Sedimentary facies and soft-sediment deformation structures in the late miocene-pliocene Middle Siwalik subgroup, eastern Himalaya, Darjiling District, India

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Abstract

The Himalayan fold-and-thrust belt has propagated from its Tibetan hinterland to the southern foreland since ~55 Ma. The Siwalik sediments (~20 - 2 Ma) were deposited in the frontal Himalayan foreland basin and subsequently became part of the thrust belt since ~ 12 Ma. Restoration of the deformed section of the Middle Siwalik sequence reveals that the sequence is ~325 m thick. Sedimentary facies analysis of the Middle Siwalik rocks points to the deposition of the Middle Siwalik sediments in an alluvial fan setup that was affected by uplift and foreland-ward propagation of Greater and Lesser Himalayan thrusts. Soft-sediment deformation structures preserved in the Middle Siwalik sequence in the Darjiling Himalaya are interpreted to have formed by sediment liquefaction resulting from increased pore-water pressure probably due to strong seismic shaking. Soft-sediment structures such as convolute lamination, flame structures, and various kinds of deformed cross-stratification are thus recognized as palaeoseismic in origin. This is the first report of seismites from the Siwalik succession of Darjiling Himalaya which indicates just like other sectors of Siwalik foreland basin and the present-day Gangetic foreland basin that the Siwalik sediments of this sector responded to seismicity.

Keywords: soft-sediment deformation ; Seismite ; Siwalik ; Neogene ; Foreland basin ; Siwalik Sedimentary facies

INTRODUCTION

Penecontemporaneous deformation structures generally form in unconsolidated to partly consolidated fluid-laden sand intercalated with finer sediments (Einsele et al. 1996). These structures may be: (i) syn-depositional (deformation event effective during deposition), (ii) meta-depositional (deformation after deposition but before sedimentation of younger layer) and (iii) post-depositional (deformation after deposition of the younger layer) (Nagtegaal, 1963, 1965; Allen, 1982; Owen, 1995; Mazumder et al. 2006). Though meta-depositional deformation is rarer than the other two, seismic shocks are potential triggers for meta-depositional deformation as the deformations occur after some degree of consolidation of sediments. (Mazumder et al. 2006).

Deformation of the unconsolidated sediment may be sedimentary or tectonic in origin (Owen, 1987); analogously, Leeder (1987) distinguished "allokinetic" deformation structures formed by earthquake-related stresses, from "autokinetic" or those formed solely by sedimentation processes (Røe and Hermansen, 2006). Van Loon (2009) divided these structures on the basis of genesis into (1) endoturbations (formed due to endogenic forces particularly earthquakes), (2) graviturbations (formed under the gravitational control) and (3) exoturbations (formed due to exogenic factors including sedimentation and bioturbation processes). From a single structure it is almost impossible to specify seismicity as the trigger event, but many workers have summarized some collective attributes of the soft-sediment deformation features for such an interpretation. These include the presence of soft-sediment deformation structures in discrete sediment horizons (Mazumder et al. 2006 and references therein), lateral continuity of such beds (Obermeier, 1996), their vertical repetition within a succession (Mazumder et al. 2006), presence of bounding undeformed beds (Sims 1973, 1975), presence of various soft-sediment deformation structures together (Kleverlaan, 1987; Obermeier, 1996; Pope et al. 1997; Rosetti and Góes, 2000), association with sedimentary breccias, conglomerate and massive sandstone (Mazumder et al. 2006), and deviation of palaeocurrent indicators from the normal palaeoflow pattern (Mazumder et al. 2006). According to Wheeler (2002), there will always be some degree of uncertainty about the seismic origin of soft sediment deformation structures because other causes for formation of similar structures cannot be easily ruled out. He proposed that the seismic origin of a soft sediment deformation structure or a group of structures can be tested with evidences of sudden generation of such structures, synchroneity, wide spatial distribution and favourable tectonic and depositional setting.

This paper aims to examine soft sediment deformation structures from fluvial deposits within the Neogene Middle Siwalik Subgroup of eastern Himalaya, Darjiling district, India. The source of sediments of the Siwalik basins is mainly from the rocks of the Greater Himalayan Crystalline Complex (GHC) to the north (DeCelles et al. 1998; White et al. 2001). Keeping in view the syn-tectonic deposition of Middle Siwalik sediments within the foreland basin of the Himalayan orogenic belt (Moores and Fairbridge, 1997) during the uplift of GHC in the Middle and Late Miocene (Negi, 1998; Tabata, 2004; Yin, 2006 and references therein), a strong case can be made for a predominantly seismic origin for the penecontemporaneous deformation structures in the Middle Siwalik sequence. Evidences of paleoseismicity have been reported from Siwaliks of western Himalaya (Kumar et al. 2005; Singh et al. 2007). This paper presents the first report of a suite of soft sediment deformation structures from the Middle

Siwaliks of the eastern Himalaya of India within a set of fluvial deposits. These structures are related to a predominantly tectonic rather than a sedimentary origin. This paper thus also aims to contribute to the ongoing debate on the folding of the cross beds to recumbent folds in soft sediment deformation (e.g., Røe and Hermansen 2006, 2007; Mazumder and Altermann, 2007).

GEOLOGICAL SETTING

The fold and thrust belt of the Himalayan orogen (Fig. 1) consists of the following major structural units from north to south: South Tibet Detachment (STD) hanging wall, Main Central Thrust (MCT) sheet, Ramgarh Thrust sheet, Lesser Himalayan Duplex (LHD), Main Boundary Thrust (MBT) sheet and Main frontal Thrust (MFT) sheet. The STD hanging wall consists of Proterozoic-Eocene marine fossiliferous rocks of the Tethyan Himalayan Sequence; the MCT carries Proterozoic-Ordovician metamorphites of the GHC; the Ramgarh Thrust (locally designated as North Kalijhora Thrust, (Mukul, 2000) carries the Proterozoic Lesser Himalayan metamorphic sequence (DeCelles et al, 1998; Mukul, 2000) over the Gondwanas and the MBT carries the Gondwanas over the Siwaliks (Yin, 2006 and references therein). The southernmost unit of Himalayan orogen, the foothills, comprising of Miocene-Quaternary sedimentary succession bounded by the MFT in the south (Hodges, 2000; Yin, 2006 and references therein) (Fig. 2).

A sedimentary pile of ~ 6 km thickness of fluvial conglomerates, sandstones and mudrocks has developed in the Indo-Gangetic foreland basins since the Middle Miocene, as a result of the uplift and concomitant erosion of the Himalayan orogenic belt (e.g., Nakayama and Ulak, 1999). These sedimentary strata comprise the Siwalik Group (cf.

“the sub-Himalayas”; in Nepal, it is termed the Churia Group; Nakayama and Ulak, 1999) which thus forms the foreland part of the Himalayan fold and thrust belt (Yin, 2006 and references therein).

The Siwalik rocks are divided into three broad biostratigraphically-defined Subgroups (Upper, Middle and Lower) (Medlicott, 1864) which are further subdivided (Pilgrim, 1913) mainly on the basis of mammalian faunal assemblage (e.g., Nanda, 2002). In the western part of the Siwalik sequence, in Pakistan, magnetostratigraphy and lithostratigraphic subdivisions have been successfully applied (Johnson et al. 1982; Opdyke et al. 1982) to augment the mammalian stratigraphy, and such methods have also been applied more recently in other areas (e.g, Nakayama and Ulak, 1999 and references therein); however, application and correlation between these schemes remains somewhat problematic (Nanda, 2002). In general terms, the Siwalik Group deposits can be subdivided into: (1) an upward-coarsening mudrock-sandstone succession (Lower Siwalik Subgroup), (2) the sandstone-dominated Middle Siwalik Subgroup and (3) conglomerates, sandstones and mudrocks of the Upper Siwalik Subgroup (Kumar et al. 2003). The Siwaliks are well studied in the western and in Nepal Himalaya of the Himalayan orogenic belt (e.g., Brozovic and Burbank, 2000; Thomas et al. 2002; Sharma et al. 2002; Kumar et al. 2004; Ulak, 2005). This study will examine soft sediment deformation features from the eastern part of the Siwaliks, in Darjiling district.

In the eastern Himalayan sector, the Upper Siwalik Subgroup is either not exposed or absent (Banerji and Banerji, 1982). The Lower Siwalik rocks, exposed in the Tista River section around Kalijhora in Darjiling District, are carried by the South Kalijhora Thrust

(SKT) over the Middle Siwaliks (Fig. 3). Lower Siwalik rocks are tectonically deformed into a series of open antiforms and synforms (Basak and Mukul, 2000).

The Middle Siwalik rocks are exposed in the footwall of the SKT and continue up to the mountain front for an aerial distance of ~ km. The Middle Siwalik Subgroup of the area of study consists of alternating sandstones, mudstones, heteroliths (fine sand-mud intercalations) and subordinate but thick units of conglomerates (Table 1). The sandstones are mainly medium to coarse grained and were deposited within a fluvial setting (Acharyya, 1973; Banerji and Banerji, 1982). The Middle Siwalik section is repeated by several imbricate thrusts forming a frontal schuppen zone (Acharyya, 1976; Mukul, 2000; Mukul et al, 2007).

The Middle Siwalik succession (Banerji and Banerji, 1982) in the Darjiling Himalaya representing almost all the sedimentary strata of the Middle Siwaliks comprises of cyclic repetitions of conglomerate - pebbly sandstone – medium-grained sandstone – fine-grained sandstone - mudstone associations. A detail litholog of the Middle Siwalik Subgroup of the Tista section is presented in Fig. 4.

SOFT SEDIMENT DEFORMATION STRUCTURES

Various types of soft sediment deformation structures are preserved in different horizons within the Middle Siwalik Subgroup. Soft sediment deformation structures are especially well developed in the heterolithic domain in the sequence. The deformation structures preserved are convolute lamination, flame structures, various kinds of deformed cross-stratifications and syn-sedimentary faults.

Convolute Lamination

Convolute lamination are present in the sand-mud intercalated horizons or heteroliths (Fig. 5 and 6). This is a deformation feature typical of sediments in the soft state. The convolute laminations morphologically are simple to complex; often looks like broad hinge folds with variable geometry. Upward closing ‘fold hinge’ (‘domes’) of the folds remain unbroken and nowhere have we observed truncated heads of the domes. The layers containing the convolute lamination structures are sandwiched between undeformed layers having plane laminated or cross-stratified sedimentary strucutres.

Flame Structure

These are present within heterolithic units comprising of very thin sand-mud interlaminations (Fig. 6). These deformed horizons are overlain and underlain by mudrock layers without any load cast. Associated deformation features within the same horizons in the vicinity of the flames are convolute lamination. At a particular exposure the deformed horizon contains recumbent folded cross-strata adjacent to flame structure. Directions of the flames are upward, i.e. almost perpendicular to the palaeocurrent direction. The frontal part of the flame structure associated with convolute lamination show near orthogonal relation with the deformed lamination (Fig. 6).

Deformed Cross-Stratification

Deformed cross stratification within heterolith horizons are sandwiched between undeformed layers consisting of thin interlaminated fine sand and mud. Deformed cross-stratification are either overturned or over-steepened. Overturned cross-strata form recumbent folds in the strike parallel section of the host bed (Fig. 7). Overturning direction and foreset inclination are concordant. In oversteepened cross strata (Fig. 8) the middle parts of the sets are inclined more steeply than the lower and the upper part. The deformed beds having recumbent folds and convolute laminations are present in succession of 3 or more units and they are bounded by undeformed strata.

Locally, small lensoidal fragments of cross-stratified units having a clearly different orientation to the surrounding cross-stratified sequence are preserved (Fig. 9).

Syn-Sedimentary Fault

Syn-sedimentary faults are occasionally observed within plane laminated sandstone beds where fault planes abut against overlying undeformed laminated sandstone of the same facies (Fig. 10). The hanging wall of the fault carries sandstone with curved lamina which are parallel to the fault plane.

INTERPRETATION

Convolute Lamination

Both fluvial processes and earthquakes can cause liquefaction of sediment, leading to the formation of convolute lamination and different water escape structures (Allen, 1977; Chakraborty, 1977). When deformation is controlled by fluvial processes, the tops of the domes of convolute lamina are likely to be broken, due to the unidirectional fluvial flow (Selley et al. 1963). According to Reineck and Singh (1980) convolute bedding associated with erosional surfaces may form due to current drag in fluvial environments. In the Middle Siwalik beds, the domes are intact and are not associated with erosional surfaces. These structures are restricted only to certain horizons, suggesting that momentary triggering episodes were responsible for development of these structures. Hence the deformation can be inferred to be syn-depositional and most likely resulted from seismic shock (cf. Friend et al. 1976; Cojan and Thiry, 1992; Davies et al. 2004). Smooth folds indicate liquefied state of the sediment during the folding. Convolute lamination with smooth troughs and domes are commonly developed by single or repeated triggers and the complex fold geometry may be due to repeated deformation (cf. Schneiderhan et al. 2005) that can only be attributed to recurrence of earthquake tremors.

Flame Structure

Formation of flame structure is attributed to directional fluidization and escape of water due to density contrast between sand and mud layers along the interface (e.g., Collinson and Thompson, 1982). Flame structures formed by fludization resulting from the load of overlying sediments are associated with load structures, however, in the Middle Siwalik sequence of the present area load casts are conspicuously absent in the horizon that contains flame structure. Therefore the development of the flames can be ascribed to earthquake induced (Visher and Cunningham, 1981; Obermeier, 1996) fluidization and resulting water escape, rather than to an autocyclic sedimentary origin.

Deformed Cross-Stratification

Overturning of cross-strata is thought to have been produced by a deformation mechanism triggered by earthquake or by dragging of a sand-loaded flow over cross-beds (McKee et al. 1962; Døe and Dott, 1980; Owen, 1995; Mazumder and Altermann, 2007).

Steepening of foresets cannot be used as an identifying signature of a particular deformation process. The horizons preserving deformed cross strata are sandwiched between underformed plane laminated sand-mud layers. Thus the deformation may be syn- or meta-depositional (cf. Owen, 1995). As a consequence, the possibility of quick deposition of sand in high energy regime above unconsolidated sediment producing a shear stress and deforming the sediment underneath, can be eliminated. Deformed cross-strata are not extensive and so cannot be confidently attributed to fluvial dragging and shearing (Owen, 1995). Overlying undeformed beds, and the lateral persistence of various deformation features all through the deformed horizons indicating earthquake trigger (Mazumder and Altermann, 2007; Kundu and Goswami, 2008). According to Sims (1973) earthquake shocks can generate recumbent folds in sediments underlying mud layers near the surface. In the Middle Siwaliks these recumbent folded sand-mud lamina are overlain and underlain by muddy and fine sandy layers and hence may be considered as seismites. The perpendicular relation between the axial trend of the syn-sedimentary folds and the palaeocurrent direction observed in the area also strengthens our claim that the deformation is seismogenic. Closure direction of recumbent folds and the flame structures are different, indicating earthquake shocks as the most likely cause of development of these structures (cf. Upadhyay, 2001). Lensoidal fragments of cross-stratified unit within the cross stratified sequence, must have been derived from elsewhere and the transportation is possibly seismic.

Syn-Sedimentary Fault

The syn-sedimentary faults are localized features. The surface do not have any diastrophic structures like slickensides on them or crushing adjacent to them. Hence the faulting here can be interpreted as a syn-depositional or meta-depositional feature. The fault plane is inclined opposite to the palaeoslope. Load features are also absent above the deformed horizon. So this faulting is not due to slope-gravity controlled slumping of the undeformed sediment. Hence a seismic shaking can be envisaged for the development of such soft sediment deformation features (cf. Singh and Jain, 2001).

DISCUSSION

Sediments in the Neogene Middle Siwalik Subgroup in the Darjiling area of the sub-Himalayas were deposited in the foreland basin of the Himalayan orogenic belt. The Neogene Middle Siwalik Group is a fluvial succession in which several horizons, particularly the heterolith ones, preserve soft sediment deformation structures. The observed soft sediment deformation features in the study area are convolute lamina, deformed cross-strata, flame structures and syn-sedimentary faults.

It is always challenging to distinguish the soft sediment deformation structures genetically, as similar features may form by different deforming mechanisms (e.g., Sims, 1973; Røe and Hermansen, 2006; Gruszka and Van Loon, 2007, 2009). When the deformations are seismogenic, the host sediment should generally be well sorted, with fine sand-mud interlayering, porous and wet (Dugué, 1995). Fluidization and liquefaction of sediment, which are the main mechanisms for such deformation structures (cf. Allen and Banks, 1972), can be triggered either by the sedimentation process itself (including the action of gravity on active bedforms; Jones and Rust 1983) or by earthquake shock (e.g., McKee et al. 1962; Rust, 1968; Seilacher, 1969; Turner, 1981; Allen, 1985; Røe, 1987; Ord et al. 1988; Seth et al, 1990; Røe and Hermansen, 1993; Wells et al. 1993; cf. Bhattacharya and Bhattacharya, 2005 and references therein).

Non-tectonic or sedimentary soft sediment deformations are attributed to factors such as quick deposition, differential loading, slope controlled density currents, etc. (Bowman et al. 2004). Tectonic deformations or earthquake tremor-induced deformations result when seismic wave acceleration supercedes the shear strength of the sediment (Einsele et al. 1996) and when the sediment is subsequently liquefied and fluidized seismically (Obermeier, 1996). Liquefaction happens when upward fluid movement results from downward movement of grains; in contrast, fluidization of sediment happens when there is upward movement of fluid without any downward movement of grains (Lowe, 1975; Middleton and Southard, 1978).

When earthquake-induced deformation structures are preserved in a bed over long distances, they are commonly referred to as "seismites" (Seilacher, 1984) or "seismically triggered soft sediment deformation" structures (Ricci Lucchi, 1995). In the study area, only river and road sections can be investigated and thus the lateral continuity of the soft sediment deformation structures cannot be checked for long distances, although they are laterally persistent in the exposed portions. The types of deformation structures in different deformed horizons are dissimilar. If normal fluvial depositional processes were responsible, then it is more likely that the deformation structures would be similar. Soft sediment deformations are sandwiched between undeformed layers, suggesting that the deformations are syn- or rarely, meta-depositional. The presence of features such as syn-sedimentary fault, drifted lensoidal cross-stratified fragments with unmatched palaeoflow direction, overturned cross-stratification and flames with varying vergence are clearly indications of palaeoseismic origin of the structures (Singh and Jain, 2001; cf. Upadhyay, 2001).

Most of these structures can be ascribed to the effects of liquefaction and fluidization of unconsolidated sediment. Presence of various soft sediment deformation structures in a single bed or within a set of adjacent lamina sandwiched between undeformed beds points to momentary and synchronous origin of these structures. Soft sediment deformation structures of similar dimensions have been established as seismites from western part of the sub-Himalayas (Kumar et al. 2005; Singh et al. 2007). These structures pass the tests for sudden formation, synchroneity, size, tectonic and depositional setting as proposed by Wheeler (2002). Any zoned map distribution for such structures in the Siwaliks is unavailable and thus the related test is not performed. So earthquakes are the most plausible events responsible for the formation of these structures. A number of horizons in the outcropping sections are deformed which points to recurrence of the inferred earthquakes at intervals.

Naturally, we cannot fully exclude an autocyclic fluvial sedimentary origin for the observed soft sediment deformation features, but in each case, we have been able to at least argue, on the basis of field evidence, for a preferential seismic origin. The Siwalik sedimentation was taking place during and after the uplift and exposure of the GHC, which served as the source of Siwalik sediments (DeCelles et al. 1998; White et al. 2001) between 12 - 1 Ma (Sangode et al. 1996; Meigs et al. 1995). The approximate time of the deposition of Middle Siwalik is ~ 11 – 7 Ma (Yin, 2006 and references within). Thus seismic activities during deposition are a very logical explanation for the features we have discussed in this paper. The tectonic disturbances in the Siwalik sediments during its depositional stage have been induced from the movement of the Lesser Himalayan thrusts (Huyghe et al. 2001), formation of north-trending rifts in the eastern Himalaya (Harrison et al. 1995) and may also be from the STD along the Tibet-Bhutan border (Edwards and Harrison, 1997).

Many authors have worked on the relation between soft sediment deformation structures and earthquake intensity (Tasgin and Turkmen, 2009 and references within). According to Marco and Agnon (1995) liquefaction of unconsolidated sediment initiates over a magnitude 4.5 whereas according to Sims (1975) a magnitude of 6 or higher is necessary to deform an unconsolidated sediment horizon. However, other workers estimated that a magnitude of 2-3 is sufficient for soft sediment deformation (Seed and Idriss, 1971). According to Castilla and Audemard (2007) an earthquake of magnitude ≥ 7 is essential for thrusting and liquefaction takes place within magnitudes 5.5 -7 within 150 km of the epicentre for such a range of magnitude. Faulting in the Himalaya are well within the required distance of 150 km from the Siwaliks. Therefore the seismic tremors along the faults are the likely causes of the soft sediment deformation in the Middle Siwalik rocks.

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Table Caption:

Table 1: Rock types and sedimentary structures of Middle Siwalik Subgroup in the Darjling district

Figure Captions:

Figure 1. (a) A generalized map of the Himalayan orogen (after Yin 2006). (b) Detail map of the Tista River Section with a part of the area of study (marked box).

Figure 2. A generalized cross section across Himalaya showing major thrusts and litho-tectonic units (after Harrison *et al*, 1999).

Figure 3. Part of Tista Section showing the SKT (South Kalijhora Thrusts), MBT (Main Boundary Thrust), folds in Lower Siwalik and the imbricate zone (multiple thrusts) in Middle Siwalik. (after Mukul 2000).

Figure 4. Litholog of Middle Siwalik along the Tista River Section from South to North.

Figure 5. Convolute lamination showing complex highly irregular fold geometry in heterolith. Coin diameter 2.5 cm.

Figure 6. Association of flame structure and convolute lamina within same horizon in heterolith. Note the orthogonal relation between the flame and the overlying lamina. Pen length 15 cm.

Figure 7. Folded cross bedded structure in heterolith. Pen length 13 cm.

Figure 8. Cross beds show variation of inclination from top to bottom in foreset unit. Pen length 13.5 cm.

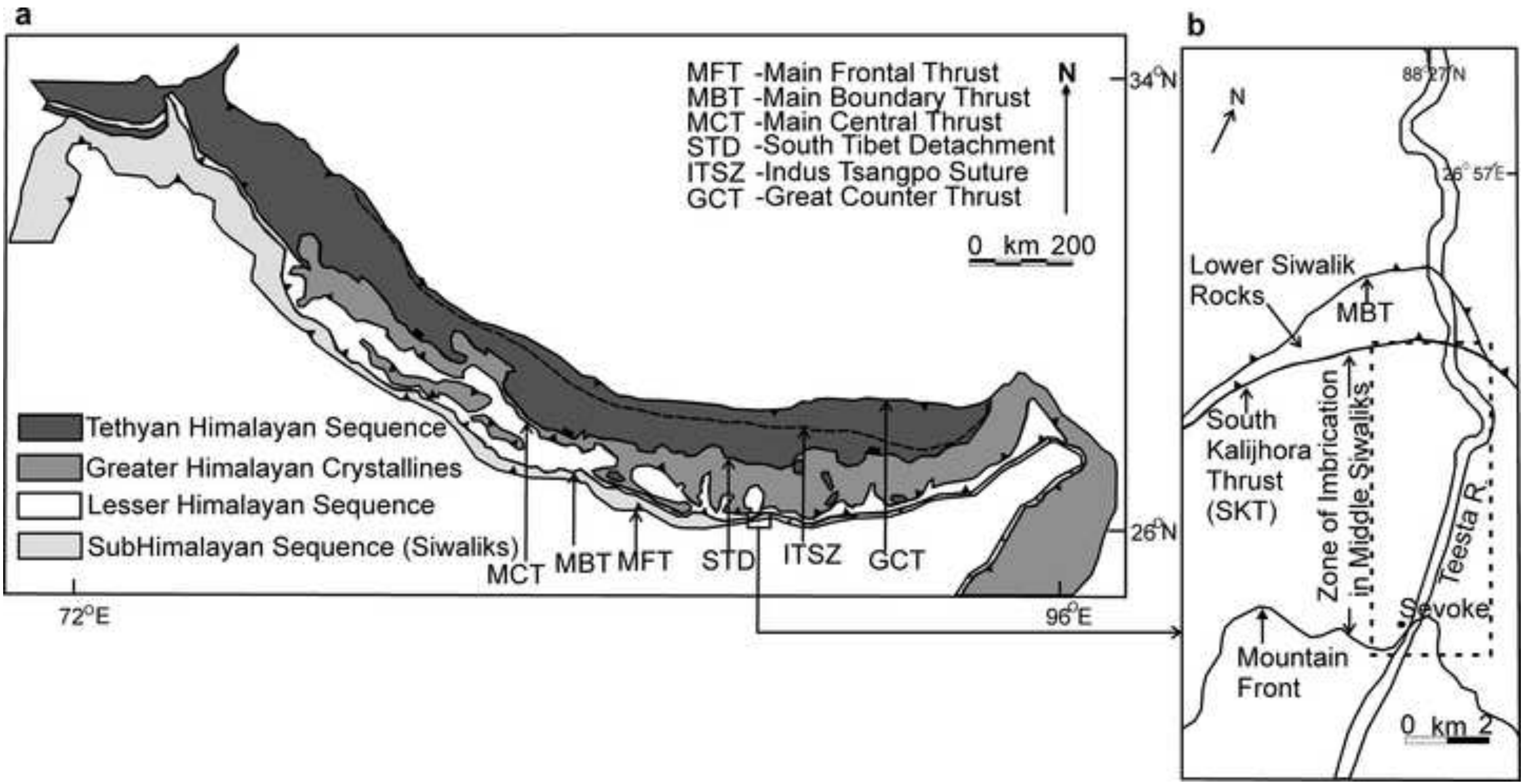
Figure 9. Drifted lensoidal fragment of cross-stratified unit. Cross-strata within the lensoid unit are different in orientation to surrounding ones. Pen length 13.5 cm.

Figure 10. A syn-sedimentary fault (marked arrowhead) in the Middle Siwalik sandstone. Note that the fault truncates the lamina in the lower unit but it abut against the overlying lamina. Pen length 15 cm.

Table 1. Rock types and sedimentary structures of Middle Siwalik Subgroup in the Darjling district

Lithology	Character	Thickness	Sedimentary structure
Conglomerate	Dark grey, oligomictic, clast to sandy-muddy matrix supported. Angular to subrounded clasts, largest clast 17 cm	Individual beds less than 1 m to 5m	Tabular and shallow trough cross stratification
Pebbly sandstone	Light to dark grey and yellow. Pebbles are of various sizes, angular to rounded	Individual beds 1 to 3 mt.	Crude cross stratification
Coarse to medium grained sandstone	Yellow to brownish yellow	Individual beds 30 cm to 6 mt	Sheet geometry and lensoidal channel geometry. Channels with tabular and trough cross stratification.
Fine sandstone Some horizons are interstratified with thin dark mud lamina (heterolith).	Buff or yellow coloured	Individual beds less than 1.5 mt thick	Small troughs and tabular cross strata are main structures. Heteroliths preserve soft sediment deformation structures.

Figure 1



a
MFT -Main Frontal Thrust
MBT -Main Boundary Thrust
MCT -Main Central Thrust
STD -South Tibet Detachment
ITSZ -Indus Tsangpo Suture
GCT -Great Counter Thrust
N
34°N
0 km 200
Tethyan Himalayan Sequence
Greater Himalayan Crystallines
Lesser Himalayan Sequence
SubHimalayan Sequence (Siwaliks)
MCT
MBT
MFT
STD
ITSZ
GCT
26°N
72°E
96°E
b
N
Lower Siwalik Rocks
MBT
South Kalijhora Thrust (SKT)
Zone of Imbrication in Middle Siwaliks
Teesta R.
Sevoke
Mountain Front
0 km 2

Figure 2

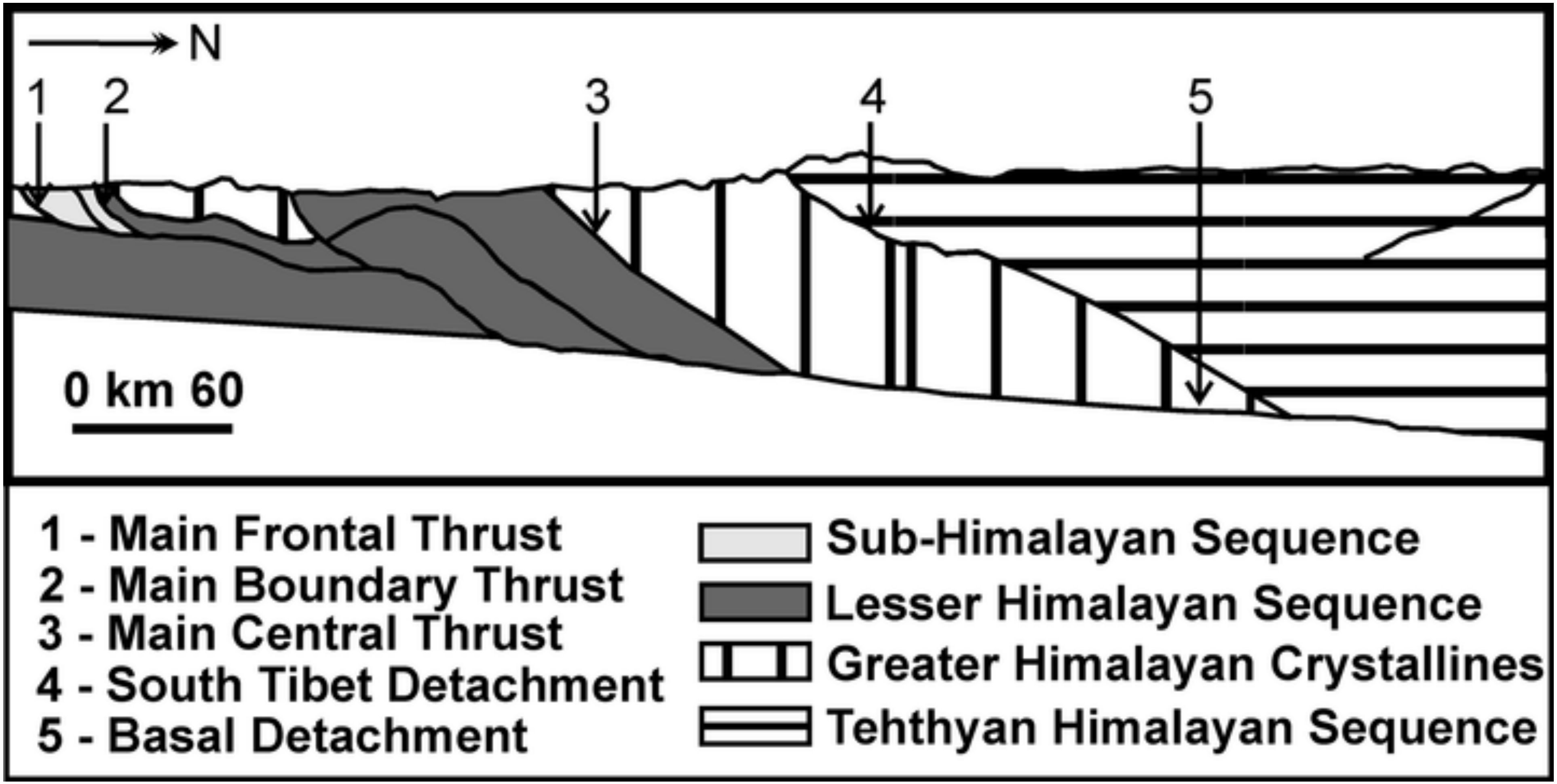
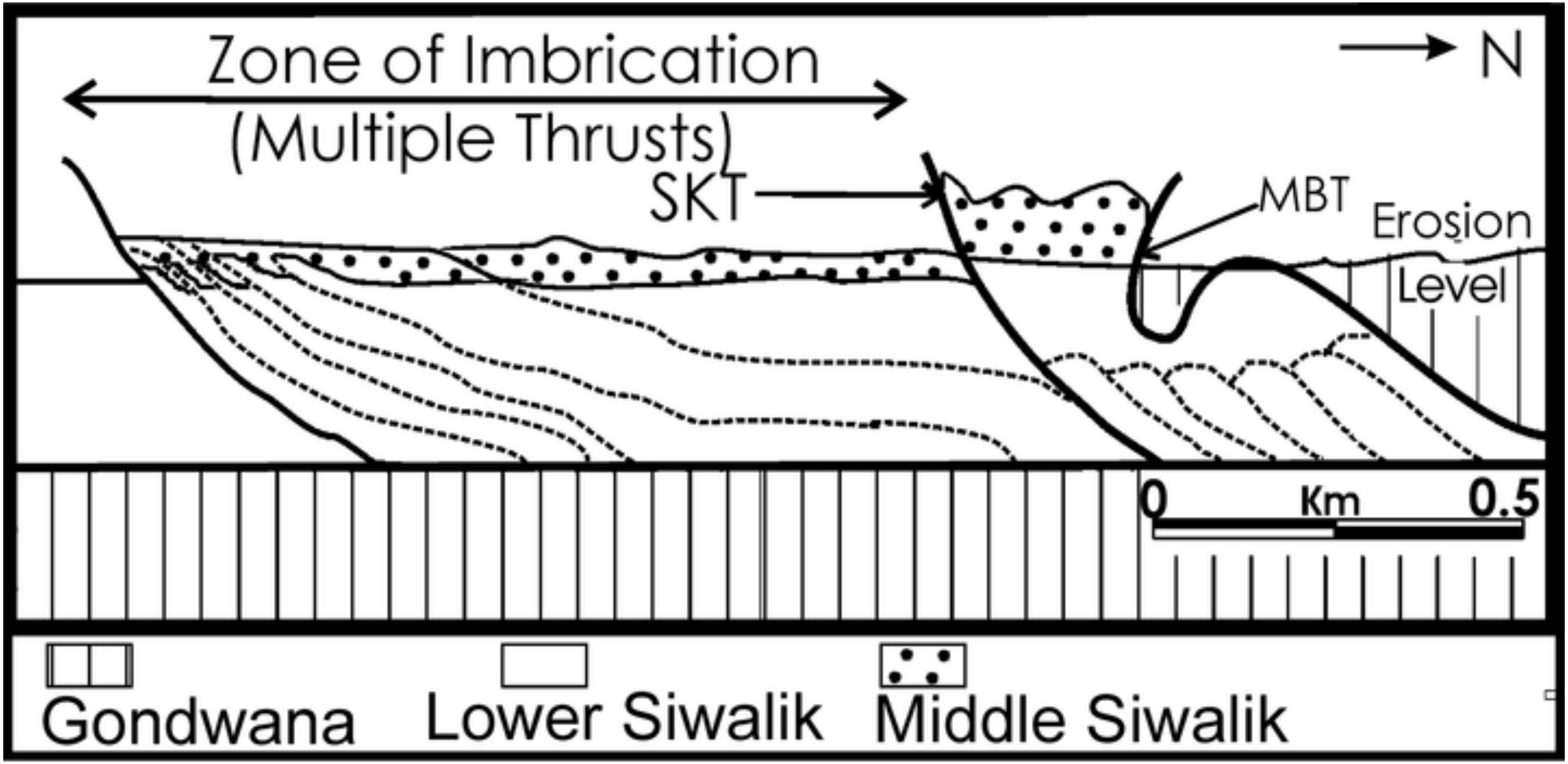
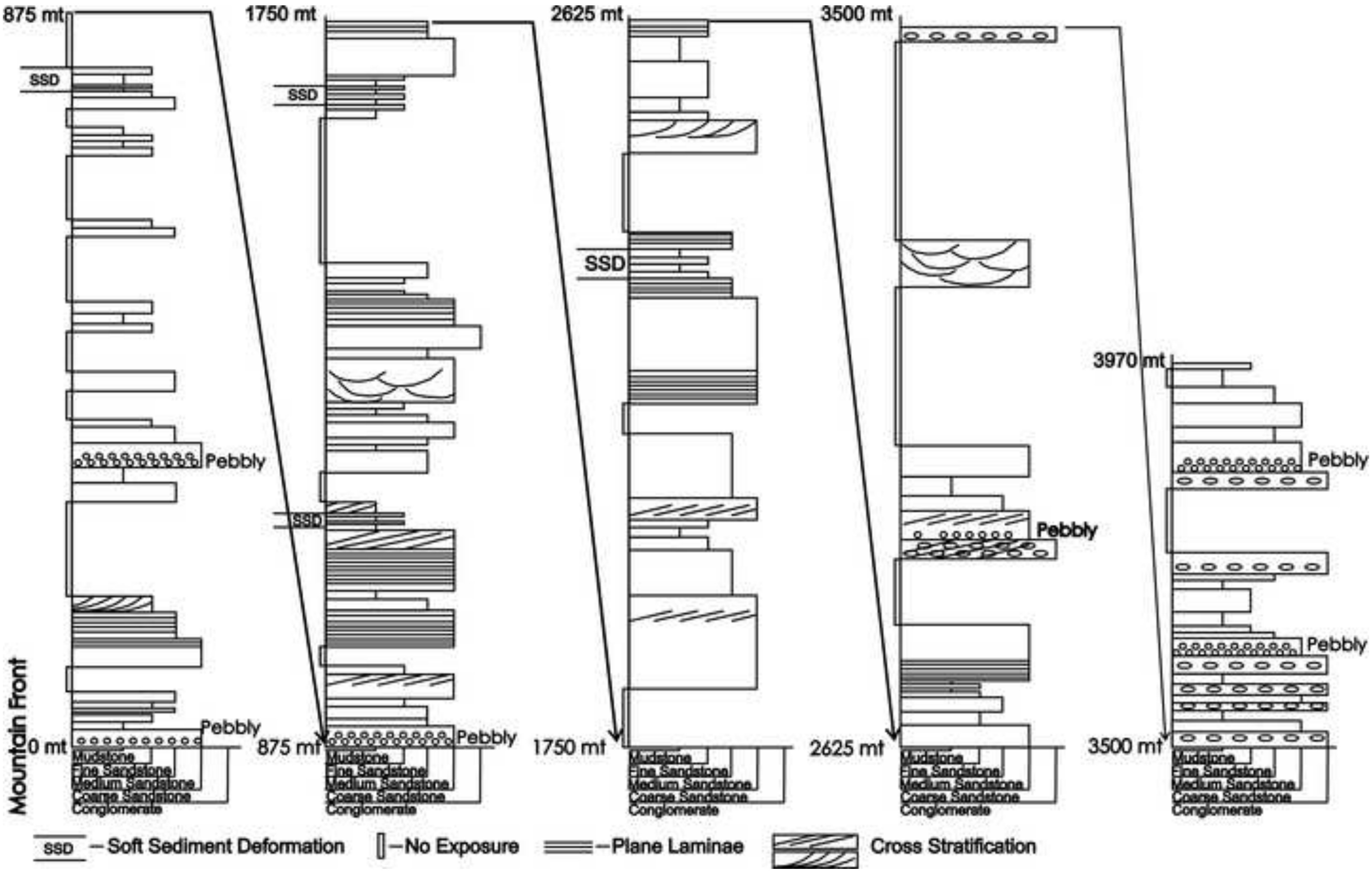

N
1
2
3
4
5
0 km 60
1 - Main Frontal Thrust
2 - Main Boundary Thrust
3 - Main Central Thrust
4 - South Tibet Detachment
5 - Basal Detachment
Sub-Himalayan Sequence
Lesser Himalayan Sequence
Greater Himalayan Crystallines
Tehthyan Himalayan Sequence

Figure 3



Zone of Imbrication
(Multiple Thrusts)
N
SKT
MBT
Erosion
Level
0
Km
0.5
Gondwana
Lower Siwalik
Middle Siwalik

Figure 4



875 mt
1750 mt
2625 mt
3500 mt
3970 mt
SSD
Pebbly
0 mt
875 mt
1750 mt
2625 mt
3500 mt
Mountain Front
Mudstone
Fine Sandstone
Medium Sandstone
Coarse Sandstone
Conglomerate
SSD – Soft Sediment Deformation
– No Exposure
– Plane Laminae
Cross Stratification

Figure 5

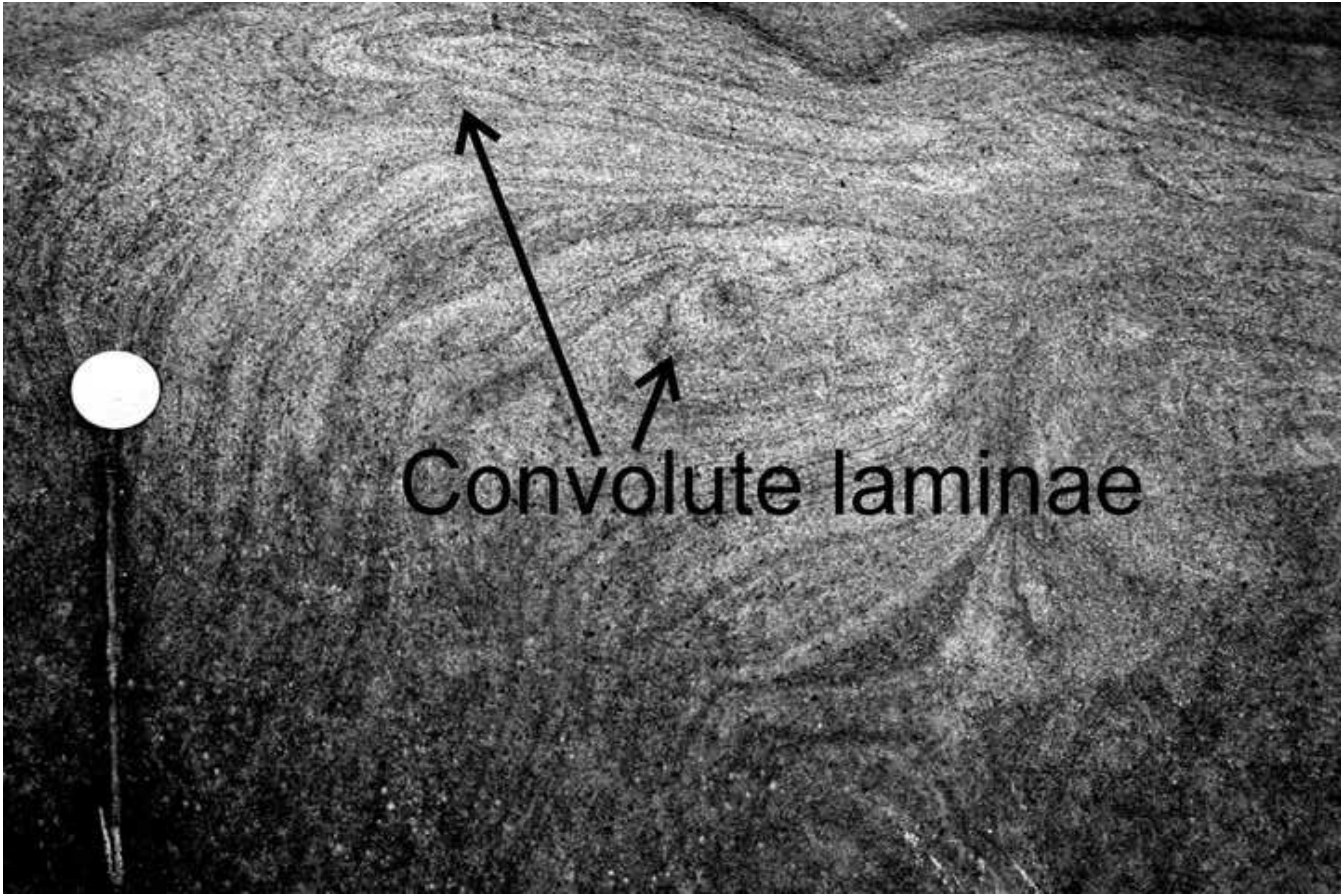


Figure 6

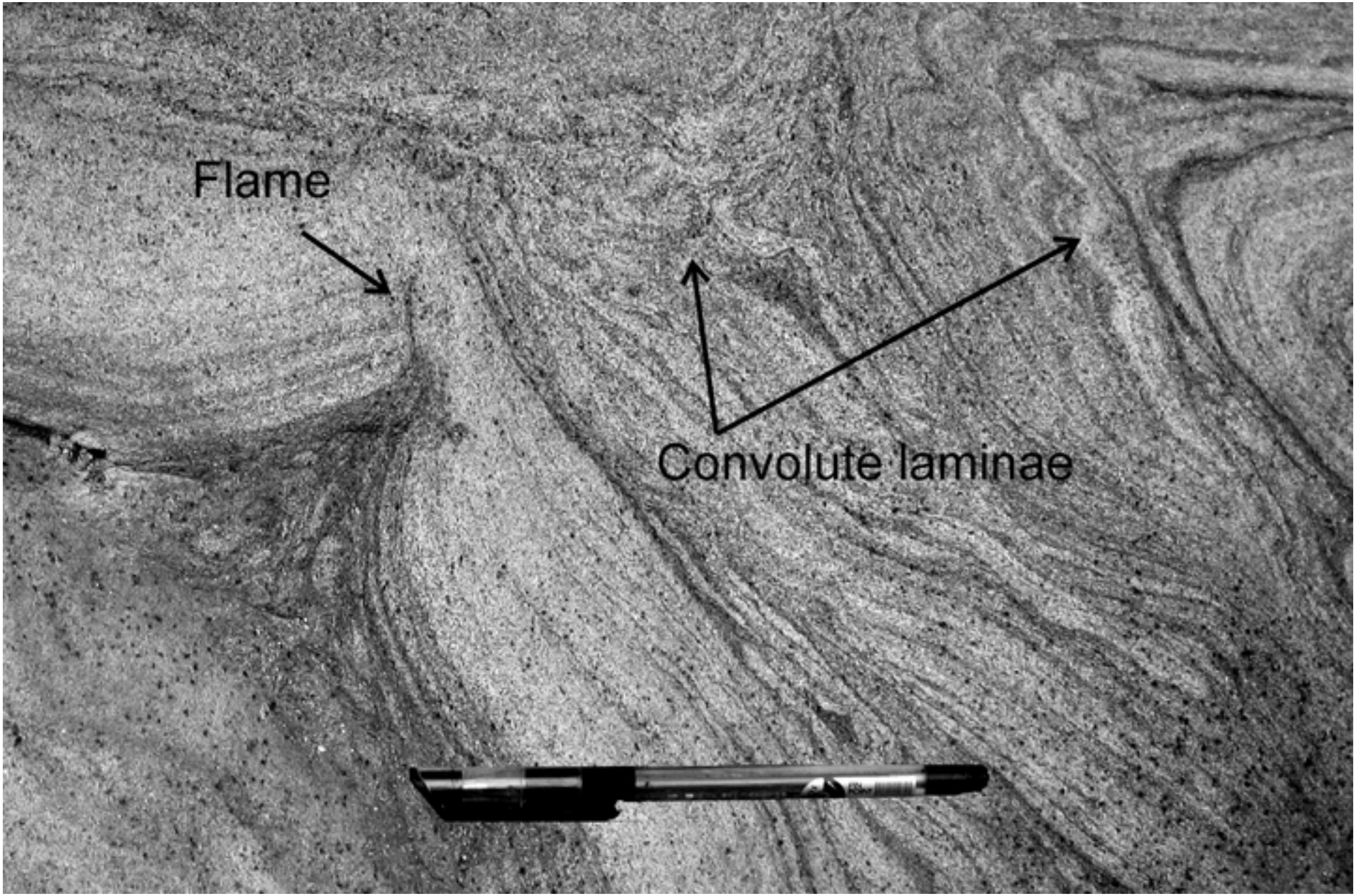


Figure 7

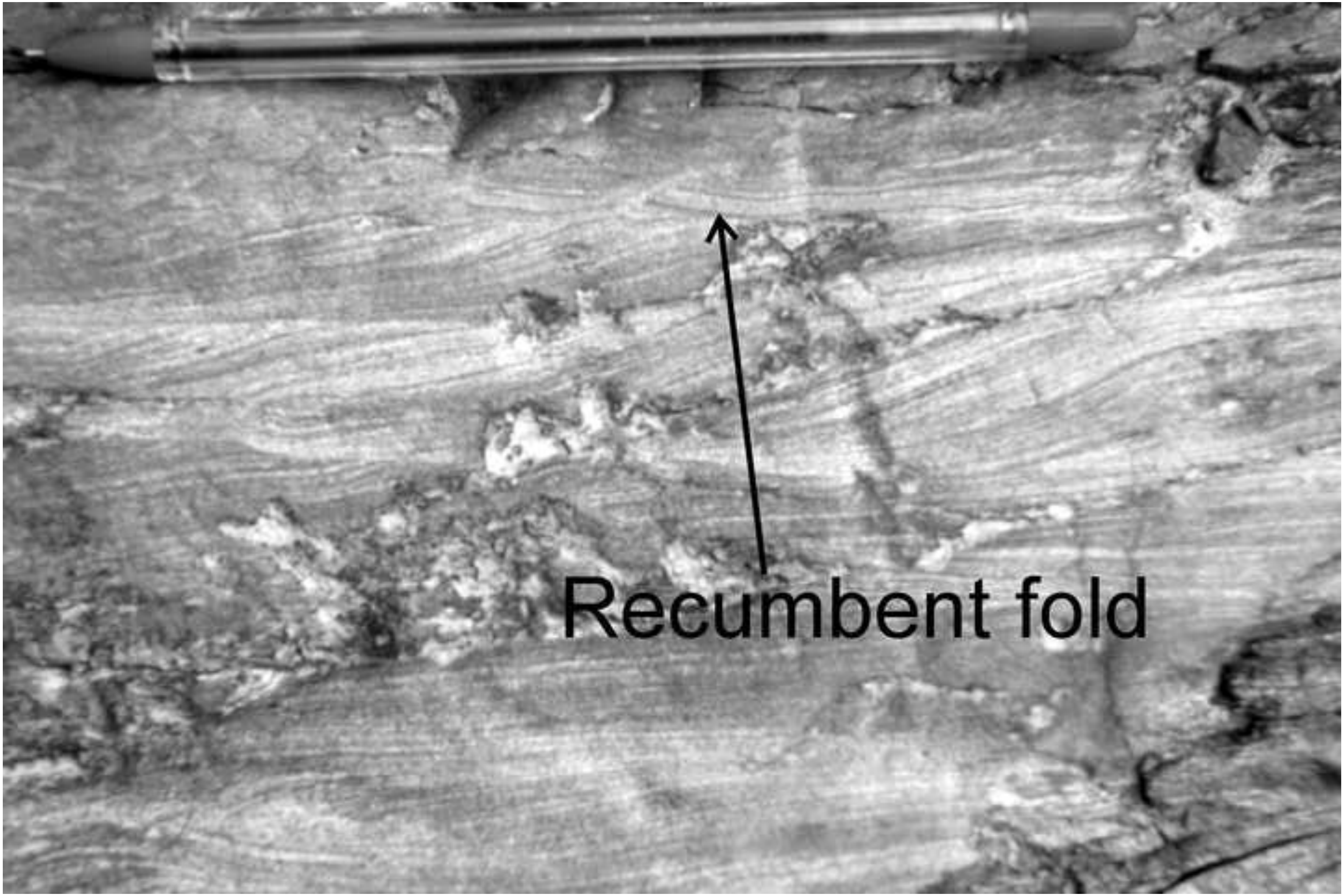


Figure 8

Figure 9

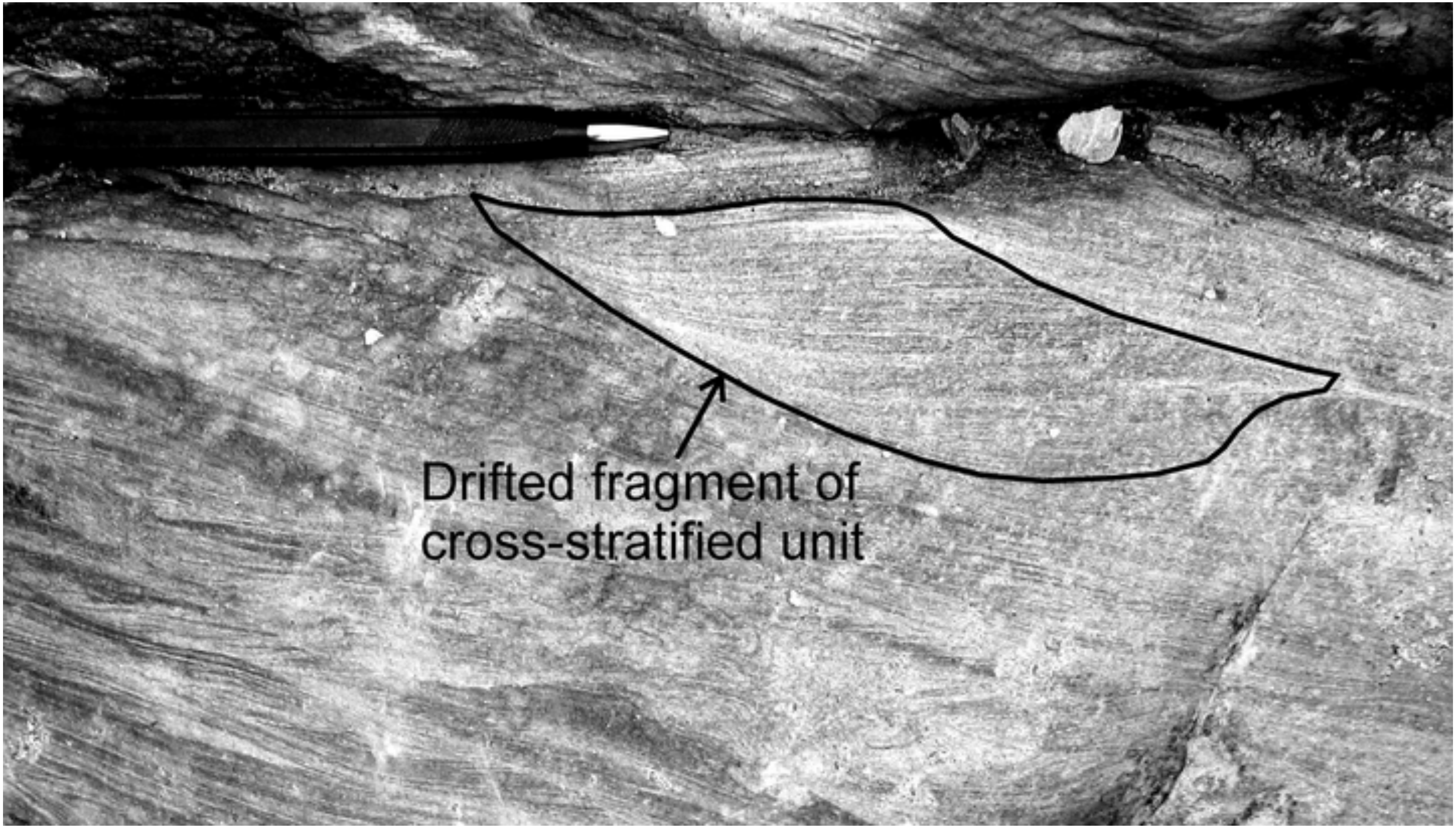


Figure 10