Climate change in Northeast Iran based on the morphology of palygorskite and pedogenic carbonates in loess deposits

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Loess/paleosol sequences near the city of Mashhad in Northeast Iran date back to last glacial/interglacial cycle. The Holocene loess containing a weakly developed Bk horizon and a paleosol of last interglacial period (OIS 5) with a Btk horizon have developed. Loess deposits in this area appear to have a local origin and their main source is Pliocene gypsiferous marl containing a high amount of palygorskite. The aims of this study were (i) to identify palygorskite in different landforms and sediments, (ii) to investigate the microscopic and submicroscopic analyses of palygorskite and associated pedogenic carbonates and (iii) to understand the paleoclimatic conditions prevailing in the area.

From west to east, Robat-e Khakestari section on a plateau-like geomorphic surface in the granitic hilly lands and Tappeh Salam section in the piedmont of granitic hilly lands containing loess/paleosol sequences, Astan-e Ghods section in the piedmont plain and Tangal Shour section in the gypsiferous marly hilly lands were studied. The clay fraction of soils and sediments were analyzed using X-ray diffraction (XRD) and transmission electron microscope (TEM) techniques. Undisturbed soil samples were impregnated with resin and thin sections were prepared and studied using polarizing microscope. Undisturbed samples were mounted on Al stubs and examined by a scanning electron microscope (SEM).

The XRD patterns showed the presence of palygorskite in different horizons of Tangal Shour section, Bk horizon of Holocene soils of Robat-e Khakestari and Astan-e Ghods sections, saline layers of Tappeh Salam section and also in gypsum enriched layers in loess deposits that showed the evidence of solution and recrystallization of gypsum. The short

fibers of palygorskite are visible in TEM micrographs of the Ap and Btk horizons of Robat-e Khakestari section, Btk and loess layers of Tappeh Salam section and in less quantity in Bw horizon of Astan-e Ghods section. The SEM analysis of undisturbed samples showed that palygoskite fibers were as long as 5-10 microns in the gypsiferous marls and the lower parts of Tappeh Salam section. In the Bk horizons and gypsum enriched layers, a few short fibers of palygorskite could be observed. The micromorphology revealed different form of carbonate accumulation in Bk and Btk horizons. In the Bk horizon, the typic carbonate nodules as a result of impregnation of groundmass without any translocation (orthic nodules) were observed. Some nodules encompass the coarse grains (Nucleic nodules). In the Btk horizons the carbonate nodules have been separated from the groundmass and represent some translocation or rotation but the internal fabrics of nodules are similar to groundmass (disorthic nodules). The carbonate nodules in Btk horizons have been covered by nonlaminated dusty clay coating representing polygenetic development.

In conclusion, based on the amount and morphology, four kinds of palygorskite in sediments and soils were distinguished. 1) A high amount of well-grown fibers in the gypsiferous marls of Tangeh Shour section and the saline part of Tappeh Salam section as a product of *in situ* formation. The clay mineralogy of Pliocene gypsiferous marls in the area is in agreement with late Pliocene sediments in Southern Iran and Oligo-Miocene sediments from Central Iran. 2) A somewhat high amount of palygorskite in weakly developed Bk horizons of Holocene soils on loess deposits and layers containing recrystallized gypsum, as a result of illuviation of palygorskite in association with carbonates or gypsum which is easily detectable by XRD, 3) the lesser amount of palygorskite in the red Btk horizons (OIS 5 paleosols) in loess sections. The existence of carbonate nodules covered by clay coating represents a moist condition after carbonate illuviation and unstable environment for palygorskite during last interglacial. 4) Very little amount of detrital palygorskite in unaltered loess deposits originating from gypsiferous marly material during loess deposition.