The Mesozoic-Tertiary weathering mantle of the Rhenish Massif. Characteristics and genesis

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Morphological, mineralogical and geochemical investigations were carried out on overlapping exposures and drill cores of the autochthonous Mesozoic Tertiary weathering mantle (MTV). The exposures give a complete picture of the weathering mantle from the fresh slate up to the recent land surface as well as the spatial distribution related to neo-tectonics and relief. The aim of the investigations was to reconstruct the genesis and the quaternary superimposition of the weathering mantle.

The study area "North eastern Eifel" is situated in the declination zone from northeastern Eifel to the Lower Rhine Embayment. The area encloses the territory of the Ahrberge in the south of Bad Neuenahr and the territory in the north of the lower Ahr up to Bonn. The eastern border is the Rhine river and in the west the line between the villages Mayschoss and Meckenheim. The study area "Eastern Hunsrück", situated in the south eastern part of the Rhenish Massif, left of the river Rhine, is bordered in the south by the Soonwald, in the east by the Rhine river, in the north by the Mosel river and in west by the ridges of Hochwald and Idarwald. The highest elevations of this flat upland area amount between 450 and 500 m a.s.l.. In both study areas large-dimensional relics of the younger peneplain (R1-plain) and its thick weathering mantle exist as a result of the relatively weak tectonic elevation during Upper Tertiary and Quaternary.

In both areas the parent rocks are predominantly Lower Devonian clay and silt slates. Depending on the region, layers of sandstone (greywacke), quartzite and quartz veins are inserted. Samples of the slates were geochemically and mineralogically analyzed as a basis for the evaluation of element losses and weathering intensity of the saprolites, which developed from them. The main constituents of the fresh slates are about 30 – 40 mas.% illite-muscovite, up to 40 mas.% quartz and 25-30 mas.% of Fe-Mg-chlorite (Fe-rhipidolite). Chlorite shows the lowest weathering stability and is relatively easily soluble in acids. Up to 1 mas.% coaly-bituminous organic substance gives the slates their black-grayish color. An increase of the sand fraction is related with an increase of quartz content and a decrease of the Ti/Zr-ratio. The mineral composition of the slates is uniform in both study areas. Chlorite shows the lowest weathering stability and is relatively easily soluble in acids.

Under warm and humid climates of Upper Mesozoic and the Tertiary, a weathering mantle with a thickness up to 150 m was formed. It can be subdivided into the genetic units "solum" and "saprolite" (Fig. 1). The solum developed near the land surface by pedogenetical processes and shows soil horizons with neo-formation of structure. With respect to the morphogenesis of the peneplain by denudation due to climatic changes and tectonic uplift, the solum represents the youngest formation of the weathering mantle.

The saprolite underlying the solum was developed by downward weathering. It shows an undisturbed rock structure. The conditions of the saprolite formation were persistent tectonic repose periods and a warm and humid climate accelerating the weathering processes. During these phases the advance of the weathering base downwards exceeded the rate of denudation of the land surface. Due to its characteristics the saprolite is subdivided into an upper oxidation horizon and a lower reduction horizon. In the Rhenish Massif each of them can have a thickness of more than 40 meters. In both of the main horizons zonal features were formed, which are designated by the horizon symbol "mCj" in combination with additional feature symbols (see Fig. 1). The zones do not only run horizontally but also vertically, because their formation was related to the structure and permeability of the rock.

In the reduction horizon of the weathering mantle the slates were kaolinized under water saturation and leaching of silica and cations by lateral moving ground water. The deepest zones of the reduction horizon include kaolinite and smectite side by side as a neo-formation after chlorite (Fig. 1). With increasing permeability in upper zones and leaching due to a higher weathering intensity of the

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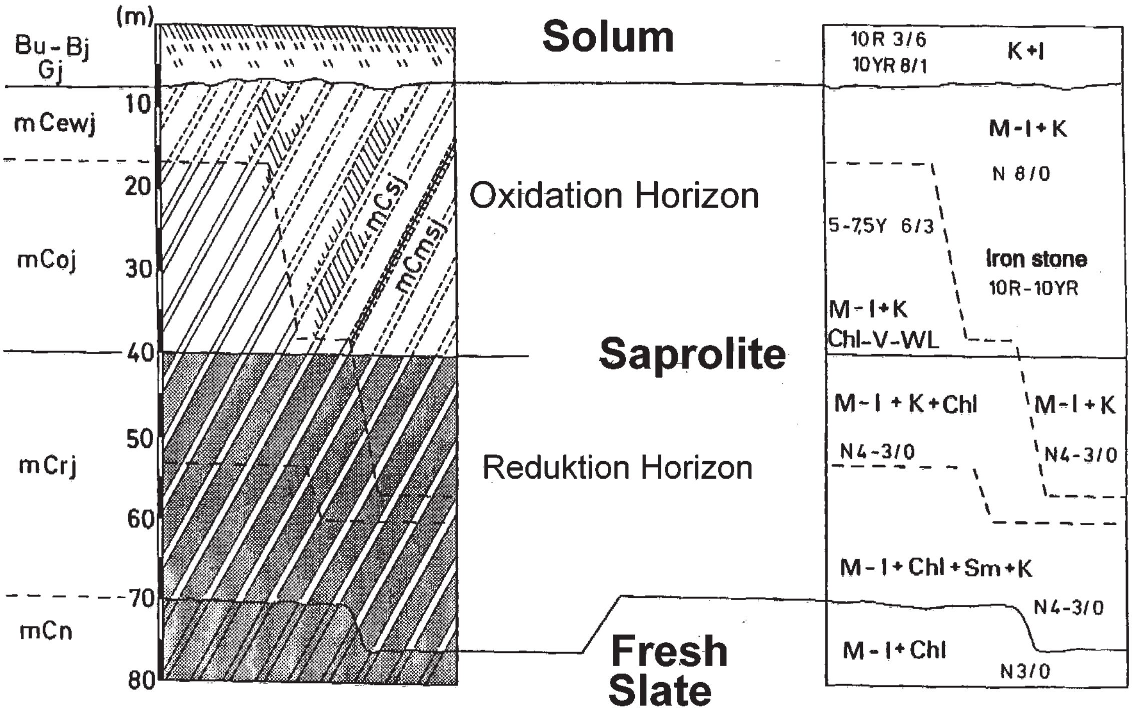

Fig. 1.- Morphological and mineralogical subdivision of the Mesozoic-Tertiary weathering mantle (Chl = primary Fe-Mg chlorite; Sm = smectite; M-I = Muscovite-Illite; Chl-V-WL = chlorite-vermiculite mixed layer minerals; K = kaolinite)

Horizons (according to the German Soil Classification):
mCrj: reduction zone, black-grayish color of the fresh slate
mCoj: oxidation zone, brown-, to grayish olive color, weak elution, absence of accumulation of oxides
mCewj: Bleached saprolite, white to light grayish color
mCsj: Accumulation zone of iron and manganese oxides, yellow, brown, red and purple colors, relatively weak accumulation of oxides (<10% FeDCB)
mCmsj: Massive, brown, red and purple-reddish banks of iron stone, predominantly running vertical within the bleached saprolite, strong accumulation of oxides (>10% Fe_{DCB}).

saprolite, smectite disappeared from the mineral association. The residual chlorite was completely kaolinized or transformed to 1:1 chlorite-vermiculite mixed layer minerals under oxidizing conditions, which affected the reduction horizon in areas of rather low rock permeability after the decrease of the ground water level. In the bleached saprolite ("Weißverwitterung"), that forms the uppermost, up to 40 metres thick zone of the oxidation horizon, kaolinite is the only neo-formation beside residual muscovite-illite and quartz.

Additional to the weathering of primary and the neo-formation of secondary minerals, leaching of soluble elements was the third process of deep weathering. Leaching processes prevented chemical equilibriums in the pore solution and enabled the advance of the weathering basis with depth. The leaching of mobile elements occurred under reducing conditions. Its intensity was controlled by the movement of ground water within the permeable rock zones. Mass losses of the weathered slates by leaching amounts to 25-30 vol.- %, related to the unit weight of fresh slates. The results of iso-volumetric balances show, that in all zones of the saprolite silica has the highest proportion of the total mass losses. It originates from the dissolution of quartz and illites rich in Si. The increasing pore volume of the weathering rock enhanced the permeability of the saprolite and the efficiency of deep weathering.

During phases of descending ground water level, oxidizing conditions within the bleached zone of the saprolite resulted in the decay of primary coaly-bituminous organic substances, as well as in the formation of oxide accumulation zones. The accumulation of oxides was orientated to the most permeable zones of the rock (quartz veins, banks of saprolite from sandstone), which already became aerated, while the adjacent banks of saprolite from clay or silt slate, rich in fine pores, were still saturated by water leading to a continuation of reducing conditions. Therefore, over a distance of several meters, the diffusion of mobile elements followed a redox and concentration gradient. In the deepest parts of the oxidation horizon the banks of iron stone completely consist of goethite, frequently accompanied by Mn oxide concretions. The contents of hematite increases in the upper zones of the saprolite. Ore microscopic and mineralogical investigations prove that the oxide enrichment was bound to an epigenetic displacement of kaolinite.

A fossil pre-Oligocene soil, superimposing the bleached saprolite, was investigated as an example for the solum of the weathering mantle. Similar to other autochthonous Tertiary paleosols, the investigated profile can be subdivided from top to bottom into a concretionary layer, a plinthite layer and a bleached layer. According to the German soil systematics, it can be classified as a ferrallitic Red Plastosol, which nearly corresponds to a Ferrali-Gleyic Acrisol according to the legend of the FAO soil map. The horizonation of the soil, as well as the oxide accumulation within the pores, mark a primary soil genesis under the influence of a high ground water level. Compared to the saprolite, the clay contents of the soil horizons is distinctly increased, especially in the fine clay fraction. The mineral association reflects a progressive kaolinization of illite-muscovite from the saprolite to the top soil. In contrast with the saprolite, the neo-formed kaolin minerals of the soil clay fraction predominantly consist of “DMSO-intercalation disordered” kaolinite (“fireclay minerals”). A neo-formation of gibbsite could not be proved.

In respect to the relationship between the autochthonous weathering mantle and Tertiary tectonics as well as Tertiary sediments, two main genetic periods can be stratigraphically defined. The older period with high ground water levels reaching up to the soil horizons, lasted from the Upper Cretaceous or Lower Tertiary to the Upper Oligocene. During lower Miocene, decreasing ground water levels due to tectonical uplift and semi-arid climatic conditions led to the formation of the up to 40 meters thick bleached saprolite (“Weißverwitterung”) and the Hunsrück iron stones. It is likely that a second period of deep reaching oxidation took place during Pliocene.

The soils of the Miocene landscape were extensively removed by Upper Tertiary erosion processes. With the beginning of the Quaternary, about 2 million years ago, the more or less eroded saprolite probably outcropped at the land surface.

During the cold periods of the Pleistocene, processes of cryoturbation, solifluction and regressive erosion led to a further removal of the weathering mantle and a dissection of the peneplain. At the slopes of the deeply incising river valleys and at the edges of the stronger uplifted fault blocks, the reduction horizon of the saprolite or the fresh slates were exposed. Superficial periglacial layers were deposited on top of the autochthonous relics of the weathering mantle. They can be subdivided by heavy minerals, texture and morphology into a stratigraphic sequence of three layers. Due to cryoturbation and congelifraction, the saprolitic rock changed into a structureless loam, which was re-distributed by fluvial or solifluidal processes.

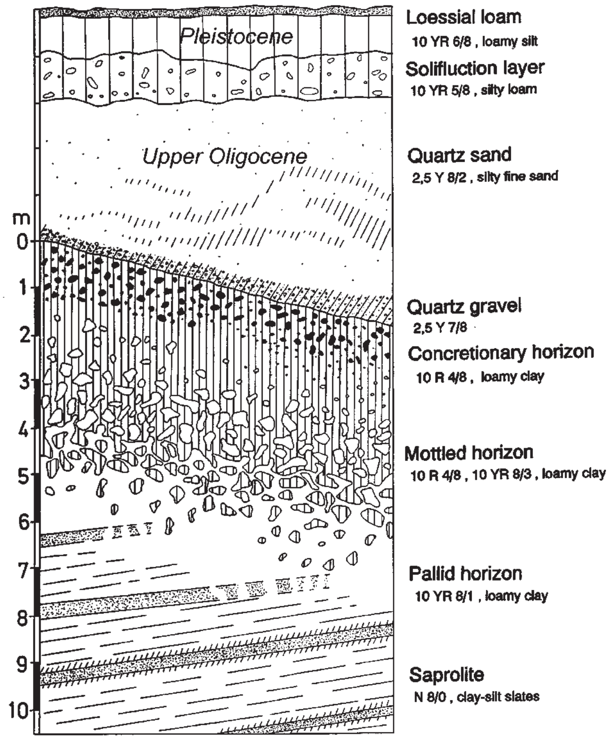

Fig. 2.- Profile characteristics of the autochthonous pre-Upper Oligocene paleosols, site “Bengen”, northeastern Eifel (for details see Felix-Henningsen & Wiechmann, 1985 and Felix-Henningsen, 1992).

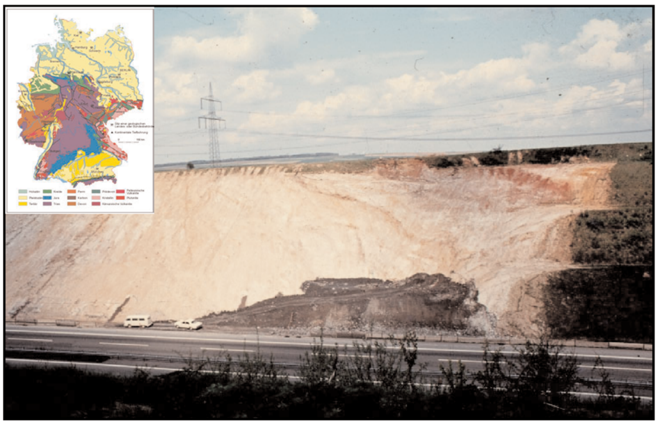

Photo 1.- Road cut a site “Bengen”, displaying the bleached saprolite from Devonian slate and the pre-Upper Oligocene ferrallitic soil.

Relics of this substratum remains as “Gray Loam” on top of the eroded saprolite and forms the basal layer, which is free of loess. It is overlain by solifluction layers of the middle layer, which contains loessial loam. Soil horizons from this layer micromorphologically display periglacially reworked or redeposited argillans of an interglacial Luvisol. Therefore, a Riss glacial age for the deposition of the loess can be assumed. The uppermost solifluction layer consists of eolian loessial pumice dust, containing minerals of the Laacher See tephra, and therefore was deposited in the late glacial during the Younger Tundra Age.

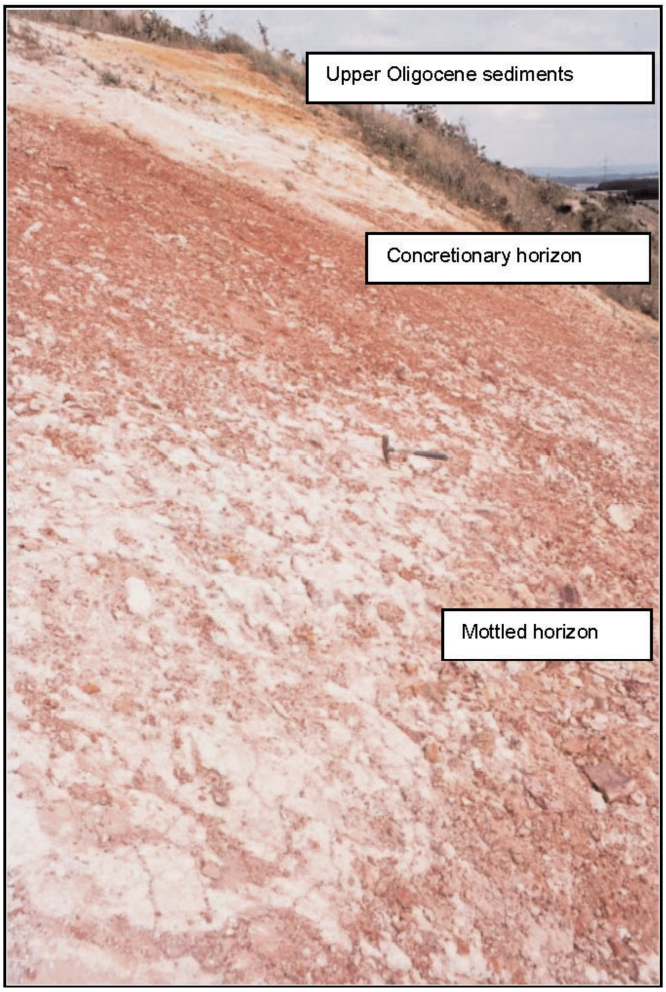

Photo 2.- Site “Bengen” – pre-Upper Oligocene red ferrallitic paleosol.

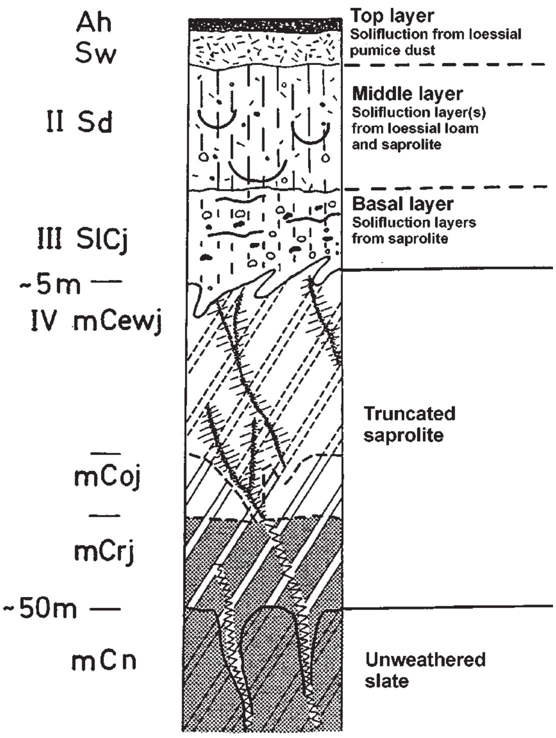

Fig. 3.- Vertical section of the partial eroded Mesozoic-Tertiary weathering mantle overlain by periglacial superficial layers (horizon symbols s. Fig. 1).

The Holocene soil development in the Quaternary superficial layers was marked by progressive weathering of silicates and the influence of logged surface water. On the other hand, clay migration was hardly important. The Gray Loam does not represent the Tertiary solum on any account, as previously assumed by soil scientists and geomorphologists. As a sediment, which derived from the underlying saprolite, a designation as “Gray Plastosol” on the systematical level of soil type or subtype according to the German Soil Systematic does not seem to be justified. Gray Loams can derive from diverse zones of the thick weathering mantle and they are not only related to the Tertiary landscape, but frequently cover slopes and bottoms of Pleistocene valleys. Therefore, the importance of Gray Loams for morphogenetic and paleoclimatic statements is rather limited. The investigated soils from the Quaternary superficial layers belong systematically to the soil types of Pseudogley (FAO : Stagnic Luvisol or Cambisol) and Brown Earth-Pseudogley (FAO : Cambi-Stagnic Luvisol) respectively.

In the Eastern Eifel area of Quaternary volcanism, as well as more seldom in areas of Tertiary volcanism, post-volcanic activity still recently occurs. It is characterized by mofettes of which some of them raise mineralized thermal waters with a temperature between 8 - 30° C. Iron ochre in the surrounding of CO_2 springs consists of ferrihydrite and carbonates, which derive from hydrothermal alteration of the Fe-Mg-chlorites in the slates. In these areas as well as in areas of deep tectonic faulting and of Tertiary volcanism narrowly extending zones of deep kaolinization are reaching far below the base of Mesozoic-Tertiary weathering. They developed by hydrothermal alteration, due to the hydrolytical activity of thermal H_2CO_3, and show no mineralogical depth gradient. According to the absence of oxygen, hydrothermally altered slates display the same gray color as the fresh slates. Neo-formation of smectite, kaolinite and especially of dickite from primary chlorite are the mineralogical characteristics. While primary quartz veins in the deeper parts of the alteration zones were subject to dissolution, secondary quartz occurs as coatings in joints of sandstones near the surface. Also the Mesozoic-Tertiary weathering mantle was subject to hydrothermal alteration, characterized by the occurrence veins of kaolinite-dickite and secondary quartz. Quaternary basalt dikes crossing the kaolinitic saprolite, frequently show characteristics of “auto-hydrothermal” alteration due to the transformation of basalt into pure smectite.

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