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A phenomenon of unusual flattening in folds associated with a Himalayan thrust

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Abstract

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The paper reports a phenomenon of flattening in mesoscopic folds around a major geotectonic element of the Himalaya, called the Main Central Thrust (MCT). The study demonstrates that the amount of flattening of folds gradually increases towards the MCT. The MCT zone itself shows the strongest flattening of associated folds. A direct control of the MCT is established over the fold shape in a zone of 5 to 6 km across. This phenomenon appears significant for the Himalayan terrain. It is held to represent a well-defined zone of ductile deformation around a 'ductile thrust'.

Introduction and geological setting

The paper presents some results of flattening measurements in mesoscopic folds in a zone along the Main Central Thrust (MCT) of the Himalayas, where the Central Crystalline Zone of the Greater Himalayas has been thrust southwards over the (younger) sedimentary belt of the Lesser Himalayas. The study is confined to an area of about 250 km^2 covering a 20 km strike of the MCT in the northern Pithoragarh district of the Kumaun Himalayas (Fig. 1). The terrain is highly rugged and inhospitable, but the exposures are much better than in many other sections. Aspects of geology, stratigraphy and structure of the area have already been presented (Bhattacharya 1979, 1980 a, 1982, 1983 a) in addition to the generalised work of Heim & Gansser (1939) and Gansser (1964).

The Kumaun region contains all the four major lithotectonic-physiographic subdivisions of the Himalayas of Gansser (1964). They are, from south to north (Fig. 1): (A) The Outer Himalaya (mainly with the molassic Siwalik Supergroup), which is delimited in the north by the Main Boundary Fault from (B) the Lesser Himalaya (with highly folded Precambrian – ? Palaeozoic (meta)sedimentary strata together with a few outcrops of older crystalline rocks). The Lesser Himalaya in turn is bounded in the north by the MCT against (C) the Greater Himalaya (north-dipping metamorphics of the Central Crystalline Zone), which is separated by the Martoli Fault from (D) the Tibetan or Tethys Himalaya (with a thick pile of sediments of Cambrian to Cretaceous ages).

The Central Crystalline Zone to the north of the MCT in the study area is composed of meso to kata zonal rocks (Misra & Bhattacharya 1976; Bhatta-

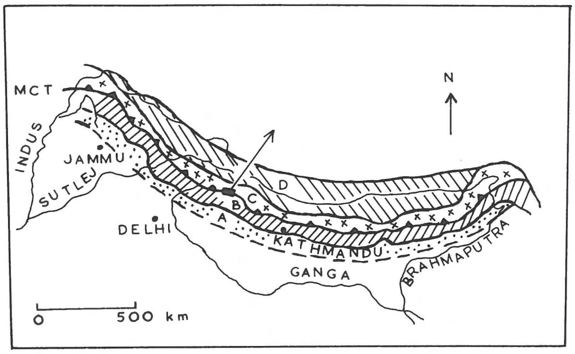

Fig. 1. Geological sketch map of the Himalaya showing the position of the Main Central Thrust. A, Outer Himalaya; B, Lesser Himalaya; C, Greater Himalaya; D, Tethys Himalaya. The area studied is indicated by an arrow.

charya 1980 b) comprising a lower Dhakuri Formation (dominantly augen gneisses) and an upper Khati Formation (various types of schists, calc granulites, marbles, pegmatites and massive granites). The sedimentary belt south of the MCT is regionally folded into the ESE-WNW trending Tejam Anticline and is represented by – from old to young – the argillaceous Hatsila Formation, the calcareous Kapkot Formation, the phyllitic Saling Formation and the arenaceous Berinag Formation (Bhattacharya 1979, 1982). The recent discovery (Bhattacharya 1983 b) of a very rare and typically Lower Riphean stromatolite *Plicatina* from the Kapkot Fm may broadly indicate a Riphean age for the sedimentary belt, so far broadly believed to be of Upper Precambrian age. The Central Crystalline zone is conventionally believed to be of even more ancient age (Archaean – Lower Precambrian) (see Krishnan 1982).

Main Central Thrust

The Main Central Thrust is a major tectonic element of regional significance in the Himalaya. The minor folds on either side, remote from the MCT, are of the open type with large interlimb angles (up to 90°). They become gradually more tight with very small interlimb angles (down to 15° or even less) as the thrust is approached. There is a general tendency for the neoformation of highly platy minerals towards the MCT. Interestingly, there is a general absence of parallel folds in the area, and all are flattened folds of Ramsay's (1967) 1C, 2 and 3 class (Fig. 4). This fact enabled a systematic (quantitative) study of the phenomenon of flattening in the folds of the area. Other aspects of the MCT have been presented earlier (Bhattacharya 1979, 1980 a, 1982; Misra & Bhattacharya 1976).

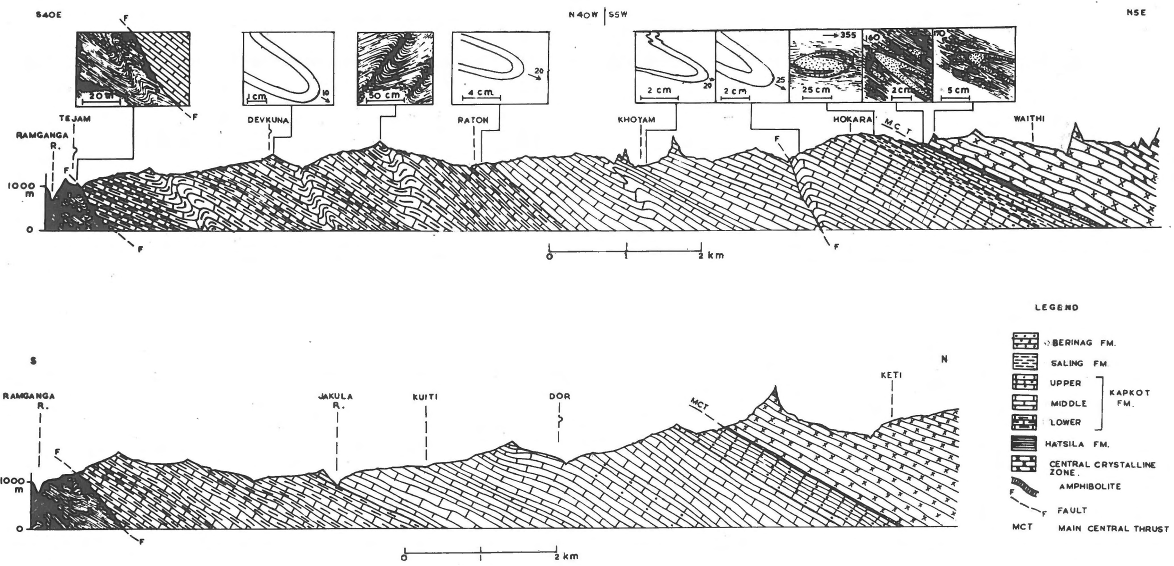

Fig. 2. Geological cross-sections to show the structure in the western (upper) and eastern (lower) parts of the area (along the traverses T_1 and T_6 respectively in Fig. 7).

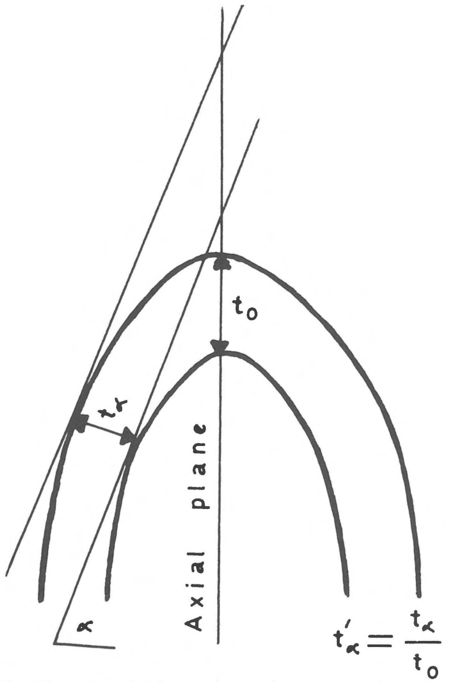

Fig. 3. Profile of a fold to show the parameters used for calculating the flattening (after Ramsay 1962). The symbols have been explained in the text.

Distribution of flattening data

Since shortening of parallel folds can never exceed 36 percent (De Sitter 1964), continuing shortening is possible only by flattening of the previously formed fold. This occurs when the fold limbs become parallel to the axial plane. Further deformation takes place by thickening of the bed at the hinge and stretching of the fold limbs. The folds of the area under study typically exhibit these flattening characteristics. They also show marked variations in the curvature of the folded layers on the convex and concave sides of the folds and they have a low wavelength/amplitude ratio. These data are rather difficult to explain by pure buckle folding. Instead, there must have been a marked amount of extension along the axial traces of the folds, assumed to be the result of the flattening of buckle folds.

Methods for calculating the flattening of originally parallel folds have been suggested by Ramsay (1962) and Hudleston (1973). In this study, Ramsay's method has been followed. On the basis of profiles of folded competent layers (Fig. 3), $t'_\alpha = t_\alpha/t_o$ has been calculated; t_α is the orthogonal thickness of the two parallel tangents drawn on a selected competent bed and t_o is the thickness of the folded material at the hinge measured along the axial trace of the folds. α is the angle of the tangents

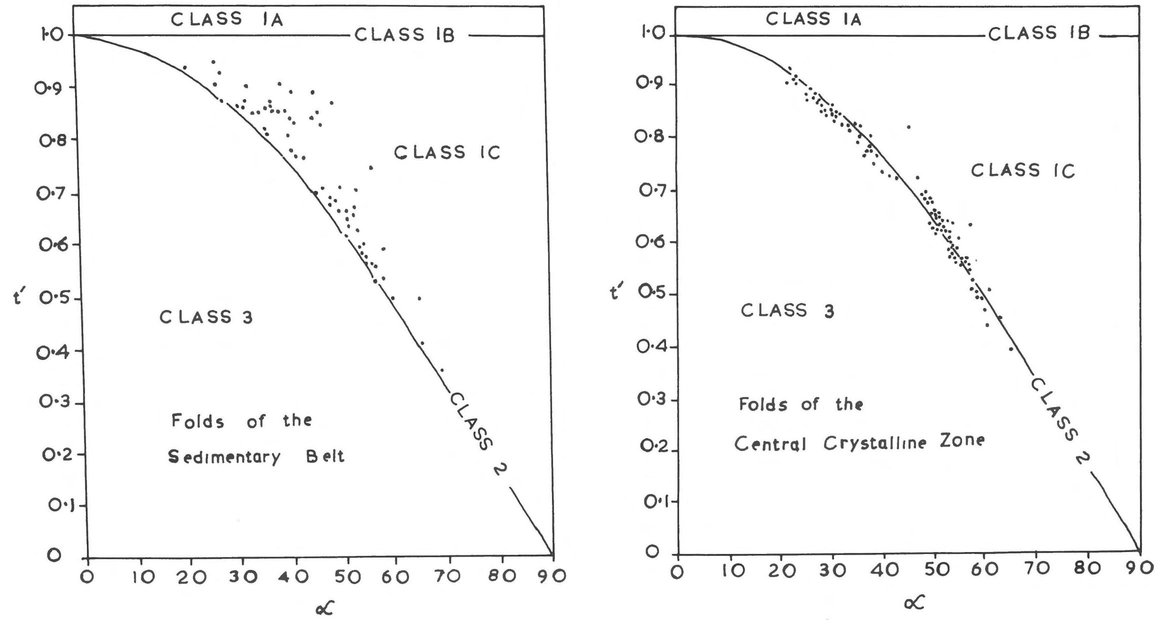

Fig. 4. Plots of folds of the sedimentary belt (left) and the Central Crystalline Zone (right) on Ramsay's (1962) graph. Note all the folds are flattened folds belonging to classes 1C, 2 (similar) and 3.

with the axial trace. From a plot of α versus t_α' on the Ramsay (1962) graphs (Fig. 5), the percentage of flattening can be directly read. In each fold, two points on either limb have been plotted. All these points fall on a curve which, according to Ramsay (1962), '. . . indicates that the flexure folds have been flattened by the amount indicated by the curve itself'.

Flattening (Fig. 5) has systematically been measured along six north-south traverses across the strike of the rock formations as well as across the MCT. Folds have not been noticed in the quartzites (Berinag Fm) and phyllites (Saling Fm) of the area but only in the sediments and crystalline rocks. The measurements clearly indicate that (1) the MCT is characterised by the highest value of fold flattening: usually > 60 percent in the sedimentary rocks and > 90 percent in the crystalline rocks, (2) the flattening values gradually decrease away from the thrust within a tract of 5 to 6 km extent on either side and (3) outside this tract, the values reduce to a low to moderate range (40 to 15 percent) in the sedimentary rocks and up to around 45 percent in the crystalline rocks (see Fig. 7). The area around the MCT, in contrast to other areas and tectonic planes of the Himalayas (see Bhattacharya 1979,

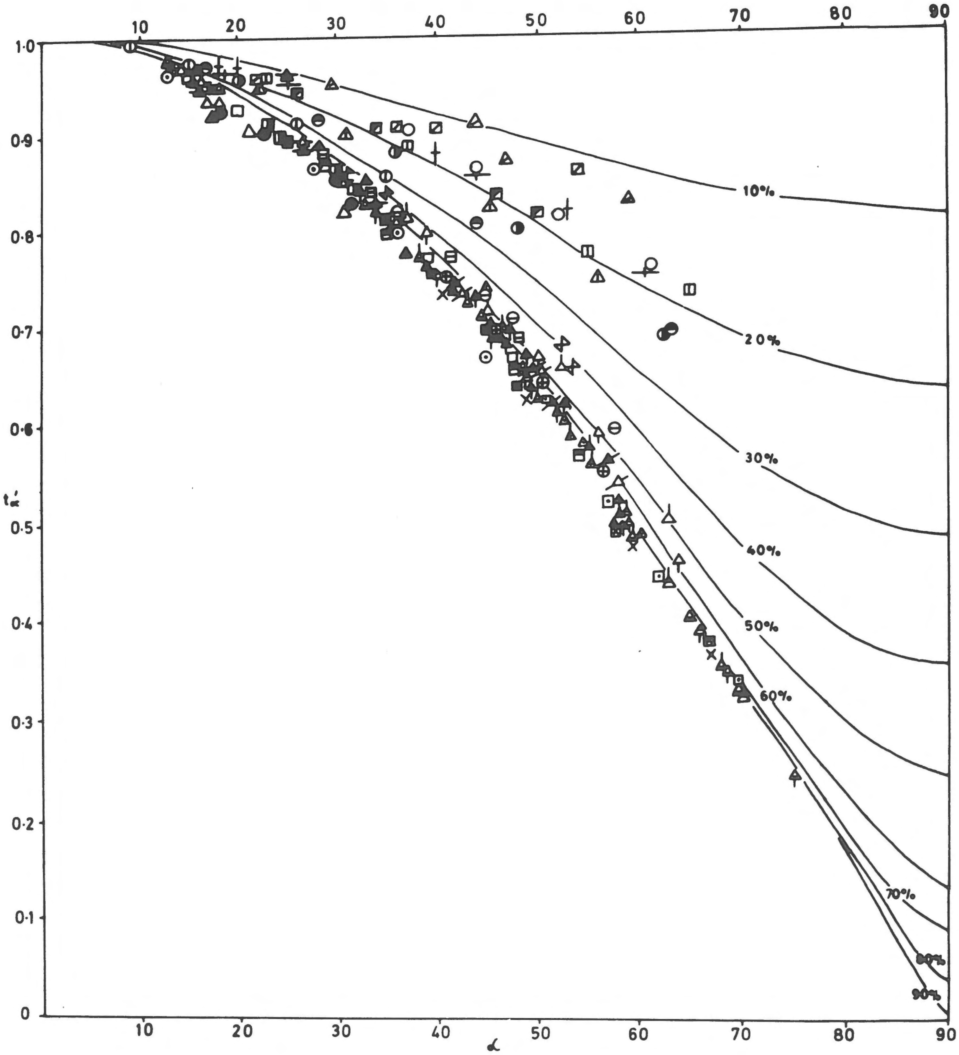

Fig. 5. Plot of α versus t_α' for the folds of traverse T_1 (Fig. 7) on Ramsay (1962) graph for measurement of flattening. Individual folds have been represented by four points with similar ornaments. The folds of only one traverse are presented here to demonstrate the applied method.

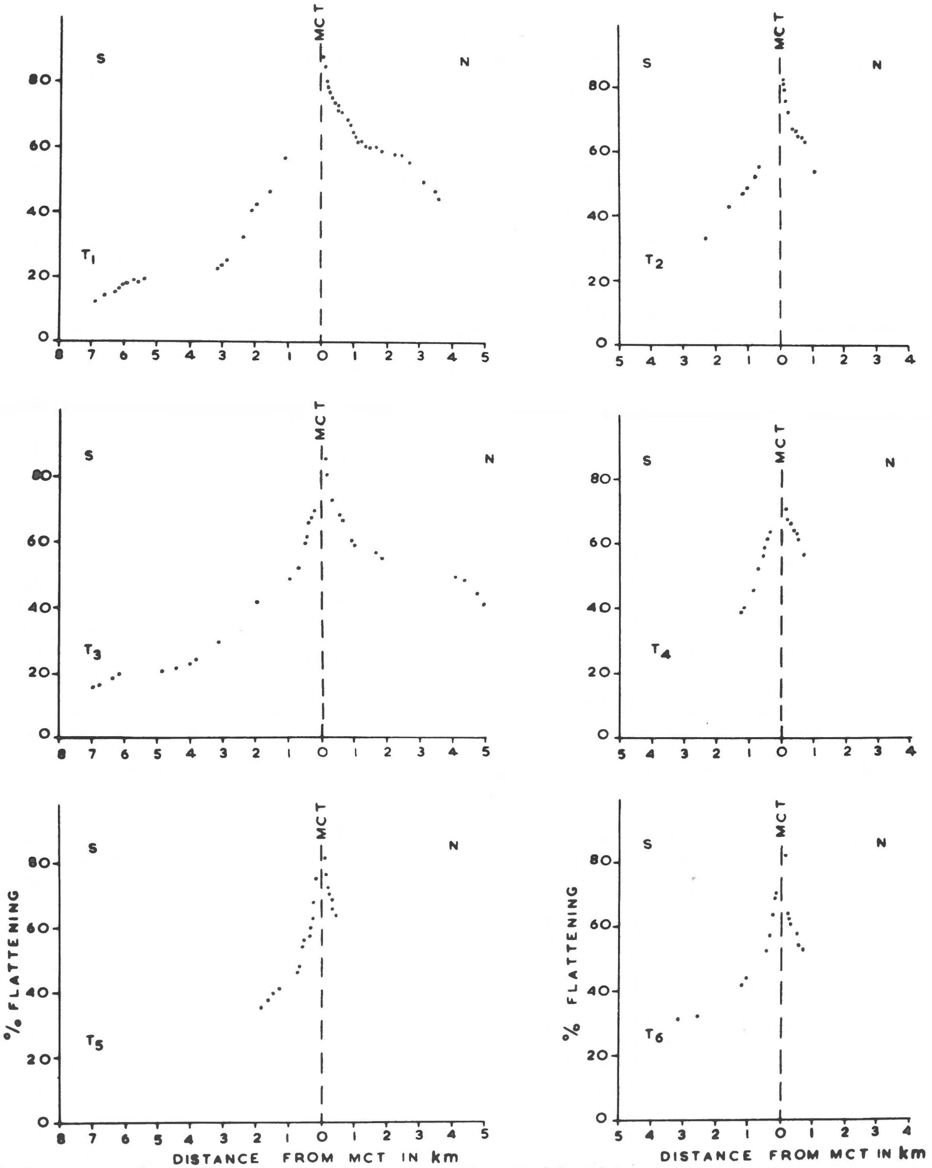

Fig. 6. Graphical representation of flattening data for traverses T_1 to T_6 (Fig. 7) in relation to MCT. The graphs indicate the gradual increase of flattening towards the MCT, where it reaches its maximum.

1980 a, 1982, 1983 a), appears to be unusual in the sense that the thrust appears to be the controlling factor responsible for the observed stronger flattening of the folds.

Discussion and conclusions

The spatial distribution of the data in relation to the MCT (Fig. 7) indicates that there is lateral continuity in the amount of flattening. This can be shown by *flattening contours* around this particular Himalayan thrust (compare Bhattacharya 1980 a). The contour with the highest value coincides with the thrust. A flattening pattern of this type is restricted to the area around the MCT and has not been found elsewhere in the Himalayas.

The folds developed within a wide ductile tract on either side of the MCT, show higher values of flattening than folds further away from the MCT.

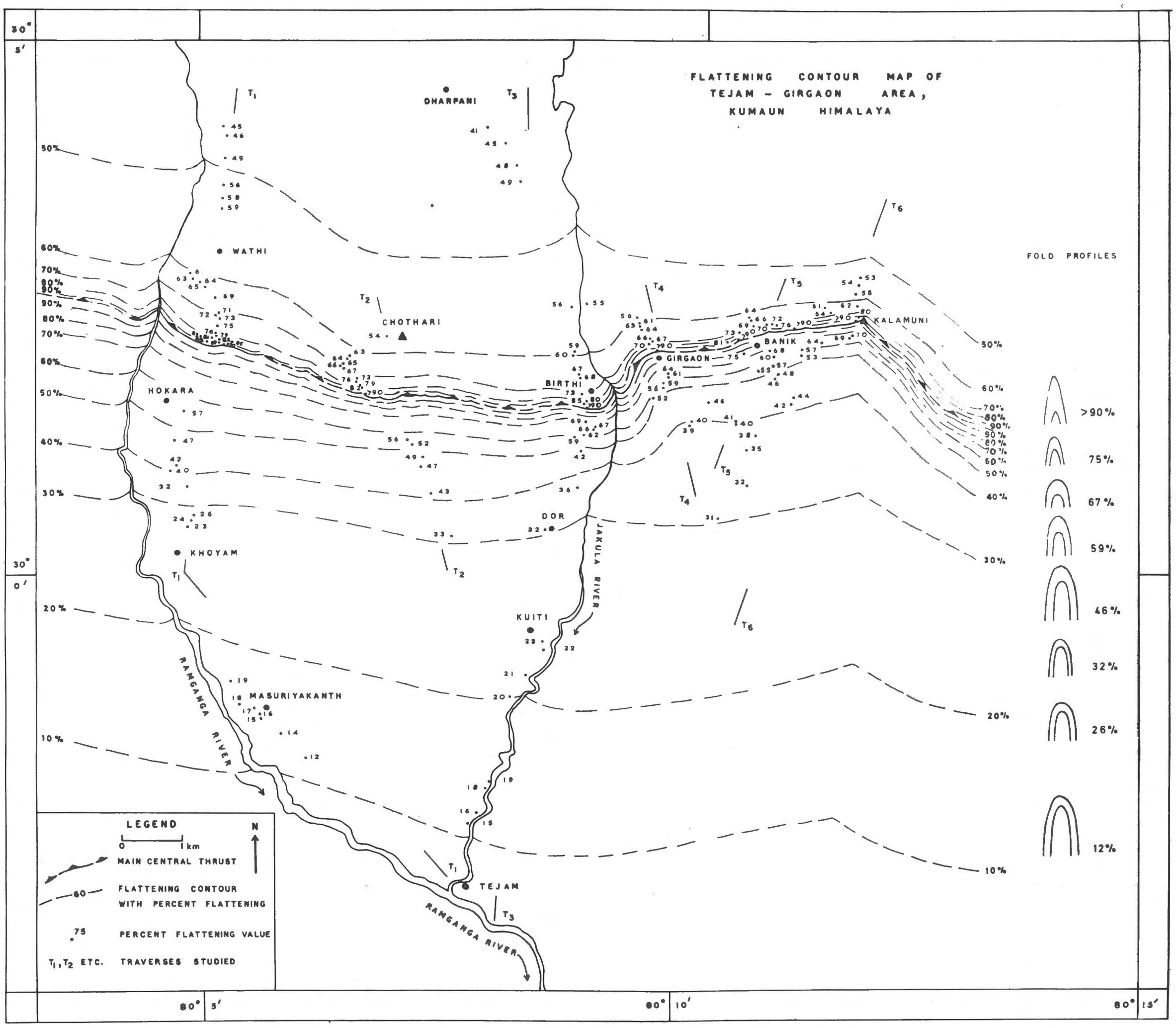

Fig. 7. Spatial distribution of flattening data in the area around the MCT. Each point represents a location and its flattening percentage. 'Flattening contours' for the area have been indicated. The highest value is reached at the location of the MCT. Note the remarkable regularity of the increase in flattening towards the MCT.

Further, pre-thrusting folds and their interference patterns – so common elsewhere (see Bhattacharya 1982; Misra & Bhattacharya 1976) – are typically absent in the area around the MCT, where the fold axes tend to be geometrically related to the direction of thrusting, possibly due to rotation towards the shear direction. It follows that the relationship between foldform and thrusting can genetically be explained by folding and subsequent modification by strains associated with thrusting.

Flattening in folds, by definition, is generally the result of a modification of their shapes by the superimposition of homogeneous strain, or some flattening process, in environments where the rock materials are ductile during deformation. Folds with very high flattening values thus indicate that they underwent strong ductile deformation.

There are several arguments in favour of a deep intracrustal character of the MCT (cf. Le Fort 1975; Pecher 1977; Valdiya 1981). The huge pile of about 12 000 m crystalline rocks which once formed the basement of a 12 000 m thick pile of Tethyan sediments, has now been elevated to heights of more than 6 000 m above sea level, implying a vertical uplift of at least 20 000 m for the base of these crystalline rocks. Further arguments are of microscopic/metamorphic/microstructural character (for details, see Bhattacharya & Siawal, in prep.) The intensity of deformation and the degree of metamorphism show a gradual increase towards the thrust, from greenschist facies to granulite facies. Fold hinges tend to be more or less curvilinear, showing marked effects of recrystallisation and grain rotation. Generally the most common rock types at the MCT are gneisses and marble (rarely, highly recrystallised quartzite) respectively on the crystalline and sedimentary side. On a regional basis, the MCT coincides with a line of hot springs (see Jangpangi 1976; Bhattari 1978) and with a zone of prominent seismic activity (see Le Fort 1975; Kaila & Narain 1976).

In conclusion: the MCT is a 'ductile thrust' developed at a deep crustal level. None of the above attributes of the MCT are present elsewhere in the Himalayan region. Other Himalayan faults could be considered as 'brittle faults' restricted to shallower levels of the crust. The MCT thus appears to be unique among the Himalayan thrusts.

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References

Bhattacharya, A.R. 1979 New light on the stratigraphy and structure of the Kumaun Lesser Himalaya: A study in mathematical perspective. In: P.S. Saklani (ed.): Structural Geology of the Himalaya - Today & Tomorrow's Publishers (New Delhi): 149-167

Bhattacharya, A.R. 1980 a A concept on the origin of similar and related folds: Based on the study of Himalayan tectonites – Proc. Indian Natl. Sci. Acad. 46 A(1): 72-80

Bhattacharya, A.R. 1980 b A new scheme of structure and stratigraphy of Kumaun-Garhwal Himalaya with special reference to tectonic evolution, nappe concept and Himalayan palaeogeography (Abs.) – 26th Int. Geol. Congr, Paris, Section 5: 319

Bhattacharya, A.R. 1982 Geology of the Thal-Tejam-Girgaon area, Kumaun Himalaya, with special reference to the record of Schuppen structures and measurement of flattening in folds – Geosci. J. 3: 27-42

Bhattacharya, A.R. 1983 a On the nature of the Main Boundary Fault in Kumaun-Garhwal Himalaya with special reference to measurement of flattening in folds – Neues Jahrb. Geol. Palaeont. Monatsh. 1983: 193-204

Bhattacharya, A.R. 1983 b Record of the stromatolite *Plicatina* from India – Geol. Mag. 120: 543-548

Bhattari, D.R. 1978 Some geothermal springs of Nepal – Proc. Geodyn. Conf., Kathmandu Tectonophysics 62: 7-11

De Sitter, L.U. 1964 Structural Geology – McGraw-Hill (New York): 551pp

Gansser, A. 1964 Geology of the Himalayas – Interscience (London): 289 pp

Heim, A. & A. Gansser 1939 Central Himalaya: Geological observations of the Swiss expedition – Mem. Soc. Helv. Sci. Nat. 75: 1-245

Hudleston, P.J. 1973 Fold morphology and some geometrical implications of theories of fold development – Tectonophysics 16: 1-46

Jangpangi, B.S. 1976 Thermal springs of southern Bhutan – Geol. Surv. India, Misc. Publ. 24: 459-464

Kaila, K.L. & H. Narain 1976 Evolution of the Himalaya based on seismotectonics and deep seismic soundings – New Delhi Sem. Himalayan Geol., Spec. Publ., NGRI, Hyderabad: 30 pp

Krishnan, M.S. 1982 Geology of India and Burma – CBS Publishers (New Delhi): 536 pp

Le Fort, P. 1975 Himalayas, the Collided Range: present knowledge of the continental arc – Am. J. Sci. 245 A: 1-44

Misra, R.C. & A.R. Bhattacharya 1976 The Central Crystalline Zone of northern Kumaun Himalaya: its lithostratigraphy, structure and tectonics with special reference to Plate tectonics – Himalayan Geol. 6: 133-154

Pecher, A. 1977 Geology of the Nepal Himalaya: Deformation and petrography in the MCT zone – In: Himalaya, Sciences de la Terre – CNRS: 301-318

Ramsay, J.G. 1962 The geometry and mechanics of formation of 'Similar' type folds – J. Geol. 70: 309-327

Ramsay, J.G. 1967 Folding and Fracturing of Rocks – McGraw-Hill (New York): 568 pp

Valdiya, K.S. 1981 Geology of Kumaun Himalaya – Wadia Inst. Himalayan Geology (Dehra Dun)