THE LOWER DEVONIAN MUTH FORMATION (HIGHER HIMALAYA, NW INDIA): EXCITING STRUCTURES IN MONOTONOUS QUARTZITES

Erich DRAGANITS

Institut für Ingenieurgeologie, TechnischeUniversität Wien, Karlsplatz 13, A-1040 Wien

The prominent Muth Formation belongs to the Tethyan Zone of the Higher Himalaya tectonic unit, which records an almost continuous stratigraphic sequence from the Neoproterozoic up to the Eocene, deposited at the northern Indian continental margin (Bhargava & Bassi 1998). The Muth Formation is fairly uniform in lithology throughout its entire outcrop and has been traced from Kashmir to western Nepal. The formation comprises monotonous white, fine- to medium-grained, extremely pure quartzites with high textural and compositional maturity; the only exceptions are thin horizons of sandy and silty dolomites in higher levels of the formation. Due to its monotonous lithology hardly any detailed investigations have been carried out. At Spiti these sediments were deformed during the Himalayan orogeny into large-scale, SW-vergent, inclined horizontal folds, with NW-SE trending axes and wavelengths of approximately 5 km (Fuchs 1982, Wiesmayr & Grasemann 2002).

The Muth Formation reaches some 300 m thickness in the investigated sections in the Pin Valley. Based on sedimentary structures its general depositional environment is interpreted as a wave-dominated barrier island system. The contact to the underlying Pin Formation, a peritidal, dolomitic-calcareous, argillo-arenaceous succession with sporadic small reefal complexes, is a pronounced unconformity showing subaerial exposure and erosion. The contact to the overlaying Lipak Formations, a peritidal mixed carbonate-siliciclastic succession is gradational. The age of the virtually unfossiliferous Muth Formation in the Pin Valley is bracketed by Llandoverian conodonts from the uppermost part of the underlying Pin Formation and by Givetian conodonts in the basal beds of the following Lipak Formation (Draganits et al. 2002, Suttner 2003).

In contrast to its monotonous lithology, the Muth Formations contains several exciting sedimentary and deformation structures, with important implications for the interpretation of its depositional environment. Microbially induced sedimentary structures (Draganits & Noffke have been found in several levels of the formation; they include spectacular ”siliciclastic domal stromatolites”, as well as ”microbial gas pits”, ”microbial gas domes”, ”multidirected ripple marks” and ”polygonal shrinkage cracks”. These different siliciclastic microbial structures in the Muth Formation have close analogues in modern peritidal environments and they are characteristic for shallow-intertidal to lower supratidal environment and have been found in intervals of the formation associated with sedimentary structures indicating at least temporally emergent conditions. All of them can be explained by the formation of microbial mats and their interaction with a variety processes in shallow marine environments. The siliciclastic domal stromatolites indicate an environment of higher hydraulic energy and probably have formed in shallow sub-tidal settings. The microbial gas pits and the microbial gas domes record a lower supratidal zone influenced by tidal flushing. The multidirected ripple marks document a series of reworking events interfering with microbial mat growth. The polygonal shrinkage cracks are typical for episodic desiccation of microbial mats in semi-aride climates.

The discovery of abundant trace fossils (Draganits et al. 2001) in the Lower Devonian Muth Formation (Pin Valley, Spiti, northern India) contributes to our understanding of the diversity and distribution of Early Devonian arthropod activities in a marginal marine environment. The ichnoassemblage consists of abundant *Palmichnium antarcticum* and

Diplichnites gouldi with rarer *Diplopodichnus biformis*, *Taenidium barretti*, *Didymaulichnus* cf. *lyelli*, *Didymaulyponomos* cf. *rowei*, *Selenichnites* isp. and vertical burrows of unclear affinity. The abundance of trackways enables the documentation of size- and gait-variations among producers of single trackway ichnotaxa. Within the barrier island paleoenvironment of the Muth Formation the arthropod trackways occur only in beach to coastal dune environments. Most of the *Palmichnium* and *Diplichnites* trackways are interpreted as subaerial. *Palmichnium antarcticum* trackways are abundant and they frequently show sub-parallel orientation, predominantly perpendicular to the paleocoastline.

Cylindrical structures, cross-cutting stratification at right angles have been found in several levels of the Muth Formation (Draganits et al. 2003). These structures are up to 1.5 m in height and 0.8 m in diameter with an internal structure comprising concentric, cylindrical laminae. The pipes, which probably represent water conduits for laminar upward flow of ground water, initiate from relatively thin horizons, with upper terminations formed by spring pits. Thus the structures in the Muth Formation represent a rarely observed combined occurrence of spring pits and their conduits below. Their formation is explained by rising ground water seepage in a coastal depositional environment that produced a relatively high hydrostatic head, resulting in the formation of springs. The rise in relative sea-level might be related to tectonic subsidence caused by tectonic activity linked to the formation of conjugate deformation bands in the Muth Formation. This means, if tectonic activity was involved, it did not form the cylindrical structures by seismic liquefaction directly, but might be responsible indirectly through ground water seepage rise resulting from tectonic subsidence. Due to the little relief in this environment, the sea-level rise affected a relatively large area and fluidization structures can be found widespread in distant sections.

Deformation band faults and zones of deformation band faults (Draganits et al. submitted) have been found in several parts of the Muth Formation. Their orientations cannot be reasonably grouped with the orientations of faults related to Himalayan deformation in the Pin Valley. Additionally the deformation band faults are superimposed by Eo-Himalayan (Eocene) folds, which in turn are cut by faults. Thin section analyses show that the deformation band faults in the Muth Formation formed in the then porous Muth Formation by deformation mechanisms of cataclasis, translation, rotation of quartz grains and effective porosity reduction. In contrast the faults that cross-cut the Eo-Himalayan folds developed in already cemented Muth Formation at much higher temperature and pressure conditions by crystal plastic mechanisms, indicated by quartz crystals with undulatory extinction, abundant kink bands, dislocation glide, elongated subgrains, slightly curved deformation lamellae and pronounced shape preferred orientation. These completely different deformation mechanisms on the microstructural scale evidence the existence of two separate fault sets that formed at different depths in the crust. Based on these evidences a pre-Himalayan origin of these structures is concluded and the deformation band faults represent thus a set of rare pre-Himalayan deformation structures. After unfolding to account for Eo-Himalayan crustal shortening the spatial orientation of the deformation band faults and field observations of offsets of sedimentary bedding are most compatible with broadly E-W oriented shortening associated with N-S extension. The age of the deformation band faults in the Muth Formation is bracketed by the Early Devonian sedimentation age of the Muth Formation and the timing of considerable cementation, which is probably not later than Middle Cretaceous as deduced from the burial curve. Among the known pre-Himalayan (pre-Tertiary) deformation events the Neo-Tethys rifting event beginning in the Early Carboniferous and the extensional tectonic related to Late Carnian/Early Norian rapid subsidence are plausible candidates for the formation of the deformation band faults, although a hitherto unknown deformation event can not be excluded.

References

BHARGAVA, O. N. & BASSI, U. K. 1998. Geology of Spiti-Kinnaur Himachal Himalaya. Geological Society of India Memoirs 124, 1–210.

DRAGANITS, E., BRADDY, S.J. & BRIGGS, D.E.G. 2001. A Gondwanan Coastal Arthropod Ichnofauna from the Muth Formation (Lower Devonian, Northern India): Paleoenvironment and Tracemaker Behavior. Palaios, 16/2, 126-147.

DRAGANITS, E., MAWSON, R., TALENT, J.A. & KRYSTYN, L. 2002. Lithostratigraphy, conodont biostratigraphy and depositional environment of the Middle Devonian (Givetian) to Early Carboniferous (Tournaisian) Lipak Formation in the Pin Valley of Spiti (NW India). Rivista Italiana di Paleontologia e Stratigrafia, 108, 7-35.

DRAGANITS, E., GRASEMANN, B. & SCHMID, H.P. 2003. Fluidization pipes and spring pits in a Gondwanan barrier-island environment: Groundwater phenomenon, palaeo-seismicity or a combination of both? In: Van RENSBERGEN, P., MALTMAN, A.J. & MORLEY, C.K. (eds.): Subsurface Sediment Mobilization. Geological Society, London, Special Publications, 216, 109-121.

DRAGANITS, E. & NOFFKE, N. 2004. Siliciclastic stromatolites and other microbially induced sedimentary structures in an Early Devonian barrier-island environment (Muth Formation, NW Himalayas), Journal of Sedimentary Research, 74, 191-202.

DRAGANITS, E., GRASEMANN, B. & HAGER, C. (submitted). Conjugate deformation band faults in the Lower Devonian Muth Formation (Tethyan Zone, NW India): evidence for pre-Himalayan deformation structures. Geological Magazine,

FUCHS, G. 1982. The geology of the Pin valley in Spiti, H.P., India. Jahrbuch der Geologischen Bundesanstalt 124, 325–359.

SUTTNER, T. 2003. Die Pin-Formation (Altpaläozoikum) von Muth, Spiti (Indischer Himalaya). Unpubl. diploma thesis, University of Vienna, 81 p.

WIESMAYR, G. & GRASEMANN, B. 2002. The Eohimalayan fold-thrust belt: implications for the geodynamic evolution of the NW-Himalaya (India). Tectonics 21, doi: 10.1029/2002TC001363.