地理学报(英文版) 2002年第12卷第2期

The property, age and formation environment of the palaeokarst in Qinghai-Xizang Plateau?

作者: GAO Quan-zhou CUI Zhi-jiu

The karst landforms distributed on the Qinghai-Xizang (Tibet) Plateau can be genetically classed with the Tertiary underground karst, which were gradually exhumed to the surface with the uplift of the plateau during Quaternary period. The relative deposits of the Tertiary palaeokarst processes, such as the residuum and speleothem, were discovered recently in the southern and southeastern fringe areas of the plateau, where has geological-currently been disintegrated by the headward erosion processes of the modern river systems. The major chemical components of the clay portion of the residuum consist mainly of SiO2, Al2O3 and Fe2O3. The clay minerals composition of the clay portion belongs to illite-kaolinite pattern for most of the residuum samples, and kaolinite-illite pattern for a few of the samples. It can be judged from the silicic acid index and the clay minerals composition that the formation of the residuum of the Plateau was in its initial phase. However, such a lower chemical weathering index only reflected the weathering degree in the bottom or lower parts of the lateritic weathering crust. The relatively intensive chemical weathering processes of the surface layers of the lateritic weathering crust could be logically speculated. The surface feature textures of quartz grains in the residuum were formed mainly by the chemical erosion, which revealed a long-term humid-tropical environment when the residuum and the palaeokarst formed.

The property, age and formation environment of the palaeokarst in Qinghai-Xizang Plateau GAO Quan-zhou1, CUI Zhi-jiu2, TAO Zhen1, LIU Geng-nian2, HONG Yun3 (1. Department of Geography, Zhongshan University, Guangzhou 510275, China; 2. Department of Geography, Peking University, Beijing 100871; China; 3. State Environmental Protection Administration, Beijing 100035, China) 1 Introduction Great advances have been achieved about the uplift processes and patterns of the Qinghai-Xizang (Tibet) Plateau, the highest and geo-tectonically youngest plateau of the Globe, which covers an area of 2,500,000 km2 and towers to one-third of the thickness of the troposphere, in recent several decades (Li, 1995; Shackleton and Chang, 1990; Shi et al., 1999; Sun and Zheng, 1998; Wu et al., 2001). However, a few studies have been conducted concerning the natural environmental properties of this extensive mid-low latitude area before the plateau uplift. Moreover, many disputes existed among different finished conclusions (Cui et al., 1996; Sweeting et al., 1991; Wang, 1990; Zhang, 1996; Zhu, 1994). How are the natural environmental properties of the fast staged-uplifted and tectonically complex young plateau (Dewey et al., 1990; Li et al., 1979)? Such a suspicion, which may be the knot for understanding the environmental evolution history of the plateau, even of the Globe, has attracted the curiosity of many geomorphologists and palaeo-geographers for many years (Bull et al., 1990; Cui, 1981; Cui et al., 1995, 1997; 1996; Dewey et al., 1990; Gao, 1996; Li et al., 1979; Peng, 1992; Sweeting et al., 1991; Zhang, 1996; Zhang et al., 1991; Zhu, 1994). The continued uplift processes of the plateau during late Cenozoic Era had made its surrounding areas, especially the southern and southeastern fringe areas be the most intensively eroded ones. In fact, regardless of the mechanical or chemical load of many rivers originated from the Qinghai-Xizang Plateau, are all firstly ranged in the global rivers (Galy et al., 1999). Over half of the riverine suspended load of the global rivers is eroded and transported into the oceans from this area (Milliman and Meade, 1983). Most of the flatten geomorphologic surfaces sculptured before the intense uplift in the eastern part of the plateau had been wiped out by the subsequently intensive erosion accompanying with the fast uplift processes. Nevertheless, it is the short geological history of the uplift of the plateau that makes some areas in the mid-western part of the plateau free of being wiped out by the headward erosion (Li et al., 1979). Those relic geomorphologic surfaces and their relative deposits make it possible for u s to explain the properties of the palaeo-environment of the plateau before its uplift. In limestone-covered areas of the plateau, palaeokarst and its relative deposits contain much more information about palaeo-geography and environment (Figure 1). Figure 1 The sketch of palaeokarst spots in the Qinghai-Xizang Plateau 2 Disintegration of the planation surface and exposure of the underground palaeokarst and its relative deposits Generally speaking, the neo-tectonic movement uplifts the Qinghai-Xizang Plateau as integrated terrestrial block (Shackleton and Chang, 1990) although significant differential movements were observed in some mountains within the plateau (Li et al., 1979). The headward erosion of modern river systems happens intensively on the fringe of the plateau under the tectonically uplift environment. The fringe of the Main Surface has been eroded into a petaloid shape in the eastern and southeastern parts of the plateau. Diverse karst landforms are being exhumed to the surface in those areas, where they are stratigraphically composed of carbonate rocks. Such palaeokarst landforms and their relative deposits were typically seen in the Anduo Mt area (Gao et al., 2001), which were located on the southern slope of the middle Tanggula Mts and the upper provenance of the Nujiang River system (Figure 1). Many relic karst landforms and features just like those in Anduo Mt had been reported in many other sites throughout the Plateau, including many sites of the Himalayans, the Tanggula Mts, the eastern and western parts of the Kunlun Mts., etc., in the past several decades of geological and geomorphologic survey (Gao, 1996) (Figure 1). Such lofty and steep limestone features on the plateau were formed underground instead of directly on the surface during the Tertiary Period, and were gradually exhumed to the surface with the uplift of the plateau during the Quaternary Period, accompanying with being eroded and broken by the frost weathering and glacier processes (Cui et al., 1995). However, the relic karst caves, residuum and speleothem could be viewed as the direct witness of the palaeokarst processes in the plateau once they survived to present. The karst speleothems record much useful information concerning environment and geomorphologic ages (Linge et al., 2001). The recrystalline calcites in palaeokarst caves can be used as fission trace (FT) dating material (Liu et al., 1984). A total of 20 FT dating of recrystalline calcite in the Qinghai-Xizang Plateau relic palaeokarst caves revealed that the formation age of the palaeokarst is between 7.0 and 19.0 Ma BP (Gao et al., 2000). 3 The environmental record of the palaeokarst lateritic residuum The lateritic weathering crust is formed on the upper part of various kinds of bedrock under a long term of humid and tropical environment. Besides aforementioned karst speleothems, some root-liked, strip-like and pocket-like lateritic residuum can be widely observed at different depths on the disrupted flange of the Main Surface of the Qinghai-Xizang Plateau. A total of 34 lateritic residuum samples were collected at eight areas and profiles of the plateau (Figure 1 and Table 1). Grain size analysis was conducted for the part less than 1000 (m in size. Major chemical elements were analyzed for the clay and colloid parts of the residuum, which size is less than 2 (m, using the method of X-ray fluorescence (XRF). The clay minerals were analyzed for the part less than 2 (m in size by X-ray diffraction (XRD). The surface feature textures of the quartz grains collected from the residuum whose size range is between 100 (m and 250 (m, were analyzed using the scanning electrical microscope (SEM, KYKY-1000B). Table 1 The location and geomorphologic site of the lateritic residuum in the Qinghai-Xizang Plateau For comparison, a total of 7 samples collected in modern karst areas, East China, with a lower altitude, were also analyzed corresponding to the above analytical items (Table 2). 3.1 Size characteristics of the residuum The analyzed results revealed that the grain size of the residuum in the plateau are distributed evenly from 1000 (m to 0.5 (m, in other words, no significant predominant grain group exists in the analyzed samples (Figure 2). Moreover, there is much more left colloid part in the fine parts less than 0.5 (m, which is the lower limit of the grain size in the analysis (Table 2). For example, there was 67% and 85% of colloid part in the bottom sample collected in Dingri west hill profile (DW-4), and in the reciprocal second sample collected in the slope profile at the Dingri east hill (DE-2), respectively. The averaged mass fraction of colloid part of the 21 samples is 43.7%. Such calculation did not include other 13 samples of the plateau, i.e., the upper five samples in the Anduo Mt profile (AD-1, AD-2, AD-3, AD-4, AD-5), and the upper four samples in the Dingri east hill profile (DE-7, DE-6, DE-5, DE-4), and all four samples in Dingri west hill profile (DW-1, DW-2, DW-3, DW-4). All those aforementioned 13 samples were not entirely composed of lateritic residuum, but interfused with other allochthonous deposits by the subsequent sedimentary events. There is no significant flexure on the grain size frequency curves of the above 21 samples from 1000 (m to 0.5 (m (Figure 2a), which correspond to the typical grain size distribution of the lateritic residuum. Table 2 The average grain sizes of the karst residuum in the Qinghai-Xizang Plateau and some modern karst areas in East China (in (m) The slope of the frequency curves of the Dingri west hill´s samples abruptly increased at the stage of 125-500 (m (the dash lines in Figure 2b), which implied that the subsequent mixed grains were dominated with fine sands. Nevertheless, the averaged mass fraction of colloid part of the four samples in the Dingri west hill profile is still 46.45%, even after being mixed with other coarse particulate. For comparison, the grain size of the lateritic residuum in the palaeokarst area of the Qinghai-Xizang Plateau was divide d into five classes, i.e., sand, coarse silt, fine silt, clay and colloid part (Table 2). It can be seen from Table 2 that the lateritic residuum of the plateau formed in the corrosion of limestone has a fine and uniformity of grain size, and plenty of colloid part. However, some of those lateritic residuum samples mixed with the allochthonous deposits due to the subsequent sedimentation, are an exception (Table 2). For example, the increasing slope of the curves of the upper 5 samples in the Anduo Mt profile (AD-1, AD-2, AD-3, AD-4, AD-5) at the stage of 30-125 (m (the full lines in Figure 2b), indicated that the subsequent mixed grains were dominated with fine sands and coarse silts. The aforementioned mixed grain sizes correspond to the dominate grain sizes of aeolian sand and atmospheric dust, which might imply that Quaternary aeolian sedimentation (Lehmkuhl et al., 2000) and frost-thaw processes together changed the size composition of the lateritic residuum near the surface. 3.2 Major chemical element composition The major chemical elements analysis results were listed in Table 3, which revealed that the major chemical components of the clay and colloid parts in the plateau lateritic residuum (34 samples) are SiO2, Ai2O3 and Fe2O3, followed by MgO, K2O and TiO2. The total of mass fraction of SiO2, Ai2O3 and Fe2O3 sums up to the range from 89.70% to 94.49% with an average of 92.23%, deducting the loss by ignition. The mass fraction of other oxides is less than 1.0%. The silicic acid index (the molar ratio of SiO2 to Al2O3) of the lateritic residuum is between 2.85 and 3.68. The allochthonous deposits enhanced slightly the silicic acid index of the samples, which can be seen from the comparison between the upper and lower samples in Anduo Mt and Dingri east hill profiles (Table 3). Figure 2 The grain size frequency curves of the residuum in the Qinghai-Xizang Plateau The silicic acid index of the lateritic residuum in the plateau is slightly higher than that in the modern karst areas. In fact, the aforementioned phenomena can be attributed to the difference in weathering index between the upper and lower layers of the lateritic weathering crust, which is generally subdued from the upper layers to the lower layers. The formation of the lateritic weathering crust is a far-flung hypergene geological process. Many factors such as the forming phase and the geographical location of the profile, and the relative position of horizon levels in a profile, affect the property of a certain level of residuum in the lateritic weathering crust. With the downward advancing of the weathering frontal, the rock was continuously broken down. Meanwhile, the existing weathered fine material above the frontal continues to undergo the subsequent weathering processes. As a result, the difference in weathering index between the upper and lower levels formed. The lateritic residuum in the plateau is located at the bottom of a huge thick lateritic weathering crust when the weathering crust was in the process of forming. In other words, the lateritic residuum, belonging to relic deposits, were gradually exhumed to the surface with the uplift of the plateau. The degree of wetness and warmth of the palaeo-climate could not be deduced directly from the deep-layer relic lateritic residuum but only from the surface one, which did not exist. To some extent, much more humid and warm environment should be logically speculated. 3.3 Clay mineral composition A total of 25 samples were analyzed of clay mineral composition (Table 4). The result revealed that the clay mineral composition of most of the lateritic residuum in the plateau belongs to "illite-kaolinite" pattern, and a few samples belong to "kaolinite-illite" pattern. The content of chlorite follows that of kaolinite. The content of montmorillonite is very little, and even is in trace-class for most of the samples. Generally, the pattern of clay mineral composition in the relic residuum changes with the progress of chemical weathering. For example, the clay minerals of the lateritic weathering crust formed on the Quaternary basalt in Hainan Island, China, dominated with kaolinite and holloysite during the kaolinization phase. However, the clay minerals tend to be dominated as kaolinite, mica, gibbsite, and goethite, during the weak laterization phase (Guo and Sheng, 1980). The preliminary formation phase of the lateritic residuum in the plateau was reflected clearly by the composition of clay minerals, which corresponds to the attestation of the chemical elements. Table 3 The average chemical composition of the karst residuum in Qinghai-Xizang Plateau and some modern karst areas in East China Table 4 The clay mineral composition of karst residuum in the Qinghai-Xizang Plateau 3.4 Quartz grain surface feature textures Quartz is an inactive mineral under the atmospheric environment. However, many sorts of micro-features formed by chemical erosion were detected under the microscope on the quartz grain surface. Moreover, much more organic acid originating from the metabolism processes of the plant and microorganism diffuses in the soil and weathering crust in humid and tropical environment, such chemically formed micro-features are frequently apt to appear (Schulz and White, 1999). Together with the mechanically formed micro-pits and holes, chemically formed micro-features are important evidences for reconstructing the palaeo-climate and palaeo-environment. Figure 3 SEM photographs of the surface feature textures of the quartz grains collected from the residua of the Qinghai-Xizang Plateau a) ?000. The quartz particulate was collected from the residuum in the Dingri west hill, Xizang Autonomous Region (Number DW-1). Some features such as newly-formed conchoid break (>10μ), V-shaped stroked pit, squama-like flake and several micro-caves can be observed. However, no significant deposits appeared. The chemical erosion features were overlapped with the newly formed conchoid break, from which a truncated chemically formed pit appeared its lowe r part. b) ?50. The quartz particulate was collected from the residuum in the Dingri west hill, Xizang Autonomous Region (Number DW-4). Some shallower and deeper pits and holes appeared in a blurring feature due to being covered by the illuvial silicon dioxide colloid on the surface. Non-oriented veins appeared on the surface. A truncated chemically formed hole appeared on a newly formed cleavage face. The lately covered deposits were eroded in the beehive-shape. The figuration of some curved cascades appeared on the lower-middle part of the photo. c) ?000. The quartz particulate was collected from the residuum in the Anduo Mt summit profile, Xizang Autonomous Region (Number AD-1). The squama-like flake and some deep dissolved pits appeared on the surface. d) ?000. The quartz particulate was collected from the residuum in the Anduo Mt summit profile, Xizang Autonomous Region (Number AD-2). Polished faces and condensed dissolved veins appeared. There are some deposits in a dissolved triangle-shape pit. Some linear scrapes appeared on the polished face. e) ?380. The quartz particulate was collected from the residuum in the Anduo Mt summit profile, Xizang Autonomous Region (Number AD-3). V-shaped pit was subsequently dissolved some silicon dioxide colloids settled on the bottom of the pit. Little squama-like flake, micro-grike and curved cascades appeared. f) ?64. The quartz particulate was collected from the residuum in the Anduo Mt summit profile, Xizang Autonomous Region (also Number AD-3). Hypo-rounded quartz sands particulate. Squama-like flake on the surface. Tortoise shell pattern formed with the silicon dioxide deposits. Oriented dissolved gyrus-like lines and deposits. Flip flake. More than 200 quartz grains were collected and observed from 31 samples in total. Before scanning, the samples were cleaned with diluting solution of hydrochloric acid for removing the carbonate, then sprayed with gold film on the surface. The micro-features observed mainly include the following: (Squama-like flake (Figure 3a, 3c, 3e, 3f); Pin-like quartz crystal; Dissolved micro-cave; Oriented micro-grike; Siliceous deposits (Figure 3b, 3d, 3f); Flip flake (Figure 3f); Siliceous micro-ball; Bud-like quartz crystal; Non-oriented micro-grike; Beehive-like dissolved pit (Figure 3b); Dissolved gyrus-like lines (Figure 3f); Crack; Dash-like pit modified by subsequent dissolution. Those features are either chemically dissolved or sedimentary features. (Conchoid break (Figure 3a); Polishing surface (Figure 3e); Curved cascades (Figure 3b, 3e); Linear scrape (Figure 3e); V-shaped stroked pit (Figure 3a); Linear cascade. Those features are mechanically formed. That dominated by the chemically formed features on the surface of quartz grains collected from the lateritic residuum reflected a long-term chemical dissolved environment within the lateritic weathering crust in the plateau. The temporal evolution sequence of the surface features revealed that the chemically formed features were overlapped with the mechanically formed ones for most of the samples. Whereas, the reverse pattern takes place for a few samples, i.e., the mechanically formed features were overlapped with the chemically formed features. The overlapped patterns reflected the complexity and cyclic evolution of the environment of the plateau since late Tertiary. As for a specific lateritic weathering crust profile, such as the Anduo Mt summit profile, the ratio of chemically to mechanically formed features get large toward the bottom of the profile, and vice versa. That reflects a gradual denudation process of the plateau surface with the intense uplift during late Cenozoic Era. Much more mechanically formed deposits may have mixed with the upper part of the lateritic weathering crust profile. 4 Conclusions The relic karst landforms on the Qinghai-Xizang Plateau originated from the Tertiary underground karst, which were exhumed to the surface with the uplift of the plateau during Quaternary period. Some traces of chemical dissolution processes of the limestone survived of the Quaternary frost weathering and erosion. The relic chemically dissolved cave and lateritic residuum together provided authentic environmental evidence, which is in the humid and tropical climate. And, plenty of speleothems collected from the relic caves can be chronologically used. Fission tracks dating affirmed that the formation age of the palaeokarst is between 7.0 and 19.0 Ma BP, i.e., in Neogene period. The lateritic residuum in the plateau has a fine and uniformity of grain size, and plenty of colloid part. Some of those lateritic residuum samples mixed with the allochthonous deposits due to the subsequent sedimentary events. Surface feature textures of quartz grains in the lateritic residuum were mainly chemically formed, with a few mechanically eroded features that reflected the long-term humid-tropical environment when the lateritic residuum and the palaeokarst were formed. The sedimentary geochemical and clay mineral evidence reflected a relatively weak chemical weathering environment. However, the much more humid and tropical environment should correspond to the non-existing lateritic residuum, covered on the top layers of the lateritic weathering crust. Given a completely formed lateritic weathering crust profile, the weathering index tends to rise from the bottom to the top of the profile. References

关键词： palaeokarst; lateritic residuum; chemical weathering; Tertiary Period; planation surface; Qinghai-Xizang Plateau