne, and must have acted as a protective cover to the underlying Blaini-Krol sequence. It is assumed that the gaps in the outcrops across the Yamuna and Ganga valleys are due to Quaternary erosion and not to pre-Nummulitic denudation, for 600-1200m of Upper Tals are present in the Yamuna-Ganga areas, and the Nummulitics rest upon Tal beds immediately south-east of the Ganga river.

It is not known if the Tal beds were originally deposited upon the Krol between Dadahu and Solan and were subsequently eroded. At Bagar, only 25km south-east of Solan, Nummulitics rest folded within the Upper Krol dolomites, without intervening Tals, and it is possible that there was a fairly rapid overlap of Nummulitics across the Tal beds on to the Upper Krol in the Dadahu-Solan area. The supposition of Medlicott and Ranga Rao requires that such overlap was accompanied by deep valley erosion between Bagar and Solan. Similarly, near Narendranagar, and between Sayasu and Dabra, erosion on this supposition must have removed more than 3000 m of rocks, while leaving intact the whole Krol sequence in the immediately surrounding areas.

With my interpretation, the Nummulitics of Narendranagar, Sayasu and Dabra occur at the base of the Krol sequence, separated by and overthrust, whereas the Nummulitics just south-east of the Ganga rest on the top of the Blaini-Krol-Tal sequence.

Such violent pre-Tertiary erosion as required by Medlicott and Ranga Rao is not reflected in exposures within the Himalaya. Where the Nummulitics rest upon Madhan Slates in the Shali area, West has not indicated any abrupt erosional changes at the contact, although of course all the formations have been subsequently tilted as a result of Tertiary orogenesis. Similarly, around Maun, south-west of the Ganga River, the Eocene-Tal contact lacks the indentations which would have been expected if the postulated late-Mesozoic valleys in the Tal sediments had been filled with Nummulitics and the whole erosional geometry had been later folded.

Both in Hazara, and in the Kotli-Riasi inliers of Jammu, the Eocene contains ferruginous pisolite or laterite, while bauxite occurs in economic quantities between Kotli and Riasi. These residual deposits are suggestive of low level plateau conditions prior to submergence of the land under the Nummulitic sea. It is doubtful if the laterite-bauxite would develop under the circumscribed conditions of a fjord

topography. Wadia (1938) has shown that the Eocene rests upon dip slopes of the Sirban limestone, and its presence at different elevations is related to pitching folds, and faults, developed during the Tertiary orogeny.

The same considerations would appear to apply to the coal of Nummulitic age which is found in Hazara, the Salt Range, Kotli, Riasi, and over a mapped extent of 80 km in west-central Nepal, from south of Dailekh to Tosh (28°07′ ; 82°37′). The widespread occurrence of this coal must surely imply a former continuity of distribution of vegetable matter on a plane of deposition rather than in narrow valleys of a deeply eroded topography, such as the Blaini valley between the Krol and Pachmanda Hills. Raiverman and Seshavataram interpret the overlying marine Nummulitics as having been deposited by turbidity currents as wide sheet flows.

There is no evidence, so far as I am aware, that the western, northern and eastern edges of the peninsula at the end of the Cretaceous possessed a markedly irregular floor, such as with fjords if the explanation of Medlicott and Ranga Rao is accepted. On the east side the Sylhet limestone follows conformably upon Upper Cretaceous and Lower Eocene, all of which regularly expand towards the newly developed ocean of the present Bay of Bengal. The Cherra sandstone of the Shillong plateau rests on a relatively smooth surface of the Archaean basement, without indication of infilling a strongly eroded topography (25°33′ : 92°44′).

On the west side in Kutch and Jaisalmer, the Eocene overlaps across the Cretaceous on to Jurassic in a regular manner. In the Salt Range, the Eocene systematically overlaps from Cretaceous to Cambrian over a distance of 150 km in a west to east direction, 850 m of Mesozoic and Paleozoic sediments being gently bevelled at an average rate of 5.7 m/km. In the individual oil fields of the Potwar there is a proved regularity in depth of the Eocene floor, which is consistent with the geometry of anticlinal folding, but not with a capricious pre-Eocene topography of dendritic valleys filled with Nummulitics as the sea invaded the hypothetical fjords.

It would appear that towards the end of the Mesozoic, a NW-SE upwarp existed which passed through the east end of the present Salt Range near Domeli (33°01′ : 73°31′). This upwarp was responsible for the progressive elevation and erosion on the south-west side of the Permo-Mesozoic succession, with eastward overlap of the Nummulitics. On the north-east side of the upwarp the Nummulitics were deposited upon Simla slates near the Gambhar river, Solan and Narendranagar. In the zone now represented by Hazara, Kotli, Riasi, Malla and Shali, the Nummulitics were deposited upon Sirban limestone, or its equivalents, of possible Permo-Carboniferous age. Still further from the upwarp the Nummulitics were deposited upon Krol and Tal rocks, of Permo-Cretaceous age. In the interpretation which I prefer, subsequent orogenesis has telescoped the variegated floor of the Nummulitic sea, so that in any one area of the Krol belt there are superimposed different parts of the original ocean bed.

It is true that the late Mesozoic topography of parts of the Indian peninsular was locally very accentuated, such as between Belgaum, Kolhapur and Radhanagiri (16°25′ : 74°00′) and also between Bhopal and Hoshangabad. The central part of the Indian peninsula, at the time of the break up of the Gondwana continent, was certainly elevated, exposed and eroded, while the flanks of the continent were subjected to depression and the Cretaceous-Eocene marine transgression. This peninsular topography was subsequently covered by Deccan volcanics, which have preserved the floor from further denudation over an area of 500,000 km$^2$.

In summary. It is considered that the different nature of the formations which occur below and above the Nummulitics throughout the Himalayan foothills is not stratigraphical, but is due to a succession of thrust planes having broken up the original diversified floor upon which the Nummulitics were deposited. Moreover, paleo-geography would appear to indicate that the edges of Indian-peninsular part of the dismembered Gondwana continent lacked the fjord type of topography which would be required with the explanation of Medlicott and Ranga Rao.

Ranga Rao has raised other objections about the roots of the supposed Krol Nappe and the nature of the Blaini. Bhargava and Srikantia have pointed out difficulties in the tectonic correlations which I had suggested, and which are in the Director's General Report for 1944 (*Rec. Geol. Surv. Ind.*, 79, pp. 516-518, 1955). It is not possible within the compass of a short paper to discuss all these points, but it is hoped to return to them later. I may stress that many points troubled me during the Survey days in the Himalaya between 1928-1939, not least the problem of the Jaunsars, Mandhalis, and Bijnis, which show features resembling the baffling Tanols or Tanawals of Hazara and Kashmir (Middlemiss 1896, pp. 237-239; Wadia 1934, pp. 147-150). Indeed, I had come to suspect the possibility of a Variscan orogeny previous to the Himalayan tectonism, linked up with folding of the Vindhyans in the peninsular.

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*Authors' reply* *

Auden's comments on my paper 'On the Krol Nappe hypothesis' which suggested that the structure of the Krol Belt is autochthonous and not a nappe can be summarized as below:

1. If the Krol belt is autochthonous, the occurrence of Nummulitics (Subathu) in the Blaini valley implies deposition of these rocks in deeply eroded valleys. The relationship of Nummulitics with the rocks occurring above and below them in the Himalaya, and the paleogeography of the Indian Peninsula at that time negates such an assumption.

2. The presence of different rock units above and below the Nummulitics would indicate that the Krol belt occurs as a rootless nappe (re-statement of his earlier argument of 1937) over Simla slate—Nummulitic rocks, a conclusion exactly opposite to that of mine.

Since the problem under discussion is whether the Krol belt rocks are autochthonous or allochthonous, I consider that the relationship of the Krol sequence with the rocks underlying and older to them, (Simla slate), is of fundamental importance. Since certain exceptionally well exposed sections examined by me show that the Krol sequence lies unconformably over the Simla slate, (a point which I emphasised in my paper, and which apparently seems to have escaped the attention of Auden), it must indeed indicate that the rocks in question are autochthonous and not allochthonous. I know that the contact between the Nummulitics, (in the 'windows' mapped by Auden), and the overlying Krol sequence is faulted. But then the question is: whether to join up all these faults and map them as major thrusts: Krol, Giri or Tons, and not take cognizance of the normal contacts, or explain them away as just fortuitous, or take the sections showing the normal contacts as evidence of *in situ* deposition and interpret the faults as local reverse faults.* The question, in my opinion, revolves round this point. As the sections are very well exposed, there can be hardly any doubt regarding the normal stratigraphic superposition of Krol sequence over Simla slate, (A & B of Figure 1, and 1 & 2 of Table I). Now, if we consider the relationship of the Blaini with the Simla slate near Solan Power House (number 2 in Fig. 2) and the same Blaini with the Nummulitics (which intervene in this locality between the Simla slate and Blaini) a mile to its north-west (Number 1 in Fig. 2), the Blaini at 2 would be autochthonous (because of the unconformity), while at 1, with Auden's interpretation, becomes a nappe (because the fault at the top of the Nummulitic is regarded as an over-thrust), with a horizontal movement of many miles. It is not easy to imagine such a structural plan. I would prefer to interpret that the Krol sequence in this area was deposited over a basement of Simla slate and during the post Krol—pre-Nummulitic interval, the area was uplifted and peneplaned (evidence—Nummulitics occur on different formations of the Krol belt with a pisolite-bauxite bed at the base), before it was submerged under the Nummulitic sea. The Nummulitic shales at locality 1 overlap the Simla slate—Blaini

* In this reply the terms:

1. 'Blaini' refers to the same formation described by Auden.

2. 'Autochthonous' is used to convey that the rocks in question have remained *in situ* over the basement on which they were deposited,

3. 'Allochthonous' is used to mean that the rocks in question have been sheared off from the basement on which they were deposited and were transported by large scale horizontal movements to their present position.

contact equivalent of the one at 2, and, therefore, the fault at the top of Nummulitic which brings the underlying Blaini on to them is not an overthrust but a reverse fault with roots *in situ*. In other words, if we drill on the Nummulitic outcrop at locality 1 we should meet Blaini and Simla slate below the Nummulitic (on my


Figure 1 A. Simla slate—Blaini contact along Giri river, near the junction of Kawal Khal with Giri (Number 4 of Fig. 2) 1. Simla slate 2. Blaini


Figure 1 B. Simla slate—Blaini contact south-west of Solan (Number 2 of Fig. 2) 1. Simla slate 2. Blaini

interpretation). However, such drilling will not be necessary, since a mile to the south-east along strike (Fig. 1B) erosion has exposed the same contact (Simla slate—Blaini), where it is normal.

Auden argues that if the Krol belt is autochthonous, the presence of Nummulitics in the Blaini valley must indicate deposition of Nummulitics in deeply

TABLE I

RELATIONSHIP OF THE KROL BELT SEQUENCE WITH SIMLA SLATE, AND THE TECTONIC SUCCESSION OF DIALEKH–DANG (NEPAL) REGION

| | Near Solan | Giri R. (30°52′20″ : 77°13′30″) | Kawal Khal (31°51′ : 77°11′) | Medi Gad (29°54′40″ : 78°43′20″) | Malat (30°0′ : 78°58′) | Dialekh–Dang area, generalised sequence on the Mahabharat Lekh north of Dang Valley |
|---|---|---|---|---|---|---|
| | (1) | (2) | (3) | (4) | (5) | (6) |
| Allochthonous | | | | Lansdowne Metamorphics<br>--x--x- Overthrust<br>Tal | | Dialekh Metamorphics<br>-x-x-x- Overthrust<br>Nummulitics |
| AUTOCHTHONOUS | Krol<br>Infra Krol<br>Blaini<br>-- Unconformity --<br>Simla slate | Krol<br>Infra Krol<br>Blaini<br>-- Unconformity --<br>Simla slate | Krol<br>Infra Krol<br>Blaini<br>-- Unconformity --<br>Simla slate | Krol<br>Infra Krol<br>Blaini<br>Nagthat<br>Chandpur (?)<br>-- Unconformity --<br>Simla slate | Nagthat<br>Chandpur<br>Mandhali (?)<br>-- Unconformity --<br>Deoban Limestone | -- Unconformity --<br>Mahabharat Group<br>-x-x--x--Fault<br>Nummulitics & Dagshai<br>-- Unconformity --<br>Mahabharat Group<br>-x-x--Main Boundary Fault-x-x--<br>Siwaliks |

eroded valleys or embayments. This argument would have been valid had the Nummulitic beds been occurring as horizontal strata within topographically lower parts in the Krol belt. Since these rocks show dips of the order of 40°–50° it must surely indicate post-Nummulitic folding. Therefore, the height difference between the Pachmunda hill and the Blaini valley must only be due to post-Nummulitic folding and faulting and is not due to the deposition of Nummulitics in eroded valleys in the Krol. Are we not, in fact, considering the above explanation adequate to account for the height differences between the Nummulitic outcrops on the Sirban limestone near Riasi and Bilaspur? (Nummulitics are known on Sirban limestone at an altitude of 3000 ft near Salal, (33°10′ : 74°50′) and at an altitude of 1400 ft on the right bank of the Chenab river). Similarly, Nummulitics occur over the Bilaspur

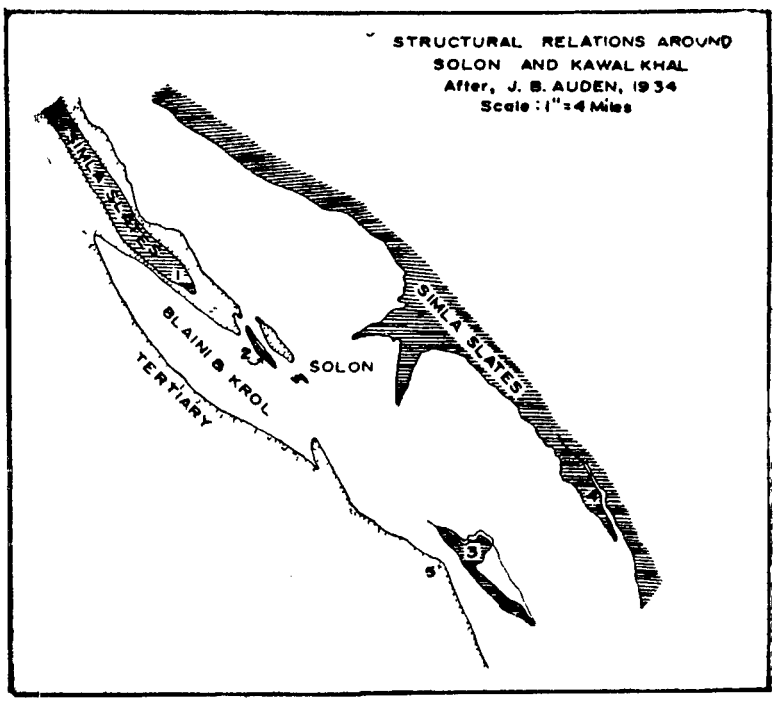



Figure 2.

limestone (local name for Sirban Limestone) near Bilaspur at an altitude of 4000 ft while a mile to the east outcrop in Ali Khad at 2000 ft height. Without question, the Sirban limestone at both these places is autochthonous and the occurrence of Nummulitics at different altitudes is only due to folding and faulting. The same considerations would appear to apply to the Solan area. The analogy would have been parallel had the Subathu beds been preserved on the Krol limestone of Pachmunda Hill and the basement of Nummulitics is the same formation. According to Auden's interpretation this diversity is because they belong to different structural units. On the other hand with autochthonous interpretation, they form one structural unit, and the diversity of Nummulitic floor is due to the deposition of Nummulitics on a peneplaned surface of this unit. Now the question is which one is correct? Apart from the evidences known already from the Nummulitic occurrences

in the Sub-Himalaya, mapping carried out by me in 1965 to the north-west of Gambhar R., also shows that Nummulitics there too occur unconformably over different lithological units of the Simla Group: Trap (this trap I believe is equivalent of Panjal Trap. Ranga Rao & Bhan 1969), Quartzite, Limestone (Kakarhatti limestone) and Shale (Simla slate of earlier workers) with a thick bauxite bed at the base. The distribution, facies and the relationship of the Nummulitics with the Simla Group suggests that the area was reduced to a peneplane before the Nummulitic transgression. Therefore the variation in the Nummulitic floor and the height differences in Nummulitic outcrops is due to folding and faulting that this surface has undergone in post-Nummulitic times, and is not because of their belonging to different structural units as required by the nappe hypothesis.

In the Krol belt proper, ten miles to the south-east of Pachmunda, in the same strike Nummulitics occur over the Krol limestone at 6,500 ft height near Bagar. But then, with Auden's interpretation these Nummulitic outcrops belong to a different sedimentation belt. Had this been so, Nummulitics occurring over the Krol belt should show variation in the facies and faunal assemblage from those that are occurring on the Simla slate. The absence of any such variation indicates that these Nummulitic outcrops are erosional remnants of a once continuous cover over the Simla slate—Krol sequence and do not belong to two different sedimentation belts; one of which (Nummulitics near Solan) remained *in situ,* while the other (Nummulitics near Bagar and along Ganges etc.) was translated over the former by post-Nummulitic thrusting.

Auden further writes, that if the Nummulitics were deposited over an eroded surface of Krol and older rocks and subsequently folded and faulted, the same formation that underlies the Nummulitics should also overlie them. He quotes, occurrence of Chail over Nummulitics in the Shali, Chandpur over Nummulitic in Lansdowne region, and Dialekh metamorphics over Eocene in Dialekh area as evidences, which are definitely allochthonous. But, then, are we justified to draw analogies from these occurrences and conclude that the structure of the Krol belt is also a nappe? Can we draw conclusions about the structure of the Foot-Hill Tertiary belt from the studies in the Krol belt alone?

Auden argues that the occurrence of Subathu over the Simla slate in Bidhalna Rao and Chandna Rao and on Tals only 12 km away across the Ganges would require us to consider (if autochthonous) that at Bidhalna Rao nearly 2000 m of sediments were eroded away during the pre-Eocene times. Auden considers that there is no evidence to assume such an erosion and therefore interprets that the Simla slates with Nummulitics formed the autochthonous basement and the Krol sequence rests upon it as a rootless nappe.

I cannot share Auden's view that there was no erosion during the Mesozoic, since examination of the thicknesses of different members of the Krol sequence in undisturbed sections (Fig. 3) indicate that there was indeed considerable erosion during this period, and that the basin during Tal deposition was narrower than in Krol times. For example, near Mussorie, the Lower Tals rest on Krol E (1240 ft thick) while in Medi Gad they rest unconformably over Krol D indicating removal of nearly 4000 ft of Krol rocks during the pre-Tal times. The absence of Tals to the west of longitude 77°25′ must indicate non-deposition in that region as in Koti Dhaman syncline, the Upper Tal quartzites become pebbly and coarser (Auden 1934) than the same horizon further to its east. Similarly, the total thickness of Tal is

4500 ft in Chipaldi Nala (Fig. 3) while in Medi Gad it measures only 180 ft. The coarser facies in the Medi Gad region indicate that it formed the eastern edge of the Tal basin. Therefore, it is clear that during the Tal times erosion was going on at places while deposition was taking place at other places.

The explanation I would offer for the occurrence of Nummulitics on Simla slates in Bidhalna Rao and Chandna Rao (also of Kawal Khal and Solan) is that these outcrops represent part of an upwarp (Ranga Rao 1963) within the Krol basin separating at least locally in Bidhalna-Ganga region into two areas of deposition: Mussorie and Garhwal areas. On the upwarp the Krol belt sequence either was not deposited or was thinly deposited and was subsequently eroded away, while comparatively greater thickness of sediments accumulated in the Mussorie and Garhwal regions in the same time interval. The difference in the facies of Krol sequence outcropping in the two synclinal areas support such a postulation. Only during the Nummulitic times the whole region including this upwarp was submerged under the sea and the present outcrops of Nummulitics on Simla slates in Bidhalna and Chandna Rao, on Tal in the Ganges region are erosional remnants left over as a witness of this transgression.

Auden further writes that since Nummulitics are thrust over the Lower Siwalik between Dadahu and Kalsi, the Nummulitics of this region cannot be considered as autochthonous. In my opinion, such a conclusion does not support Auden's case, since on this analogy the reverse faults in the Siwalik belt bringing older Siwaliks on to the younger Siwaliks would also have to be regarded as real overthrusts and consequently the structures above them as nappes. It is true that the Subathu of the Tertiary belt is separated (though not always, as in Kawal Khal) by a fault (Krol Thrust or Main Boundary Fault) but the question is whether it is a reverse fault (which it is with my interpretation) or a folded thrust plane (as in Auden's interpretation) joining up with the Tons Thrust near Dabra. I consider that the Krol Thrust was originally a normal, syn-sedimentary down to basin fault(s) originated sometime during the post-Laki times (no younger sediments are known to the north of this fault), with downthrow to the south creating the Tertiary foredeep. This fault in the post-Siwalik times became an up thrust and the Krol belt rocks were thrust over the rocks of the Foot-Hill Tertiary belt. Evidences for this interpretation are:

1. The surface trace of the thrust is more or less a straight line indicating that the angle of dip is high. (The low dips recorded at places could be due to movement at the brow of the up-thrust block over the eroded surface of the sub-thrust unit by the reactivation of the fault in Late Tertiary).

2. At places, as in Kawal Khal, instead of the fault the original foundation on which the Nummulitics were deposited is preserved (cross section No. 3 of Fig. 4).

3. At other places as between Subathu and Naugaon (31°16′30″ : 74°54″) it is made up of several *en echelon* faults.

From the above it is logical to assume that the Krol thrust is neither a folded thrust plane (as in Auden's interpretation) nor it forms the basis of a large nappe (as in Gansser's interpretation (1964)—Eocene is shown in the Subthrust to extend up to the Main Central Thrust—Fig. 2. A Section through Kumaon Himalayas) with a horizontal movement of 100 km or more, but is an up thrust and is located essentially in its primary position without any large scale horizontal movement.

Finally, Auden quotes a parallel to Dadahu area from Nepal where the Eocene

# STRATIGRAPHIC COLUMNS
## FOR
## TRAVERSES IN THE KROL BELT BETWEEN MUSSOORIE & LANSDOWNE
(THICKNESS IN FEET)

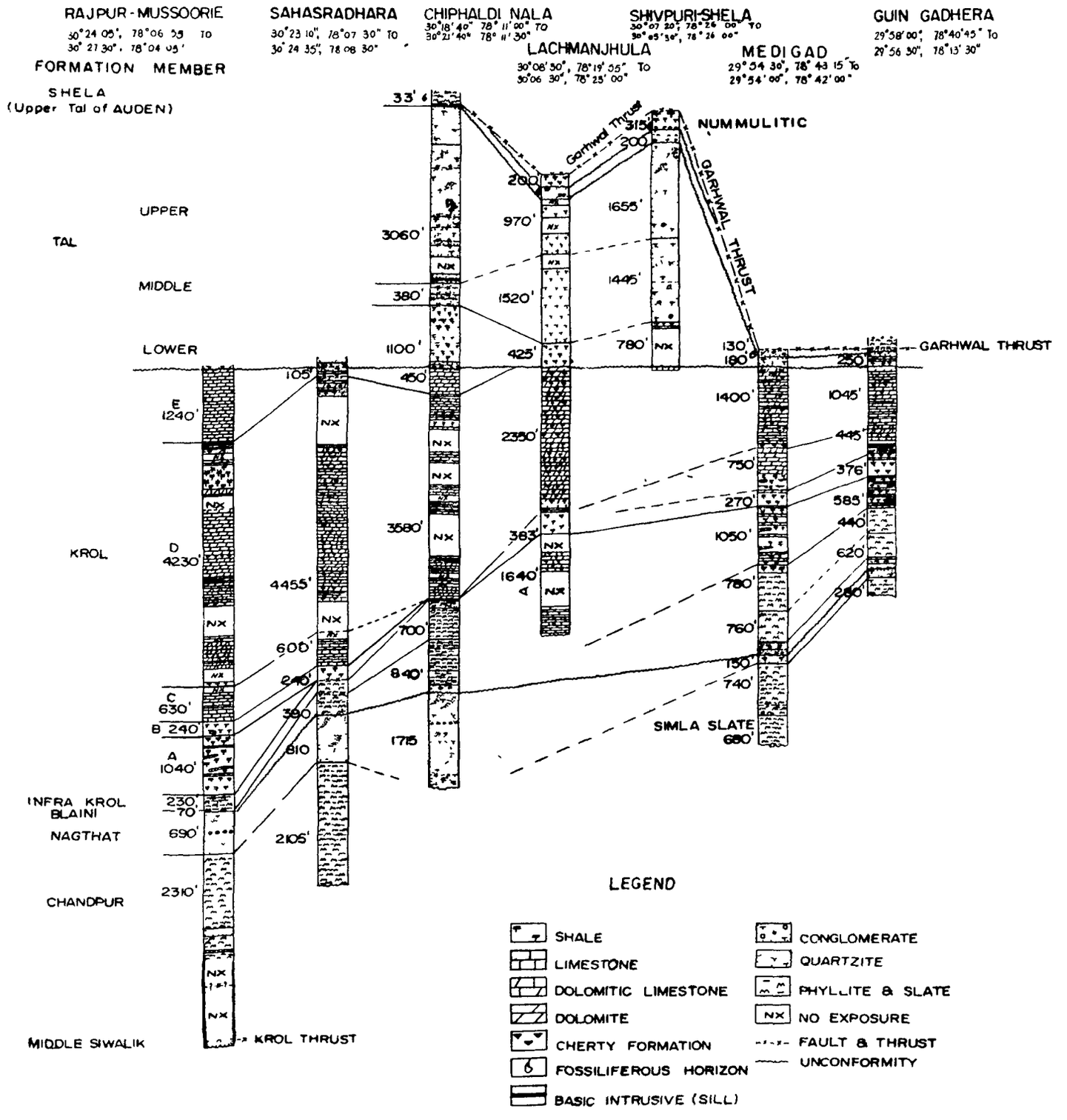
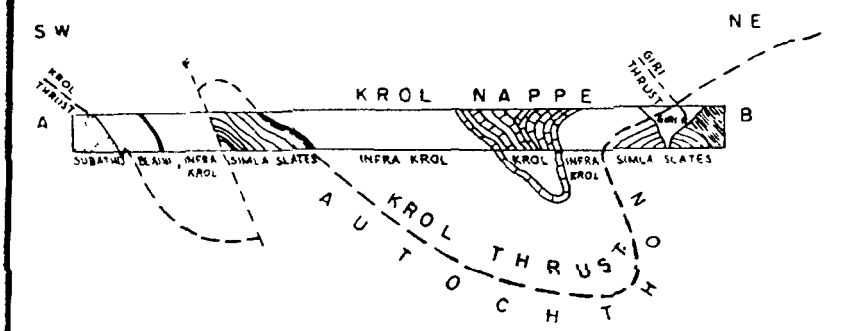
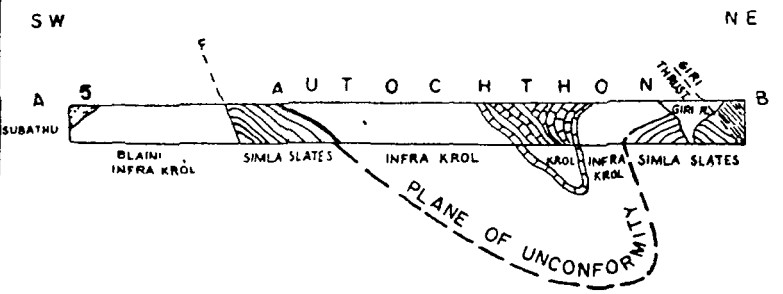



Figure 3.

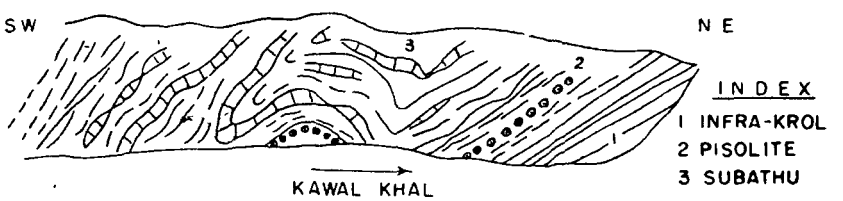
(Authors: A. R. Rao *et. al.* 1960)




1. SECTION ALONG KAWAL KHAL- AFTER AUDEN WITH NAPPE INTERPRETATION




2. SECTION REDRAWN BY THE AUTHOR




3. SECTION NEAR THE INFRA KROL—SUBATHU CONTACT AT '5' OF SECTION - 2.

SCALE IN SECTIONS 1 & 2 : HORIZONTAL SCALE 1" = 1 MILE
VERTICAL SCALE DIAGRAMATIC, SECTION 3 IS DIAGRAMATIC

Figure 4.

rocks are thrust over the Siwaliks and are in turn overthrust by the Dialekh metamorphics. From this Auden concludes that the Nummulitics here too cannot be regarded as autochthonous. In my opinion, this only indicates that the Dialekh metamorphics are allochthonous and not the underlying Nummulitics. I have mapped the area between the east of Dialekh up to Palpa and in the north up to Dhor Paten (28°29′ 83°03′), and I had always found Nummulitics lying unconformably over the Mahabharat Group (Dang Series of G.S.I., and Piuthan Zone of Toni Hagen) and are thrust over by Dialekh metamorphics and their equivalents. Outcrops of the Mahabharat group are seen up to the Main Central Thrust and Nummulitics are known to occur over these rocks far in the interior Sub-Himalaya near Dhading, (28°38′ : 82°38′), north of Rukumkot. Rocks of Mahabharat Group are also met with (correlation on the basis of lithological similarity) in a deep well drilled near Raxaul (26°56′28″ : 84°50′28″). Therefore, the Mahabharat group with Nummulitics formed the autochthonous zone over which the Dialekh metamorphics are overthrust, and hence only the Dialekh metamorphics and their equivalents form real thrust sheets. Reverse faults with large displacements do occur within the Mahabharat and Nummulitic zone but these faults root *in situ* and therefore the term autochthonous to this zone seems to be justified. I too have come across reports of the presence of coal beds in the Eocene of Nepal when I began mapping there in 1959 but have not been able to confirm their presence anywhere in the entire strike distance of 120 km of the Eocene belt that I mapped between east of Dialekh up to Palpa.

The other points raised by Auden in support of the absence of fjord topography in the Indian Peninsula during Nummulitic times need not be dealt here, since as shown above, Krol autochthonous theory does not warrant presuming the existence of such a topography.

Auden's position would have been sound, had he tried to fit the facts on which the autochthonous interpretation is mainly based: Simla slate—Blaini unconformity, Blaini—Nummulitic unconformity and the absence of roots, into his nappe hypothesis, instead of laying stress only on the position of Nummulitics. However, he promises to discuss about the root problem at a later date.

In summary. Nummulitics were deposited over a peneplaned surface of Krol and older rocks, and this peneplane was uplifted and folded by neotectonic movements (Miocene and post-Miocene) when Chail, Jutogh, Chandpur (?) of Lansdowne, Almora and Dialekh metamorphics were thrust over the Nummulitics. Therefore, only the latter can be designated as real overthrust sheets. The Simla slate—Krol belt sequence along with the Nummulitics form the autochthonous zone, (Section 2 of Fig. 4).

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