·博士论文简报·

20 万年来黄土剖面土壤发生学特征与侵蚀环境演变*

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在全球变化的背景下, 确切地理解土壤侵蚀响应机理, 控制水土流失, 改善生态环境是当前重要的科学研究任务。同时, 对土壤侵蚀发生发展规律与生态环境演变的关系进行系统研究也是国际地学研究的前沿问题, 黄土高原保存完好的黄土剖面为该项研究提供了理想条件。

长期以来, 人们多从冰期—间冰期气候旋回的全球模式去理解黄土高原黄土—古土壤序列的发生成因和其所反映的气候历史, 尽管黄土—古土壤序列的气候记录可与深海氧同位素记录进行对比, 但所显示的气候波动细节乃至幅度都有所差别, 人们还理解得不够, 直接影响了从黄土—古土壤序列中获得更深一层的古气候信息, 也影响了对第四纪黄土沉积、成壤和侵蚀过程的确切解释。深厚的黄土剖面不仅具有现代多元土壤发生剖面的特点, 而且沉积速率和土壤发育程度受时空因素的影响, 其发生特征更为复杂。在前人基础上进一步研究黄土剖面沉积、侵蚀、成壤过程的发生学特征, 深入揭示 20 万年来黄土高原生物气候和侵蚀环境演变。

通过野外综合考察, 以 20 万年以来为时间尺度, 在黄土高原不同纬度和生物气候带内选择了武功、洛川和安塞 3 个典型黄土剖面。在通常划分黄土和古土壤序列的基础上, 采用间隔 30~ 50 cm 的密集采样, 以土壤微形态方法为主, 结合理化、矿物和孢粉分析, 融合土壤学、生物学和第四纪地质学, 揭示黄土剖面中成壤和沉积过程随生物气候变化而发生交替演化的时空特征, 探讨黄土剖面形成的生物气候环境背景及土壤侵蚀强弱交替的时空规律。研究结果对黄土剖面的形成发育及第四纪生物气候环境时空演化规律取得了系列创新性资料, 丰富了第四纪研究领域; 并对黄土高原土壤侵蚀治理, 尤其对植被恢复和建造提出了重要理论依据。

1 揭示了红褐色古土壤发生环境的三元性特征

黄土剖面中黄土与古土壤之间存在着受过渡性气候作用形成的过渡层, 红褐色古土壤层经历了沉积、成壤、再沉积的作用过程, 一层红褐色古土壤层其发生历程首先是在干旱—半干旱环境下黄土母质的堆积阶段, 然后是在湿润—半湿润环境下的成壤作用, 之后又受到黄土堆积作用和覆盖黄土的物质向下迁移及埋藏后的生物化学作用, 才形成现今的红褐色古土壤层。因此, 一层红褐色古土壤层是 3 种气候生物环境在不同时间上叠加作用的产物, 其发生环境具

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有三元性特征。

2　揭示了黄土高原曾有过的森林或森林草原景观

黄土剖面中代表古土壤(S)的红褐色土层是在半湿润—湿润生物气候环境下发育的土壤类型,各土层残留的碳酸盐是成壤后期覆黄土沉积物碳酸盐下淋再积聚的次生特征。3 个剖面的古土壤层(S_0, S_1, S_2)的碳酸盐基本淋失,矿物风化显著,土壤粘粒和铁、铝的胶体物质移动积聚明显,光性方位粘土大量出现,并随时空分异呈现不同的分布形态。同时,孢粉分析表明,古土壤层上部含有丰富的乔木花粉(10%~25%),并出现亚热带的代表树种(朴、漆等)。这说明古土壤发生过强度的酸性淋溶作用,具有森林型土壤的特征。

3　论证了黄土区植被发育与黄土的地质水文特性既对立又统一,相互依赖,相互促进的关系

黄土土体的多层次有序网状水文通道体系是黄土地下水补给的主要通道;在黄土性古土壤层与红褐色古土壤层互相间成的巨厚黄土剖面内,由于黄土层和古土壤层的结构、颗粒组成、孔隙组合等特征的差异,形成水文地质特性差异很大的互层,古土壤中部的粘化层及钙质结核层和黄土层中相对较细密的层次,构成区域的相对隔水层,有效地阻止了地表水的渗漏,成为地下水,而这些隔水层的形成又与生物(植被)成壤作用密切相关,而黄土层和黄土中的粗粒层是导水性很好的水介质层,这表明黄土区具有森林植被发育的地质水文条件。

4　证实了地质时期土壤侵蚀强烈期发生在黄土沉积与成壤的过渡期,发生环境为半干旱环境

黄土高原 20 万年以来的土壤侵蚀基本表现为南弱北强。土壤侵蚀强烈期发生在半干旱的生态环境,既红褐色古土壤层与黄土层之间的过渡层。红褐色古土壤发育时期,土壤剖面发育基本完好,且发生层次清楚,3 个剖面各层古土壤发育层次明显,土层厚度基本在 100~200 cm 范围内。剖面中保存有丰富的森林或森林草原的孢粉组合,表明古土壤有植被的保护,虽降雨量大,但土壤结构好,虫孔和根系发育有利于降雨入渗;古土壤中淀积型粘粒胶膜的大量存在,证明土壤水分与溶质运移活跃,减少了地表径流,有效地抑制了土壤侵蚀的发生,表明整个黄土高原基本无土壤侵蚀。各剖面的黄土层中,也保存有大量的孢粉信息,说明黄土堆积时,地表不完全是裸露的,有一定的森林草原或草原植被覆盖。同时,还形成一定的土壤结构,如镜下多呈团粒—孔隙胶结结构,有一定抗蚀能力,并保存一定的厚度,表明无严重的土壤侵蚀。

研究表明:红褐色古土壤层与黄土层之间存在过渡的土壤发育类型,其气候环境为半干旱或半湿润气候,相当于现今的荒漠草原与草原过渡带的水蚀风蚀交错区的生态条件,土壤侵蚀异常强烈。在气候的转变时期,下垫面反应滞后,致使在有一定的降雨量时,下垫面的植被仍没有恢复,加之过渡时期气候不稳定,生态环境脆弱,高强度暴雨频率较大,因此这时期的土壤侵蚀强度较强。

Pedogenesis of Loess Profile and Evolution of Erosional Environment on Loess Plateau Since 0.2 Ma B. P.

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The loess sequence is typically characterized by an alternation of silty or sandy loess with more clay-

duality. A paleosol can record both the climate of cool-dry under which the parent material deposited and the climate of warm-wet under which the soil profile developed. It shows that there is transitional characteristics between brown-red paleosol(S) and loess(L). The so-called loess which developed in glacial period of dry-cool climate has subjected to pedogenetic process of steppe or forest steppe soil under semi-arid climate. In fact, the loess sequence is multi-genetic profile of soil affected successively and alternatively by deposition and Pedogenesis. However, because of the high influx of sediment, the influence of bio-climate and physical-chemical processes were declined leading to the soil formation characteristics are not obvious. Thus, the loess and paleosol are both soil profile but developed in different bio-climate and deposition conditions. And within the loess layer and brown-red paleosol layer, there is sub-fluctuation of climate.

3 **The climate of loess plateau in the past 0.2 Ma changed temporally and spatially**

It fluctuated transitionally in various pattern of dry-cool, dry-warm, wet-cool and wet-warm. About 10 000 years B.P., there was abrupt change from dry-cool to wet-warm. The transitional characteristic is more obvious in the south of loess plateau. The intensive soil erosion period is in the transitional period between loess deposition and soil formation. It occurred in ecological environment of semi-arid. Further more, considering the orientation and velocity of the climatic change and the surface condition, soil erosion occurred in different degree from time to time and from place to place. Soil erosion was much more intensive in north than in south. About 10 000 yeas B.P., soil erosion was more intensive than in other periods.

4 **The layers of loess and paleosol in loess profile have different hydrological properties**

This geo-hydrological condition favorites forest vegetation development. Developing of forestry vegetation has no relationship with thickness of loess sequence. Construction of vegetation on the loess plateau should follow the law of natural evolution and distribution of vegetation.

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rich paleosols. During the past decades, these alternations, in conjunction with their enclosed faunas and distinctive mineralogies and some chemical data references, have been interpreted as reflecting Quaternary glacial or interglacial episodes. And the climatic record in the loess-paleosol sequence was generally compared to the oxygen isotope in deep sea sediments。However, the details and extents of climatic fluctuation are different from each other. Further more, that model of interpretation could not fully explained various geological, biological and historical records of climate. There are several processes, such as deposition, soil formation and soil erosion, were not fully understood. The different understandings on these processes led to different interpretation of these climatic records. More over, the soil formation process in the loess-paleosol section is different from that of the modern soil profile. The sediment-added paleosol profile and the loess profile influenced by pedogenesis have the characteristics of multi-genetic profile of modern soil. Their genetic characteristics are much more complexes because of influx of sediment deposition. To recognized and understand these process, a special method and interdisciplinary knowledge are needed.

Because the loess sequence developed since 0.2 Ma B.P. holds implications for the past global climate change and anthropological history of China. Many attempts have been concentrated on understanding history of monsoon climate. The present study mainly used micromorphological method combining with chemical, mineralogical and pollen analysis to investigate the changes of soil structure, bio-turbation, leaching, illuviating and argillic processes in three loess-paleosol sequence across the loess plateau dating back to 0.2 Ma B.P.. In the view point of soil science, biology and Quaternary, the thesis throw the light on the different pedogenetic processes under different climatic condition in the loess section. The temporal and spatial characteristics of soil formation since 0.2 Ma B.P. and their bio-climatic backgrounds were discussed. And the evolution law of soil erosion and the potentiality of vegetation construction were evaluated. The conclusion cloud provide some insights and suggestions on the soil and water conservation. The main conclusion are as follows:

1 **It show that the loess plateau had been developing luxury forest or forest-steppe vegetation**

The brown-red layers(S) are paleosols developed under semi-humid or humid climatic environment. The original $CaCO_3$ was almost leached, and the content of $CaCO_3$ in the paleosol layer came from the upper loess horizon which was deposited after the paleosol formation. And optically oriented clays, which firmly indicated the soil formed under forest condition, was the origin characteristic of the forestry paleosol. Thus, during the paleosol formation period, the Loess Plateau was covering with forest. And the paleosols are the type of brown soil. The loess layers(L), which represent strong deposition process, have been affected by pedogenetic process in different degrees. Their soil types are mainly steppe/forest-steppe soils. In the three sections, within all loess layers, the $CaCO_3$ has been redistributed or leached. In south or middle sections, there is nodule of $CaCO_3$. Heavy minerals were weathered in different degrees. And there are aggregate, pores of earthworm and plants, and a certain of tree species in pollen assemblage. It shows that it had subjected to pedogenetic process under steppe/forest steppe of semi-arid.

2 **According to the bio-climate and deposition process, three developing models of loess profile were recognized**

It shows that the brown-red paleosol, in the view point of climatic environment, is characterized by