Metasomatic Mechanism of Weathering-Pedogenesis of Carbonate Rocks: I. Mineralogical and Micro-Textural Evidence*

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Abstract: On the basis of mineralogical, geochemical and micro-textural studies of the typical sections of the red weathering crust of carbonate rocks in the subtropical karst areas of Guizhou Province and Guangxi Autonomous Region, we have found, either on a microscopic or on a macroscopical scale and in different positions of the sections, the most direct and most important mineralogical and micro-textural evidence for the development of metasomatism in the process of weathering-pedogenesis of numerous carbonate rocks. This paper also has expounded for the first time and systematically the mechanism of metasomatism involved in the process of weathering-pedogenesis of carbonate rocks and proposed the sequence of mineral metasomatic evolution in the process of weathering-pedogenesis of carbonate rocks.

Key words: the red weathering crust of carbonate rocks; weathering-pedogenesis; metasomatism

Introduction

Globally exposed carbonate rocks account for about 12% of the total land area, overlying which are widely developed the red weathering crusts of varying thickness. As carbonate rocks are a kind of soluble rocks, geologists place their focus, first and for most, on their karstification while pedologists pay their attention to surface soils. Therefore, little attention has been paid to the weathering-pedogenesis of carbonate rocks and its mechanism. Even up to now, the mechanism of weathering-pedogenesis of carbonate rocks has not yet been well documented and the available data are scattered here and there in the literature (Mortini and Chesworth, 1992). Such a situation can never be matched with the fact that the red weathering crust of carbonate rocks accounts for 10% of the total global land area and its important position held in the study of natural resources and environment. The knowledge of weathering-pedogenesis of carbonate rocks and the mechanism of formation of the red weathering crust still remains at the stage of studying solution relics derived from carbonate rocks and is hard to explain the micro- and macroscopic geological phenomena observed on various scales in recent years by means of different geological approaches. This is in contrast with the great achievements made in the detailed study of weathering-pedogenesis of insoluble rocks such as granite, basalt and feldspathic sandstone (White et al., 1996). This also restricts, to a greater extent, our attempt to carry out deep exploration of the related problems of natural resources and environment.

The southern part of China is a typical karstified area where carbonate rocks are most widely distributed in the world and there are widely developed carbonate rock red weathering crusts. Of the

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tropical and subtropical karst areas in the world, the most typical ones are Guizhou and Guangxi. In recent years, with the rise of the problems of natural resources and environment related with carbonate rock-derived red weathering crusts, for example, the mechanism of formation of carbonate rock-derived laterite-type gold deposits, water erosion, land degeneration, soil acidification, soil and water pollution and red clay engineering geological disasters, the weathering-pedogenesis of carbonate rocks and the mechanism of formation of red weathering crusts have aroused great attention of the academic circles. Under the project, personally charged by the senior author and finantially supported by the National Natural Science Foundation of China "the mechanism of weathering of laterite in the karst areas of Guizhou Province and its geochemical sensitivity" (Grant No. 49463011), the senior author took the lead in carrying out a detailed and systematic study of carbonate rock-derived red weathering crusts in Guizhou and Guangxi and reported the relevant mineralogical and geochemical results concerned (Zhu Lijun et al., 1996, 1997; Zhu Lijun, 1996). On the basis of the above study, this paper presents mineralogical and micro-textural evidence for the weathering-pedogenesis of carbonate rocks and expounds the mechanism of metasomatism of weathering-pedogenesis of carbonate rocks in terms of the detailed observations of 22 typical sections, which are variable in evolution degree, of carbonate rock-derived red weathering crusts in Guizhou and Guangxi.

Characteristics and Zonation of Carbonate Rock-Derived Red Weathering Crust Sections

In the karst areas of southern China are widely distributed carbonate rock-derived red weathering crusts that are generally measured at 5 – 10 m in thickness with the maximum even up to 30 m or more. The distribution of the weathering crusts is controlled mainly by karst topographic and hydrogeological conditions. On the karst platforms, gentle hills and gentle slopes, the red weathering crust sections are rather thick with a complete vertical zonation; on the ridge-and-peak highlands and sharp slopes the red weathering crusts are rather thin, where the sections are poorly developed. The characteristic features of vertical zonation of completely developed carbonate rock-derived red weathering crust sections are presented in Table 1.

Mineralogical and Micro-Textural Characteristics of Metasomatic Pedogenesis

The term metasomatism was first introduced into geological literature by German mineralogist K. Laoman. Kirk in 1877, which refers to those early minerals or rocks. Under the influence of different physico-chemical fluid systems, at later stages, due to changes in chemical balance conditions, the original minerals or rocks would be transformed by way of old materials being replaced by new ones. In previous investigations on metasomatism the focus was placed mainly on hydrothermal deposits, especially on skarn deposits. Well-known ore deposit scientists B. Greenen and D. Korenski et al. once made detailed investigations into metasomatism and proposed the theory of metasomatic origin of hydrothermal deposits. In addition, the definite conception of metasomatism was also presented. There are two key points concerning metasomatism: one is that metasomatism proceeds in accordance with the isosteric law; and the other is that the dissolution of old minerals and the precipitation of new minerals seem to have taken place contemporaneously. The replaced rocks often maintain the solid state. Therefore, metasomatism exhibits special textural and structural characteristics (Robert et al., 1980).

Only ten years or so have passed since the concept of metasomatism was introduced into the study of weathering-pedogenesis of rocks. Chinese scholar Wang Shousong (1983) once introduced pseudomorphic metasomatism into the discussion of the forming mechanism of laterite weathering

crust derived from basalts in Hainan Island in the light of its mineralogical and micro-textural characteristics (Wang Shousong et al., 1983). In recent years a great breakthrough has been made in the study of the mechanism of weathering-pedogenesis of silicate minerals such as feldspar and mica and their host rocks. It is just on the basis of a better understanding of the mineralogical and micro-textural characteristics of the weathering crust (White et al., 1996; Merino et al., 1993). At present, both Chinese and overseas scholars commonly introduce the concept of metasomatism into their study of weathering-pedogenesis of silicate minerals such as feldspar, mica and pyroxene and their host rocks.

Table 1. Vertical zonation of completely developed carbonate rock-derived red weathering crust sections

Weathering layer zonation	Extent of weathering-pedogenesis and thickness (m)	Characteristic layer	Characteristic mineral association	Micro-texture	Geochemical zonation
Surface soil layer	Very strong (0.1-1)	Soil layer	Kaolinite-goethite-gibbsite	Pellet texture, sponge texture, vadose tube texture	Organic matter and bio-enrichment zone
	Strong (1-5)	Red ferro-aluminium clay layer or iron crust	Kaolinite-goethite (hematite)-gibbsite	Gelatinous texture, pelitic texture, metasomatic relic texture, pseodomorphic metasomatic texture, dermolith texture, honeycomb texture, kidney texture	Al-rich desilicified zone
Polyweathring layer	Strong (0.5-0.3)	Yellow limonite-bearing clay layer or banded ferrous nodule zone	Goethite (hematite)-psilomelane (pyrolusite)	Earth-like texture, pelitic banded texture, metasomatic relic texture, pseodomorphic metasomatic texture, oolith texture, honeycomb texture	Fe, Mn-rich zone
Semi-weathering layer	Moderate (0.1-0.3)	Mottled clay layer or clay-bearing porous dissolution-leaching layer	Halloysite-quartz-allophane	Earth-like texture, metasomatic relic texture, pseudomorphic metasomatic texture, porous texture, metasomatic relic bedding structure	Si, Al-rich decalcified and demagnesified zone
Carbonate rock	Weak (0.1-1)	Fractures of dissolution pore zone	Calcite-dolomite	Solution pore-fissure structure, primary rock bedding structure	Physical deintegration zone

Field and microscopic observations on the 22 typical sections of carbonate rock-derived red weathering crusts in Guizhou and Guangxi led us to see that there exist not only solution-precipitation-induced textures and structures, but also there are widely developed metasomatic textures in the carbonate rock-derived red weathering crusts. In the rock/soil transitional zones (semi-weathering layer) of the carbonate rock-derived red weathering crust sections we can observed the development of metasomatic pedogenesis on a large scale and that soil bodies in the rock/soil transitional zones still maintain the micro-bedding structure (Photos 1 and 2), resulting in metasomatic relic micro-bedding structure. Microscopically, calcite and dolomite were replaced by clay minerals, forming pseudomorphic metasomatic texture (Photos 3 and 4). Calcite (dolomite) pseudomorph is usually composed of clay minerals such as halloysite, kaolinite and illite. It can be observed in the

polyweathering layer that a large number of clay minerals (kaolinite, chlorite) are replaced by iron oxides such as goethite and hematite. As viewed from their micro-textures, the white/grey alternating pelitic banded texture originally consisting of clay minerals has been transformed into pelitic banded texture alternatively composed of iron oxide minerals (yellow and red) and clay minerals (white and grey). In further development a yellow/red alternating pelitic banded texture will be produced, which is composed completely of iron oxide minerals (goethite, hematite, etc.) (Photo 5), or a yellow (goethite)/red (hematite) alternating gelatinous texture will appear (Photo 6). By using polarization microscopic, scanning electron microscopic and electron microprobe techniques in a combined manner, we can, on an ICM scale, observe the clay minerals (kaolinite, halloysite) formed at the early stage of weathering-pedogenesis in the rock/soil transitional zones have been replaced by iron oxide minerals, which has recorded the dynamic processes of their transformation (Photos 7 and 8). In regard to the mineral evolution sequence, a complete metasomatic mineral evolution sequence is usually seen in going from the bottom to the upper part of a carbonate rock-derived red weathering crust section, i. e., calcite, dolomite→ clay minerals (halloysite, kaolinite, chlorite) →iron oxide minerals (goethite, hematite)→ gibbsite.

As carbonate rock-derived red weathering crusts are widely developed in the tropical and subtropical areas, they are in an open karst environmental system with abundant ground and surface waters and soil solutions, which creates favorable conditions for metasomatism. However, in the previous studies of weathering-pedogenesis of carbonate rocks the focus was placed on the removal of soluble components (Ca, Mg, K, etc.) and *in-situ* deposition, as residues, of almost insoluble components (Al, Fe, Mn, etc.), but the role of ground and surface waters and other fluids in importing such components as Al, Fe, Mn and Si. Although there are some differences in composition, texture and micro-fissure pattern for calcite and dolomite as well as for a series of transitional carbonate rocks, the development of metasomatism is a common feature of weathering-pedogenesis of carbonate rocks. Metasomatic pedogenesis is a main process of weathering-pedogenesis of carbonate rocks. Metasomatic pedogenesis is a main process of weathering-pedogenesis of carbonate rocks and it is developed in the whole process of formation and evolution of a carbonate rock-derived red weathering crust. Also, it is one of the essential manners in which minerals are formed in the carbonate rock-derived red weathering crust. Differences in weathering-pedogenesis of carbonate rocks of different types are reflected mainly in the extent of development of solution-precipitation. For example, at the early stage of weathering-pedogenesis of limestone such a phenomenon would be observed that the extent of solution-precipitation would exceed that of metasomatism. Near the rock/soil interface of the limestone red weathering crust section there would also be observed more clay minerals such as halloysite, allophane, and poorly crystallized gelatinous iron oxide minerals, as well as the corresponding micro-textural features.

Conclusions

In the carbonate rock-derived red weathering crusts are commonly observed the phenomena of metasomatic pedogenesis and the mineralogical and micro-textural features due to metasomatic pedogenesis. The formation of carbonate rock-derived red weathering crusts is the combined result of metasomatism and solution-precipitation while metasomatic pedogenesis is a dominant process involved in weathering-pedogenesis of carbonate rocks, which proceeds through the whole process of formation and evolution of carbonate rock-derived red weathering crusts.

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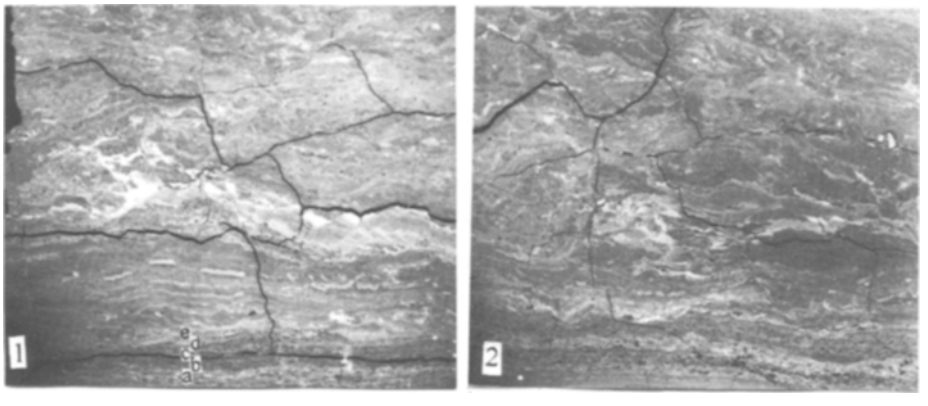
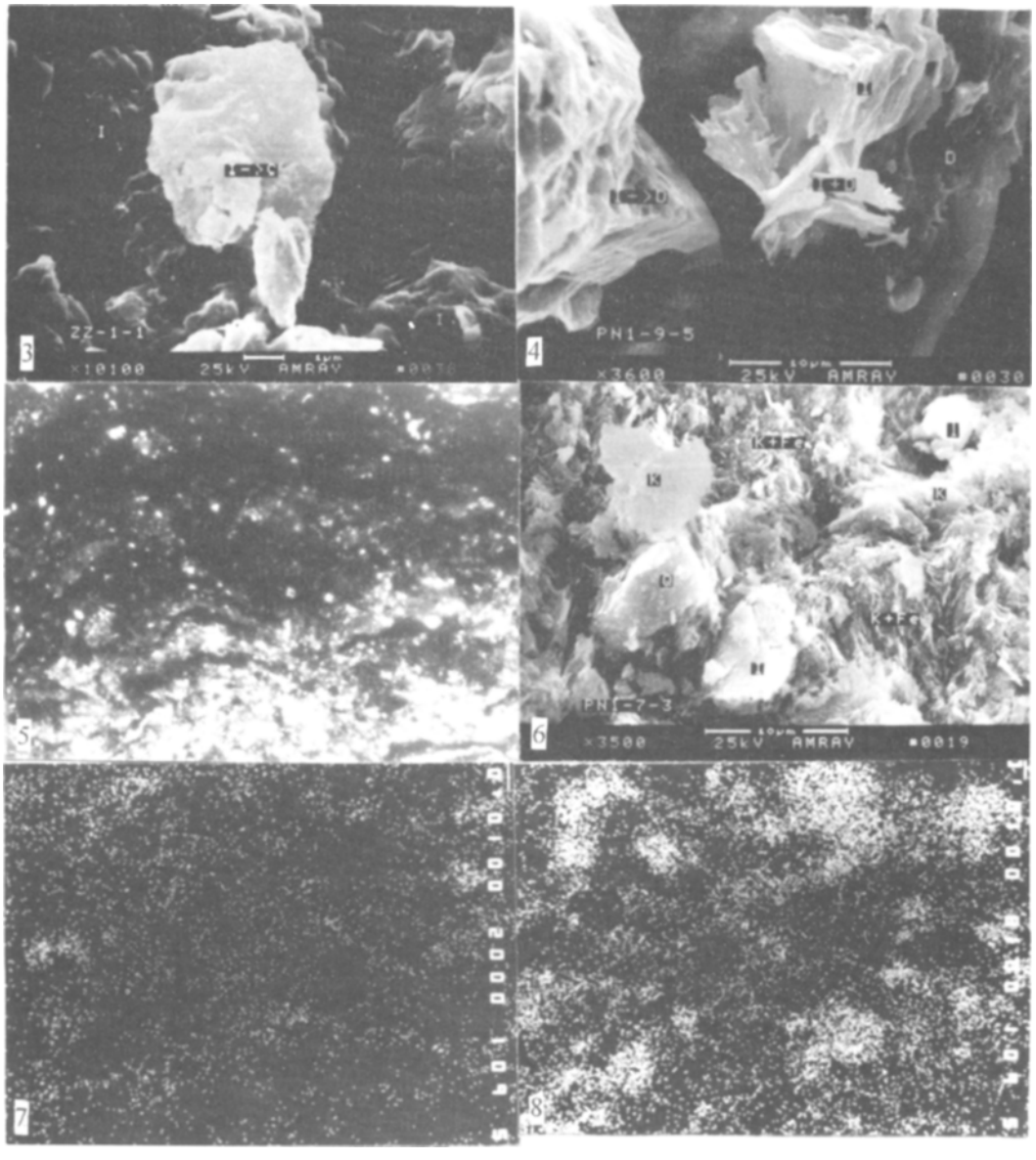


Photos 1 - 2: 1. Metasomatic relic bedding structure of a semi-weathering layer (rock/soil transitional zone) in the limestone red weathering crust. The soil bodies consisting of secondary weathered minerals (clay minerals and iron oxide minerals) still maintain bedding structure of the original rock (limestone), thin section, ×2. 2. Metasomatic relic bedding structure of a semi-weathering layer (rock/soil transitional zone) in the dolomite red weathering crust, thin section, ×2.



Photos 3 – 8: 3. Replacement of primary mineral calcite (C) by illite (I) in a semi-weathering layer (rock/soil transitional zone) in the limestone red weathering crust, constituting calcite pseudomorph metasomatic texture, SEM, ×10100. 4. Replacement of primary mineral dolomite (D) by illite (I) in a semi-weathering layer (rock/soil transitional zone) in the limestone red weathering crust, constituting dolomite pseudomorph metasomatic texture, SEM, ×3600. 5. Replacement of clay minerals by iron oxide minerals in a polyweathering layer and transformation of pelitic banded texture (lower part) originally consisting of clay minerals into one consisting of iron oxide minerals (upper part), monopolarized light, ×63. 6. Replacement of kaolinite (K) by iron oxide minerals (Fe); page-like kaolinite is still maintained locally, constituting kaolinite pseudomorph metasomatic texture, SEM, ×3500. 7. Planar distribution of the element iron in position b of Photo 1 as scanned by electron probe; at the early stage of replacement of clay minerals by iron oxide minerals, iron was distributed evenly isomorphously in clay minerals, ×600. 8. Planar distribution of the element iron in position e of Photo 1 as scanned by electron probe; clay minerals have been partly replaced by iron oxide minerals in which the element iron is distributed in the form of spherules, ×600.