

Seismites in the Kathmandu basin, Nepal

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ABSTRACT

The Kathmandu valley is a large intermontane basin carried above the Himalayan major décollement. It is limited southward by the Mahabharat Range, which forms the hanging wall of the Mahabharat Thrust, and northward by the Shivapuri Range. The Kathmandu basin is filled with a very thick (500-600 m) sequence of fluvio-lacustrine Plio-Pleistocene sediments, which unconformably overlie the folded and faulted Precambrian-Palaeozoic Kathmandu Complex. These semi-consolidated deposits mainly consist of fine to coarse sand, sandy loam, sandy silty clay, and gravely conglomerate.

New field data show that small-scale deformational structures occur in the lacustrine deposits of the central and southern parts of the Kathmandu basin. In Thimi section, these structures take place within sub-horizontal clayey layers. They mainly consist of finely contorted and folded sandy layers which form balls and pillows of about 10-13 cm thick. In a few places, the deformational structures are associated with small folds and micro-faults (normal and reverse faults), with micro-breccias and sand dykes. The convolute lamination structures show no preferential verging, thus, excluding shearing related to the influence of a palaeoslope. Such structures have been found in three different places and they were always confined to single stratigraphic horizons positioned between undisturbed parallel beds. The deformational structures described above show characteristics of seismites. The associated seismic events may be related to major earthquakes or movements along the active nearby faults. Earthquake-induced liquefaction and subtle variations in physio-mechanical properties of water-saturated fine sandy sediments have probably controlled the deformational pattern.

GEOLOGY AND TECTONIC SETTING

The Himalayan tectonics is still active and the convergence rate between India and Higher Himalaya is close to 20 mm/yr (Bilham et al., 1997). Present day seismicity (National seismological survey, 1997) and historical records indicate that the Himalaya has experienced recurrence of large earthquakes. The aim of this paper is to evidence the Pleistocene earthquakes. The evidences are deduced from the observation of soft-sediment deformation structures in the sediments of the Kathmandu basin that show characteristics of seismites (Seilacher, 1969) generated by ground motion during earthquakes.

The central Nepal Himalaya, as observed throughout the entire range, is tectonically divided into three different zones: Higher Himalaya, Lesser Himalaya, and Sub-Himalaya. Upreti and Le Fort (in press) have recognised two different thrust packages in the Kathmandu transect. According to them, two crystalline nappe units named as Kathmandu Crystalline Nappe (KCN) and Gosaikund Crystalline Nappe (GCN) are separated from each other by the Main Central Thrust (MCT) which passes to the north of the Kathmandu basin (Fig. 1). The GCN unit, which corresponds to the southward continuity of the Higher Himalayan Crystallines of the Langtang area, is brought southward along the MCT. South of the MCT, the KCN unit is thrust over the narrow zone of the Lesser

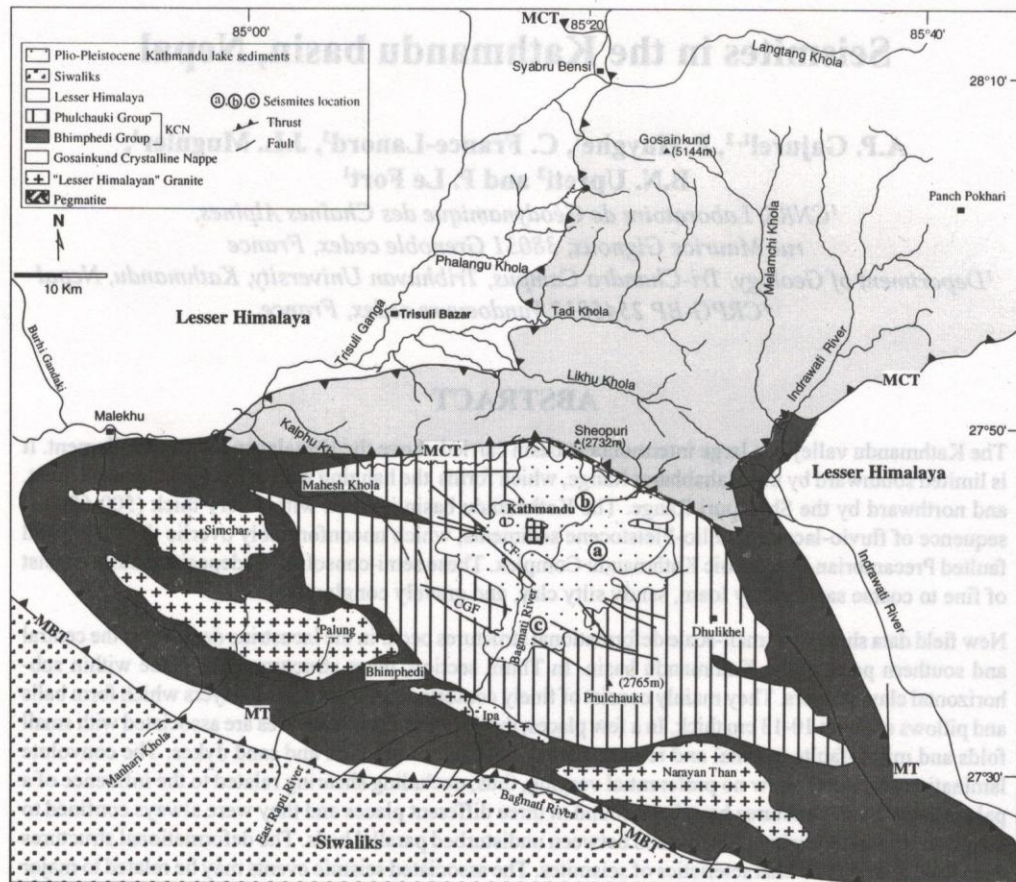


Fig. 1: Geological map of central Nepal (after Rai et al., 1997).

Himalayan metasediments along the Mahabharat Thrust (Stöcklin, 1980) as an out of sequence thrust sheet in the Lesser Himalaya (Upreti and Le Fort, in press).

The Kathmandu valley is a large intermontane basin carried above the Himalayan major detachment defined by Pandey et al. (1995), and it is the largest basin situated in the Lesser Himalaya of Nepal. It occupies the central portion of the nearly elliptical KCN towards the northern margin. It is limited southward by the Mahabharat Range, which forms the hanging wall of the Mahabharat Thrust (MT), and northward by the Shivapuri Range, which belongs to the transported sheet of the Higher Himalayan Crystallines towards south along the MCT (Upreti and Le Fort, in press). This basin lies on a basement of crystalline rocks and Precambrian to Palaeozoic

metasedimentary formations. It covers a part of the Mahabharat Synclinorium (Stöcklin and Bhattarai, 1981). It extends for about 30 km in the east-west direction and about 25 km in the north-south direction and has an almost circular shape. A lake is known to have filled most of the basin from Pliocene to Pleistocene (Yoshida and Igarashi, 1984; Dongol, 1985). The basin is filled with a very thick (500-600 m) sequence of fluvio-lacustrine sediments (Moribayashi and Maruo, 1980) that covers about 400 km² (Bajracharya, 1996). In this centripetal drainage basin (Holmes, 1964), sediments were derived from the crystalline (schist, gneiss, pegmatite) and metasedimentary (phyllite, siltstone, shale, metasandstone and limestone) rocks (Bajracharya and Verma, 1989). The semi-consolidated sediments filling the basin mainly

consist of muds, silts, sandy loam, fine to coarse sands, and gravel to cobble conglomerates.

Many faults (main trend WNW-ESE) have been mapped that crosscut the metasedimentary basement (Stöcklin and Bhattarai, 1981). Previous studies have revealed the presence of geomorphic and structural features indicative of active faults including young fault scarps and displaced lacustrine sediments. In the south-west part of the basin, NW/SE trending faults (Chobhar Fault, CF in Fig. 1, and Chandragiri Fault, CGF in Fig. 1) have been traced for about 3-4 km and have contributed to the formation of the Kathmandu basin and the upliftment of the Mahabharat Range since the Late Quaternary (Saijo et al., 1995).

During a recent survey of the lake sediments, we have discovered various types of soft-sediment deformation structures in three places of the basin (a, b and c in Fig. 1). Two of them are active quarries and the third one is a natural cliff in the southern part of the basin. Unfortunately, good exposures are rather limited and discontinuous, thus, direct correlation of the three sites is not possible. We have limited our description to the site of Thimi (a in Fig. 1), as it shows the most diverse structures.

In this article, only those structures resulting in from liquefaction in soft sediments due to seismic movement are described. It is also tried to assess the earthquake intensity from the thickness of the deformed zone and to compare them with the historical seismicity.

SOFT-SEDIMENT DEFORMATION STRUCTURES

Study of the top 32 m thick stratigraphic sequence in the central part of the basin has been carried out in detail (Fig. 2). The sequence is restricted within distinct soft and weakly consolidated sub-horizontal muddy layers. It consists of semi-consolidated Quaternary sediments of fluvio-lacustrine origin. The columnar section comprises interstratified layers of mud, silt, and sand. Mud is grey, dark grey to brown, somewhat yellowish and black in colour. Individual layers range in thickness from 5 to 60 cm. In some places, flaser beddings are observed. Silt is yellowish, grey to light

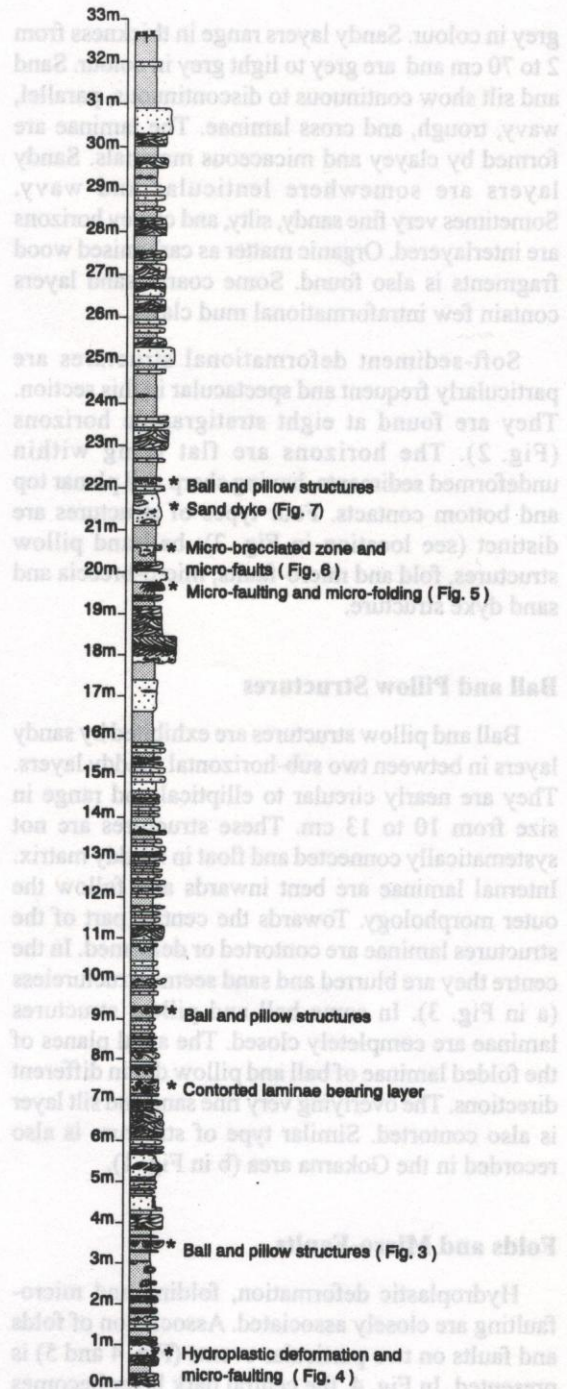


Fig. 2: Columnar section showing the distribution of the main syn-sedimentary soft-sediment deformation structures (*) within the Quaternary sediments of the Thimi section.

grey in colour. Sandy layers range in thickness from 2 to 70 cm and are grey to light grey in colour. Sand and silt show continuous to discontinuous, parallel, wavy, trough, and cross laminae. The laminae are formed by clayey and micaceous materials. Sandy layers are somewhere lenticular and wavy. Sometimes very fine sandy, silty, and clayey horizons are interlayered. Organic matter as carbonised wood fragments is also found. Some coarse sand layers contain few intraformational mud clasts.

Soft-sediment deformational structures are particularly frequent and spectacular in this section. They are found at eight stratigraphic horizons (Fig. 2). The horizons are flat lying within undeformed sediments, having sharp and planar top and bottom contacts. Four types of structures are distinct (see location in Fig. 2): ball and pillow structures, fold and micro-faults, micro-breccia and sand dyke structure.

Ball and Pillow Structures

Ball and pillow structures are exhibited by sandy layers in between two sub-horizontal muddy layers. They are nearly circular to elliptical and range in size from 10 to 13 cm. These structures are not systematically connected and float in muddy matrix. Internal laminae are bent inwards and follow the outer morphology. Towards the central part of the structures laminae are contorted or deformed. In the centre they are blurred and sand seems structureless (a in Fig. 3). In some ball and pillow structures laminae are completely closed. The axial planes of the folded laminae of ball and pillow dip in different directions. The overlying very fine sand and silt layer is also contorted. Similar type of structure is also recorded in the Gokarna area (b in Fig. 1).

Folds and Micro-Faults

Hydroplastic deformation, folding and micro-faulting are closely associated. Association of folds and faults on two particular events (Fig. 4 and 5) is presented. In Fig. 4, the central dark layer becomes thin towards the right (a) and becomes tightly folded against a reverse fault (b). On the other side of this reverse fault, other minor fractures also affect the white sandy layers and evolve to normal faults on

the right side (c). Deeper beds are deformed and folded (d). Cohesive beds are ruptured and brecciated (e). Few competent mud clasts are confined in the localised liquefied area (above e).

In Fig. 5, the central dark mud (a) is contorted and raised upward. Sandy layers descend along normal micro-fault (b). Towards the lower right corner, reverse micro-faults are observed and gradually to the upper right corner fine muddy laminae are folded (c), which are similar in form to those of Fig. 3.

Micro-Breccia

Fig. 6 illustrates a micro-brecciated zone about 10-13 cm high, and about 15-18 cm wide. The brecciated zone is confined within non-brecciated bedding. The elements of the breccia vary in size; the angular to subrounded cm-sized clasts are floated in a very fine sandy matrix. The clasts are composed of more competent mud, which has sunk in the surrounding sequence in reference to the undeformed horizon. There is neither sign of brecciated fissure filling nor clear contact within the brecciated zone (a in Fig. 6). If the disrupted muddy matter is pulverised within the fluidised matter, the colour appears uniform and the muddy fragments decrease in size (b in Fig. 6). If clasts remain bigger, the colour contrast is still apparent (c in Fig. 6). Similarly, early formed sedimentary structures are wiped out, e.g. the laminae of the overlying layer are disappeared (d in Fig. 6). At the lower right side of the plate, trail of fluidised and liquefied phenomenon form radial dewatering structure (e in Fig. 6). Normal micro-faults affect the underlying white sandy and dark muddy layers (f in Fig. 6).

Sand Dyke

Fig. 7 illustrates a sand dyke structure about 80 cm high. At the bottom, a 5 cm thick muddy layer is pierced by coarse sands (d and e in Fig. 7) giving rise to sand dyke structure (b in Fig. 7). Muddy layer is partially replaced by coarse sandy materials (c in Fig. 7). The boundary between sand dyke structure and original laminated silty layer (a in Fig. 7) is outlined by brownish material. The top part of the dyke (between 0.7 m and 1 m on the scale bar of Fig. 7) is formed by fine sand.

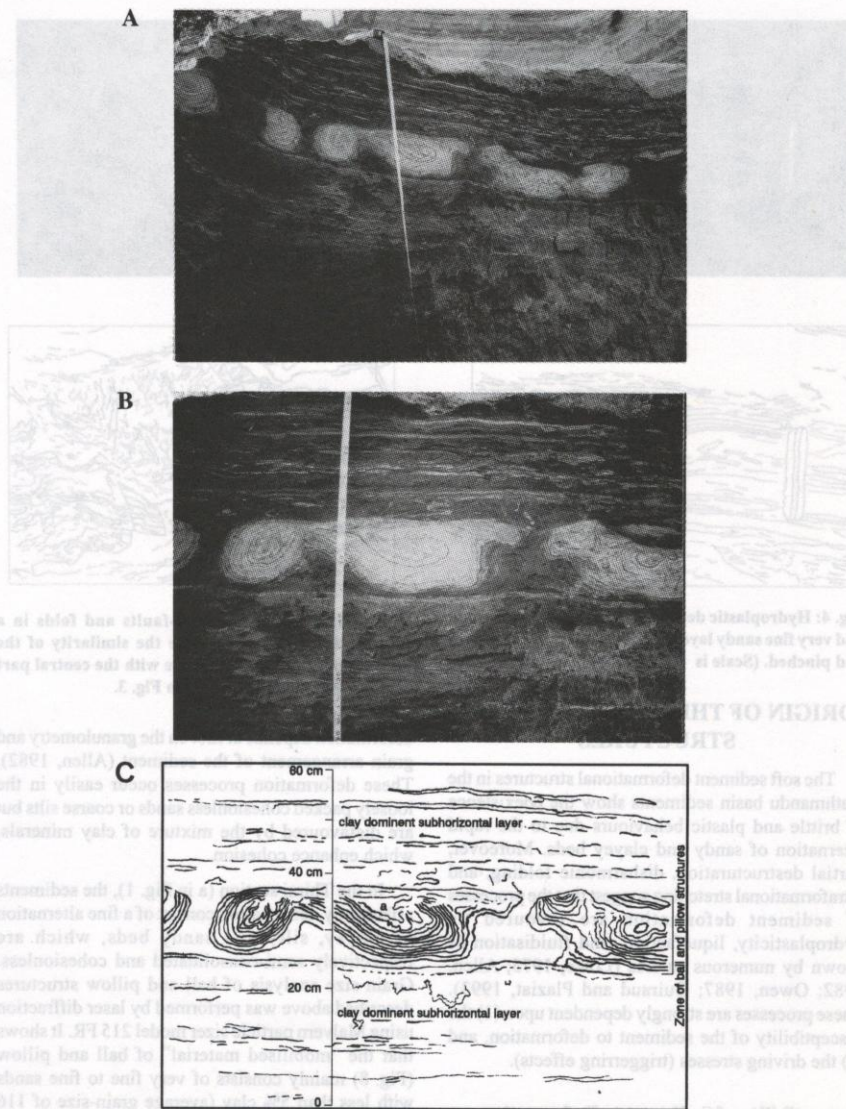


Fig. 3: Deformational structure (ball and pillow) observed within sedimentary sub-horizontal clay layers. B: detail of photo A; C: interpretation of photo B.

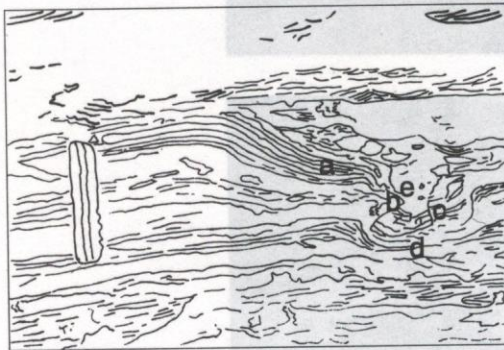
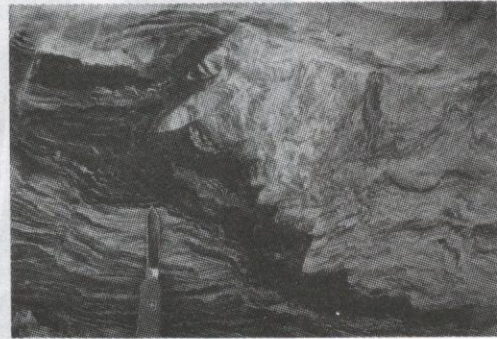


Fig. 4: Hydroplastic deformation in interlayered mud and very fine sandy layers. Muddy layers are stretched and pinched. (Scale is 9.5 cm long).

Fig. 5: Association of micro-faults and folds in a deformational structure. Note the similarity of the central portion of this structure with the central part of a ball and pillow structure in Fig. 3.

ORIGIN OF THE DEFORMATIONAL STRUCTURES

The soft sediment deformational structures in the Kathmandu basin sediments show the coexistence of brittle and plastic behaviours due to the rapid alternation of sandy and clayey beds. Moreover, partial destructuration, disharmonic folding, and intraformational stretching suggest that the processes of sediment deformation are favoured by hydroplasticity, liquefaction, and fluidisation as shown by numerous studies (Lowe, 1975; Allen, 1982; Owen, 1987; Guiraud and Plaziat, 1993). These processes are strongly dependent upon (1) the susceptibility of the sediment to deformation, and (2) the driving stresses (triggerring effects).

Susceptibility of Sediment to Deformation

The susceptibility of the sediment to hydroplastic, liquefaction and fluidisation

deformation depends at first on the granulometry and grain arrangement of the sediment (Allen, 1982). These deformation processes occur easily in the loosely packed cohesionless sands or coarse silts but are disfavoured by the mixture of clay minerals, which enhance cohesion.

In the Thimi section (a in Fig. 1), the sediments affected by deformation consist of a fine alternation of clayey, silty and sandy beds, which are respectively semi-consolidated and cohesionless. Grain-size analysis of ball and pillow structures described above was performed by laser diffraction using Malvern particle sizer model 215 FR. It shows that the "mobilised material" of ball and pillow (Fig. 8) mainly consists of very fine to fine sands with less than 5% clay (average grain-size of 116 μm), whereas the upraised material consists of silt to very fine sands with 12% clay (average grain-size of 48 μm). This outlines that low clay content

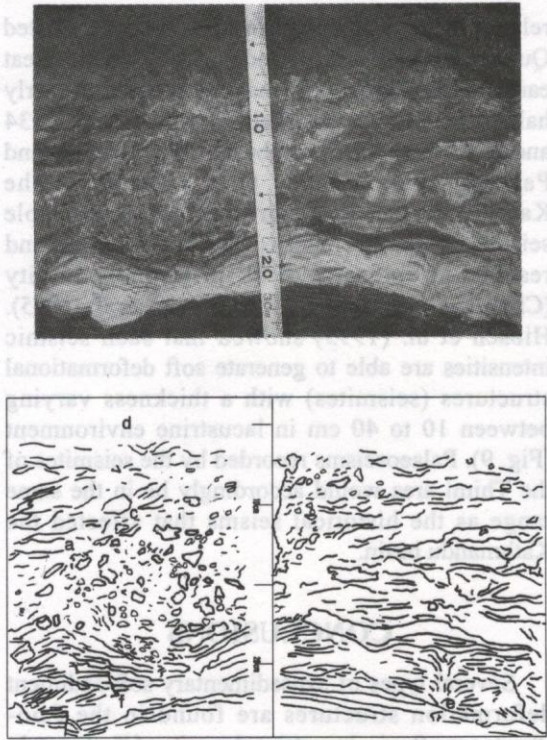


Fig. 6: Zone of microbrecciation. In the top part of the photo, structureless homogenised part is seen that might have been deposited from remobilised suspended sediments.

enhances the hydroplastic, liquefaction, and fluidisation deformation processes. Moreover, grain size analysis shows that the fluvio-lacustrine material from the Thimi area has a rather good sorting (varies from 1.54 to 1.97, which is a favouring factor for syndimentary deformation (Guiraud and Plaziat, 1993).

The Thimi sediments show typical physical properties that make them suitable for hydroplastic, liquefaction, and fluidisation deformation.

Driving Processes

A number of processes like gravity slumping, vertical load, current drag to seismic shaking may be responsible for hydroplastic, liquefaction, and fluidisation deformation.

The convolute lamination structures observed in the Thimi area show no preferential verging thus

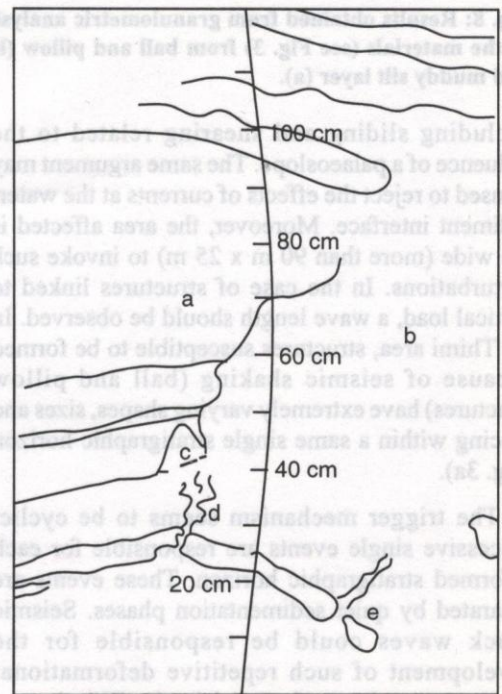
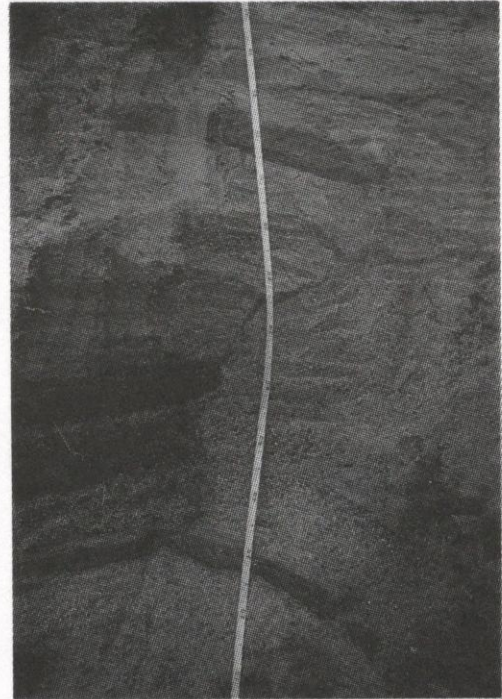


Fig. 7: Sand dyke: up-raised sandy material destroyed the original layering.

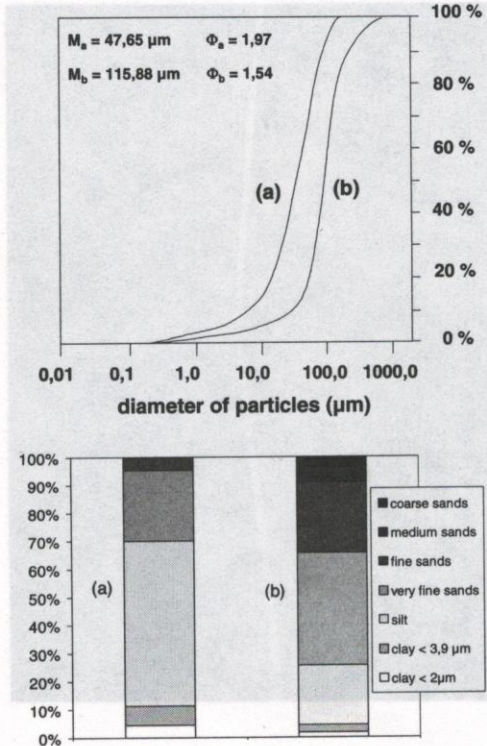


Fig. 8: Results obtained from granulometric analysis of the materials (see Fig. 3) from ball and pillow (b) and muddy silt layer (a).

excluding sliding and shearing related to the influence of a palaeoslope. The same argument may be used to reject the effects of currents at the water-sediment interface. Moreover, the area affected is too wide (more than 90 m x 25 m) to invoke such perturbations. In the case of structures linked to vertical load, a wave length should be observed. In the Thimi area, structures susceptible to be formed because of seismic shaking (ball and pillow structures) have extremely varying shapes, sizes and spacing within a same single stratigraphic horizon (Fig. 3a).

The trigger mechanism seems to be cyclic: successive single events are responsible for each deformed stratigraphic horizon. These events are separated by quiet sedimentation phases. Seismic shock waves could be responsible for the development of such repetitive deformational structures as those observed in the Thimi area. Moreover, the Thimi area lies within a seismic zone where earthquake motions are highly amplified in

relation with sedimentary facies of unconsolidated Quaternary sediments (Pandey et al., 1992). Great earthquakes of around 8.5 magnitude ruptured nearly half of the Himalayan chain in 1897, 1905, 1934 and 1950 (Seeber and Armbruster, 1981; Molnar and Pandey, 1989; Pandey et al., 1995). In the Kathmandu valley, major damages of probable seismic origin are reported to have occurred and reached an intensity of IX in Kathmandu city (Chitrakar and Pandey, 1986; Bilham et al., 1995). Hibschi et al. (1995) showed that such seismic intensities are able to generate soft deformational structures (seismites) with a thickness varying between 10 to 40 cm in lacustrine environment (Fig. 9). Palaeoseisms recorded by the seismites of the Thimi area would accordingly be in the same range as the historical seisms that affected the Kathmandu basin.

CONCLUSIONS

Several types of synsedimentary soft-sediment deformation structures are found in the Plio-Pleistocene fluvio-lacustrine deposits of Kathmandu basin. The characteristic features of the horizons of deformational structures have met the criteria proposed by Sims (1975) in order to interpret these structures as resulting from seismic events:

- 1) The structures are confined to a single stratigraphic horizon, have a large horizontal extent and occur in between undeformed parallel layers;
- 2) These structures are confined to the high liquefaction potential deposits as indicated by the

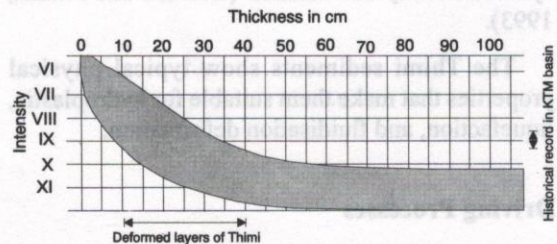


Fig. 9: Comparison of intensity of the historical seisms and of palaeoseisms in the Kathmandu basin using a diagram intensity versus thickness of liquefied layer (adapted from Hibschi et al., 1995). Grey domain refers to the domain of possible relationships between thickness of the liquefied layer and intensity of seism.

granulometric analyses and in the high shakability area as demonstrated by microtremor survey (Pandey et al., 1992);

- 3) All the layers are flat lying suggesting lack of slope failure influences;
- 4) Some structures are similar in forms to those formed experimentally (Kuenen, 1958).

It is the evidence that major earthquakes occurred periodically in central Himalaya during Pleistocene. Further work, based on dating and systematic studies of seismites, could be a way to better estimate the seismic hazard in the Kathmandu area.

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