

## Soft sediment deformation structures in the Garbyang palaeolake: evidence for the past shaking events in the Kumaun Tethys Himalaya

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**Soft sediment deformation structures are observed in the laminated sediments and sandy part of the 150 m thick palaeolake profile exposed along the Chhidu Nala near Garbyang village in the Tethys zone of Kumaun Himalaya. The deformed, laminated sediments and sand are separated by gravel. We observed both penecontemporaneous and post-depositional deformational patterns. The deformation may have taken place due to thixotropy and fluidization causing visco-plastic failure of the mud, and density inversion between mud and sand due to liquefaction, was probably triggered by earthquakes. This gave rise to soft sediment folds, dykes, faults, load and pseudo-nodule structures in mud, silt and sand. The study area lies in the seismically active zone of the Kumaun Himalaya.**

QUATERNARY deposits form an important source of information on the frequency and distribution of the earthquakes<sup>1</sup>. In seismically active regions, the soft sediment structures (seismites) are important indicators of the past seismic activity<sup>2,3</sup>. However, several classifications have been proposed using morphic or genetic parameters<sup>4</sup>. A direct relationship between earthquake occurrence and the resulting deformation of the sediments has been invoked by various workers<sup>2,3,5,6</sup>. Soft sediment deformation structures are employed for the earthquake recurrence<sup>3,7,8</sup>. This communication presents some possible 'seismites' recorded from the Tethys zone of the Kumaun Himalaya.

Neotectonic movements resulted in the blocking of ancient drainages and formation of lakes throughout the Himalayan belt, such as Karewas of Kashmir<sup>9,10</sup>, Ladakh<sup>11-13</sup> and Kumaun Himalaya<sup>14</sup>. Likewise, the Garbyang palaeolake in the Kumaun Tethys Himalaya was probably formed due to the neotectonic activity along the Trans-Himaladri Fault (T-HF) that blocked the river Kali, forming a lake for about 11 km from Garbyang to Gunji (Figure 1). The deposits, about 150 m in thickness, consist of gravel, sand, laminated sediment and morainic deposits (Figure 2). A number of levels of soft sediment structures are observed in the laminated sediments and sand, separated by gravel.

Soft-sediment deformation features in the Garbyang palaeolake can be distinguished as (a) penecontemporaneous deformation and (b) post-depositional deformation. The post-depositional features present in deformation of the affected sediment are termed as penecontemporaneous

deformation<sup>17</sup>. This group consists of two categories, viz. metasedimentary (or post-depositional) and early diagenetic deformation<sup>18</sup>. Metasedimentary deformation is induced after the deposition of the overlying layer of sediment, whereas early diagenetic deformation occurs before the deposition of the overlying sediment layer. On the other hand, the post-depositional deformation structures are formed during the compactional stage of the sediment.

The first deformed unit in the Garbyang sequence, observed at 6.2 m above the base of the profile (Figure 2), is identified as recumbent folding (Figure 3 a). The folds have amplitude of a few metres laterally and vertically, with hinges of the folds in the horizontal to sub-horizontal plane. The lower limbs of the folded laminae are marked by several small-scale normal faults exhibiting visco-plastic failure of laminated sediments (Figure 3 a). The deformation in the laminated mud and silt was probably triggered by the endogenic sources. The saturated sediments may have, thus folded along susceptible planes. Such recumbent folds are experimentally produced as a horizontal shear<sup>19,20</sup> or due to slope failure<sup>21</sup>. (See also R. K. Pant *et al.*, unpublished DST project report, 1999, p. 61.)

The second level of deformation as intrusion of dark mud into the coarse sand is observed at 10.4 m above the base of the profile (Figure 2). It is 30 cm thick mud layer extending laterally and vertically for a few metres (Figure 3 b). The thickness of the intruded material increases towards the bottom source mud layer. Due to the intrusion, sand pseudo-nodules are developed. It may be stated that when a coarser and denser sediment overlies a finer and lighter sediment, it results in density inequilibrium<sup>22</sup>. The intruded sediments are highly viscous and discordant, suggesting shear stress and reverse density gradation due to differential porosities of coarse sand and cohesive mud. The mud overlain by the sand is intruded upwards in the form of irregular veins due to density

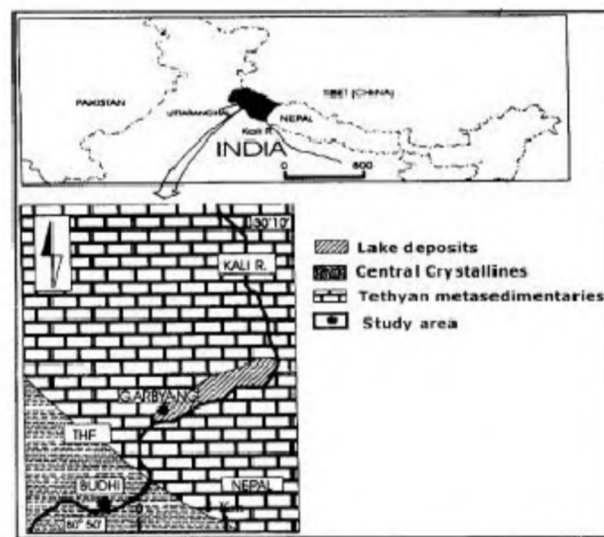


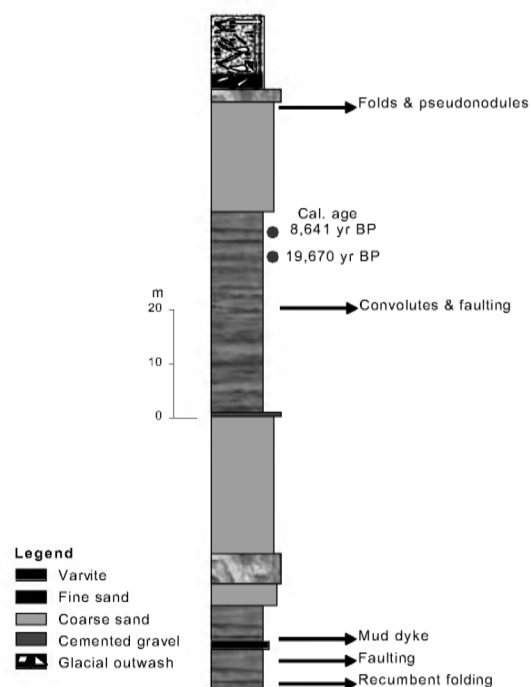
Figure 1. Location and geology of the study area.

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gradient and shear stresses, because of the differential porosity of the two lithologies<sup>3</sup>.

Another example of the metasedimentary deformation (Figure 4), represented by sand pseudo-nodes, loading, fold and faulting of the sand and mud laminae is observed at 128 m above the base of the profile (Figure 2). Pseudo-nodes are observed at the interface between sand and mud units. These have lateral extension of 3–5 cm. A few sand nodules attached to the parent sand bed exhibit load structures. The mud laminae show development of synclinal fold due to loading phenomenon by overlying gravelly sand. The sediment layer lying below the mud unit is pinched due to loading. An anticlinal fold is observed in the mud unit overlying the gravelly sand. The limb is displaced by normal fault, which in turn may have caused a change in thickness of the underlying gravelly sand. The pseudo-nodes and the development of folds may have taken place by loading and density inversion. The faulting phenomenon is restricted to the deformed part, suggesting a syn-deformational event.

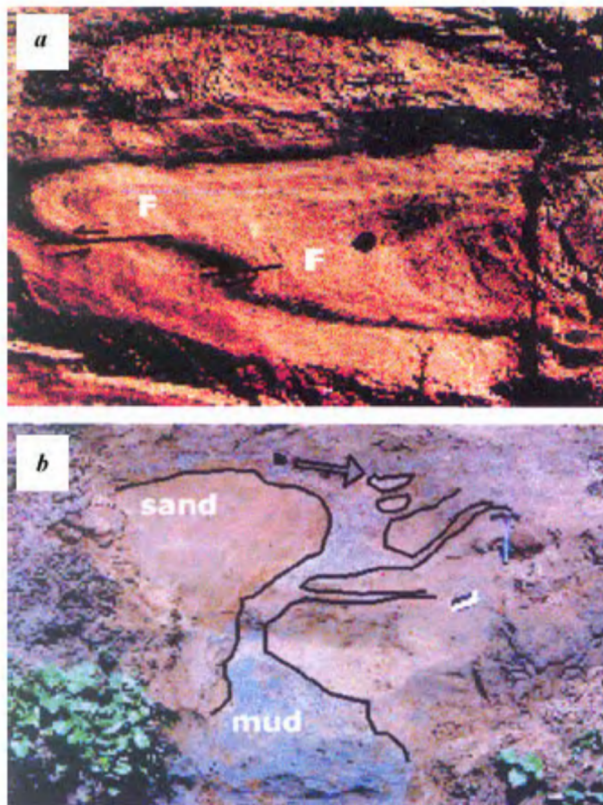
What are interpreted as early diagenetic deformation (Figure 5 *a*), is observed at 82 m above the base of the sediment profile (Figure 2), which shows influx of boulder-sized rock fragments. The disturbed unit is about 1.5 m thick and confined between parallel, undeformed laminated sediments. The deformation by influx clasts may have formed irregular convolutes and flames in the laminated sediments. The disturbed unit representing the



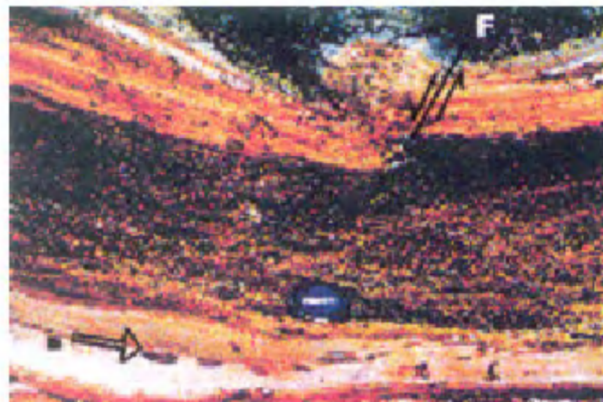
**Figure 2.** Litho-column of the Garbyang profile and various levels of soft-sediment deformation structures.

normal faults in the sediment layers, is restricted between undeformed laminated sediments indicating a syn-sedimentary deformational event. The presence of massive tree trunks and huge rock boulders suggests external triggering. Such a shaking, which may have been responsible for falling tress in the Garbyang sequence, is used to determine the timing of earthquake occurrence<sup>23</sup>.

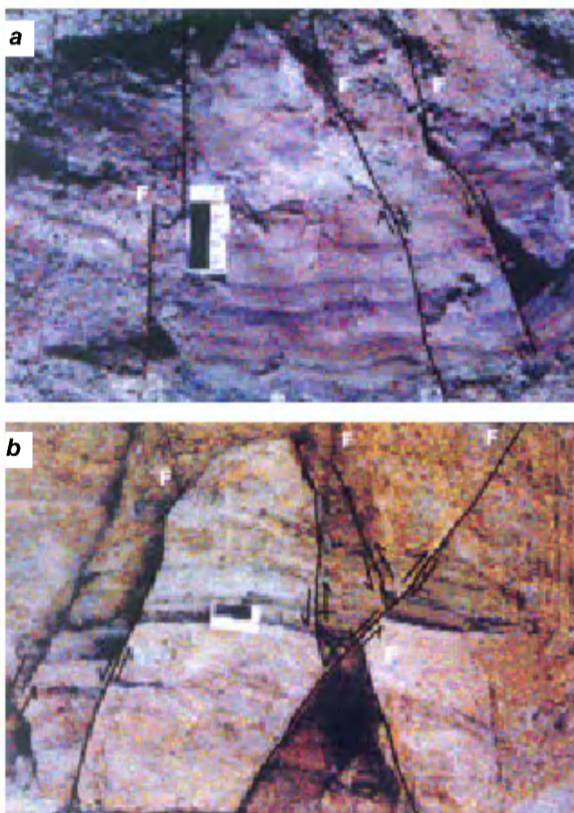
The faults observed in a deformed unit (Figure 5 *b*) constitute the post-depositional deformation. Both the normal and reverse faults show displacement. The



**Figure 3.** *a*, Recumbent folding in the mud. *b*, Mud dyke intruding into the overlying sand (arrow indicates pseudo-nodes).



**Figure 4.** Fold (F) and pseudo-nodes (indicated by arrow) in mud and sand.



**Figure 5.** *a*, Convolutes and faulting in laminated sediments; *b*, Faulting due to post-depositional deformation.

faulting in the sediments takes place because of the shaking effect<sup>24</sup>.

Soft sediment structures discussed here are produced by shaking effects. The deformed sediments occur in a basin extending for about 11 km from Garbyang to Gunji. Since the deformed units are laterally extended for several kilometres and are bounded by completely undeformed sediments, it is likely that the deformation is produced by shaking effects and not produced by slope, overburden and bioturbation. However we are not able to resolve the distance to the causative seismic sources, with the available data.

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