Loess Deposit and Loess Landslides on the Chinese Loess Plateau

Tonglu Li, Changye Wang and Ping Li

Abstract Chinese Loess is a wind origin deposit which records the continuous Quaternary history. In the past 30 years, the loess stratigraphy has achieved a great advantage that the absolute age and the litho-strata were well defined by dating and correlating with deep sea core isotopic curves. That set up a formed basis for further study in the loess properties and geological hazards in view of origin and mechanism. Loess has special characters of typical topographies, vertical joints, loose texture and water sensitivity, which makes it easy to slide. Landslides on the Chinese Loess Plateau are the most severe geological hazards, which deprive people of life, damage gas and oil routes, destroy roads and railways and decrease farmlands. Control of landslides is a long-term strategy. Besides the general used structural methods being applied in the slides related to some engineering, improvement of ecological environment, innovation of irrigation way and availability of drainage systems are more significant. Building of early warning system based on monitoring is a practical and economic way to check landslides as much as possible in considering of the present natural environment and national condition.

Keywords Loess · Stratigraphy · Loess Plateau · Landslide · Deposit

1 Introduction

Loess is an aeolian sediment formed by the accumulation of wind-blown fine sand and clay components. Loess is distributed in arid and semi-arid regions where favourable weather conditions help in its generation and deposition. Globally, loess

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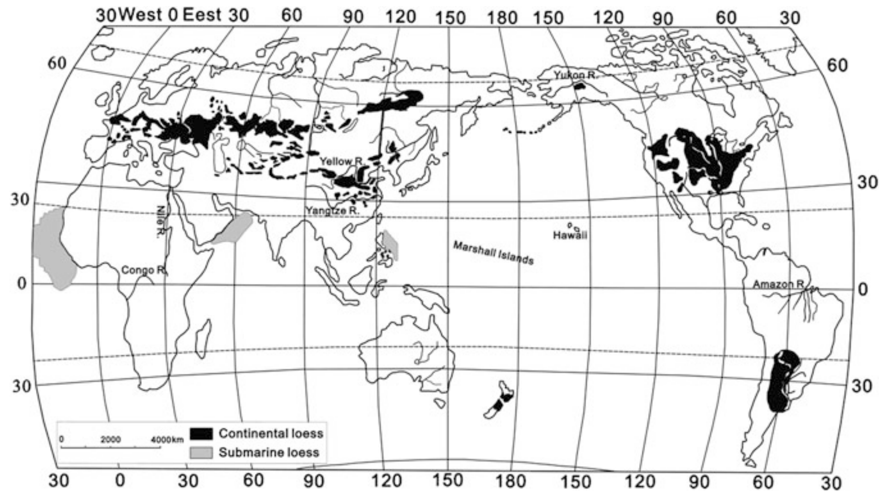


Fig. 1 Global deposits of Loess (After Sun 2005)

covers 10 percent of the earth surface and is distributed mostly in regions spanning 30–55° North and 30–40° South latitudes, which are monsoon dominated zone. As shown in Fig. 1, loess deposits are mainly distributed in the northern hemisphere, from Europe to Siberia in Russia, northern China and north America, with relative lesser deposits in the southern hemisphere, such as the center of New Zealand and the South America. In addition, loess deposits have been discovered in the ocean floor, such as the Atlantic ocean around west Africa, the north Arabian sea, the Japan sea and the sea around eastern Philippine. Loess deposits, unlike water-deposited sediments, are not only distributed in river basins; they are also distributed in the seas and oceans, which strongly prove its wind-blown origin.

Loess in China covers a total area of approximately 631,000 km^2, occupies 4.4% of the national land (Liu 1996), of which, the Loess Plateau has the best developed deposit in the world (Fig. 2). The thickness of loess deposits in this area vary from few meters to more than 300 m.

The Loess Plateau of northern China, which has an area of approximately 430,000 km^2, is located in the center of the Yellow River and is bordered by the Tengeri Desert, Wuqiao Ridge and Riyue Mountain to the west; Taihang Mountain to the east, Qinlin Mountain to the south and Yinshan Mountain to the north (Fig. 3). As monsoon winds generate fine sediments from the northern and north-western deserts, it is barred by the eastern and southern mountains; this causes the fine material to be deposited on the plateau. Field investigations and laboratory analysis have shown that particle sizes of the loess deposit changes from coarse-grained to fine-grained for sampling done from the northwestern part to southeastern end. Recently, the Loess Plateau has become an important economic zone in the western part of China, where there are plenty of natural resources such as oil and gas, coal, hydro-energy and also serves as an important site for agricultural development.

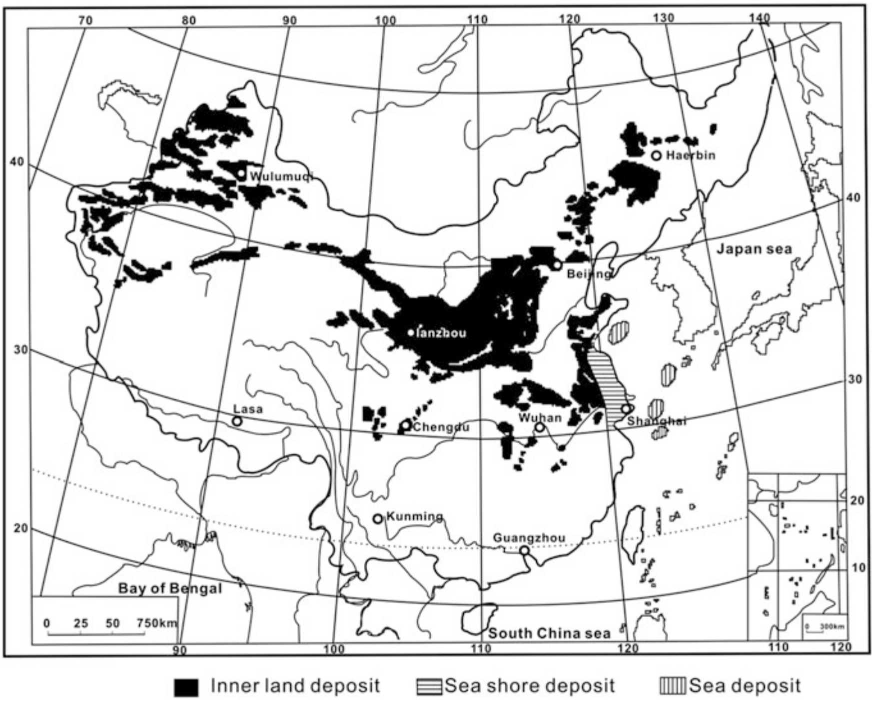


Fig. 2 Loess deposits in China (After Liu 1985)

The Loess Plateau and its environs have been affected by oil and gas explorations, mining of solid mineral deposits, civil construction and urbanization. These activities have greatly influenced the geomorphology of the Plateau, making the area prone to geological hazards. These geohazards, such as landslides, mud-flows, ground-collapses and tension cracks have continued to cause untold havoc to the economic and other developmental activities within the area. In China, landslide disaster, apart from earthquake, has recorded the highest number of fatalities in recent years.

2 Loess Stratigraphy on the Chinese Loess Plateau

In the Miocene epoch, area around the present Loess Plateau was a deep inner basin, called Ordos Basin, which received the Cretaceous-Tertiary deposits made up of sandstones, shales, mudstones and coal interbeds. At the end of the Cretaceous, the Yanshan tectonic movement led to the uplifting of the Ordos Basin to close the deposition and to suffer a long period of weathering and erosion which lasted till the end of the Pliocene and formed peneplain. Therefore, the area generally lacks the early and middle Tertiary deposits. At the end of the Pliocene, the area was still a paleo-plain of denudation, in which there were a lots of

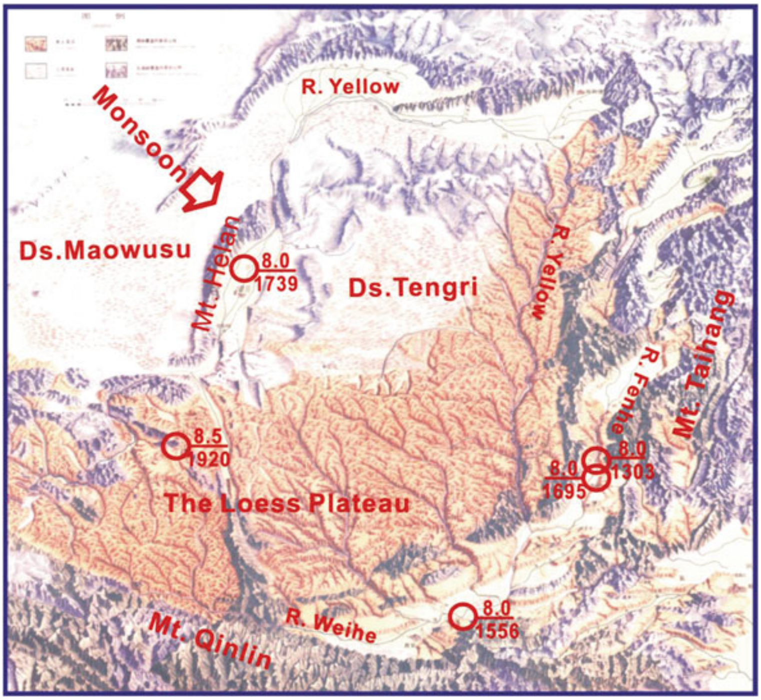


Fig. 3 The landscape of the Chinese Loess Plateau

denudation basins and rift basins. There were a inner river system which flowed from around to the center. Hipparion-red-clay, a wind-transported sediment, was deposited around the surrounding lake and river basins with thicknesses varying from tens of meters to hundreds of meters.

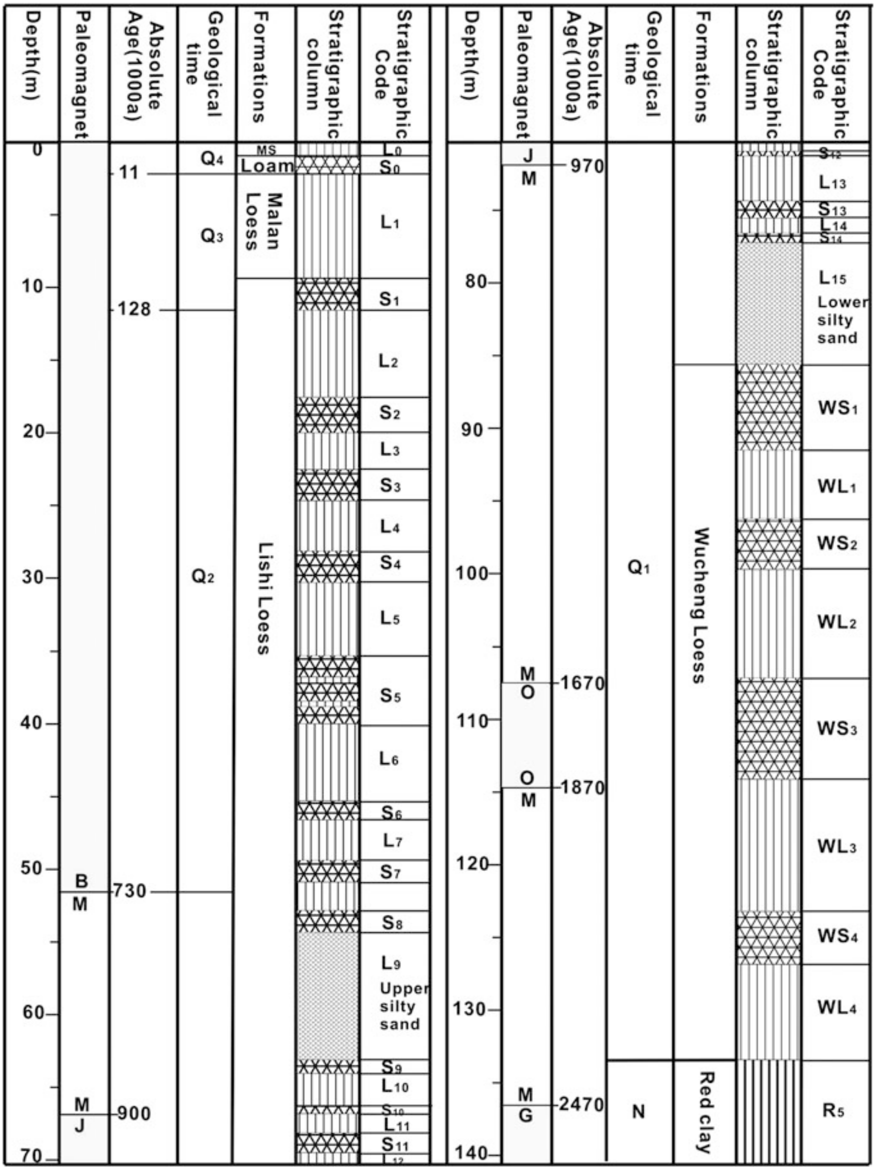
During the Quaternary, the climate became dry and cold and loess began to deposit. In the early Quaternary, the basins and the river beds were filled with lacustrine and alluvial deposits, while the surrounding high lands received the loess sediment, which made up the present loess platform. Luochuan loess platform is one of the largest loess deposits in northern Shaanxi, with successive loess sediment in the Quaternary. A loess profile in Potou village, Luochuan County, located at the western side of Heimugou gully, has been considered as a standard loess section on which the Quaternary paleo-climatic and stratigraphic studies have been carried out in detail (Kukla and An 1989). Liu and Zhang (1962) divided the loess strata into three lithostratigraphic units based on observed field characteristics. They are: the Wucheng loess (Q_1), Lishi loess (Q_2), and Malan loess (Q_3). Beside these three typical units, a layer of 2 m of Holocene deposit (Q_4) covers the upper part of the deposit. The upper part of this layer consists of brownish-yellow thin bed while the lower part consist of dark brown bed, of which the former is called Holocene loess(L_0) and the later is called black loam (S_0).

Due to incessant changes in climate during the Quaternary, the sediments are not uniform in color, composition and structure on the section. They occur as alternating beds of brownish-yellow loess and brownish-red paleosol. Loess represents the product of dry-cold climate, while paleosol, as well as the loam, represents that of warm-wet climate. Loess strata on Potou profile is made up of more than thirty loess-paleosol sequences indicating that the climate must have changed for more than thirty periods during the Quaternary. The Malan loess is the first layer of typical loess which is a set of uniform loose material corresponding to the last glaciation. Lishi loess includes the first paleosol to the fifteenth loess sequences. Of all the above loess sections, the ninth (L_9) and fifteenth (L_{15}) loess beds have a relative higher thickness and coarse particles indicating deposition under harsh weather conditions, while the fifth paleosol (S_5) is a thick layer consisting of three sub-paleosols with two thin loess beds among them. L_9, L_{15} and S_5 are considered to be the marked beds for easy identification of the loess stratigraphy in the field. Wuchen loess consists of thin interbeds of paleosol and loess with high content of calcium and stiff of properties, so it is called as lithoid loess. Below the Wuchen loess underlies Neocene red clay.

Since 1980, a detailed age dating of the loess strata has been recorded through the combined application of radioactive (C^{14}) and paleo-magnetic dating methods, and the correlation of isotope curves along the oceanic bore holes and loess sections. From the result, loess in the Quaternary are divided into Holocene (Q_4), Upper Pleistocene (Q_3), Middle Pleistocene (Q_2) and Lower Pleistocene (Q_1) series. The boundary of the Holocene and Upper Pleistocene is located at the basal section of the black loam, dating more than 11,000 years ago. The Upper and Middle Pleistocene are located at the lower part of the first paleosol (S_1), with ages dating more than 128,000 years ago. Also, the Middle and Lower Pleistocene are located in the eighth loess (L_8), with ages dating more than 730,000 years ago which corresponds to the B/M boundary of paleo-magnetism. The Lower Pleistocene boundary and the Upper Pliocene is located at the lower part of the loess, a little higher than the M/G boundary of paleo-magnetism. The age of the M/G boundary is about 2.47 million years, therefore, the boundary of the Quaternary and Tertiary is considered as 2.50 million years or so. It can be observed that there is a wide difference between the early lithologic units and the present chrono-stratigraphic units. The stratigraphic profile of the Luochuan loess is shown in Table 1. The profile also shows that the loess-paleosol sequences from different parts of the Loess Plateau are spatially correlative, as shown in Fig. 4 (Liu 1996).

As mentioned above, in the early Quaternary, the area of the present Loess Plateau has many inner basins which vanished in about 1.70 MaBP due to extensive uplift in the area corresponding to the second episode of the Himalaya movement. Meanwhile, the present pattern of the Yellow River system began to form with water flow out of the basins as loess is being deposited. Because the Plateau uplifts intermittently and the river terraces have been developed. There are generally five to six terraces along the main river and their tributaries in the Loess Plateau. The loess covers these terraces like mantles bordered by the Liupanshan Mountains. The rivers in the western region have six terraces while those in the eastern region have five terraces which shows that the whole plateau are not uniform.

Table 1 Stratigraphy of the Luochuan standard loess section



In the western region, 6 terraces can be distinguished along the river sides. The height is terrace VI, on which loess is about 310–505 m thick with 21–23 layers of paleosol, presently, the thickest loess deposits in the world. Loess on terrace VI began to sediment at 1.43 MaBP. Loess on terrace V consists of L_0 to S_{14} or S_{16}, 200–400 m in thickness, and dated at 1.23 MaBP. Loess on terrace IV consists of

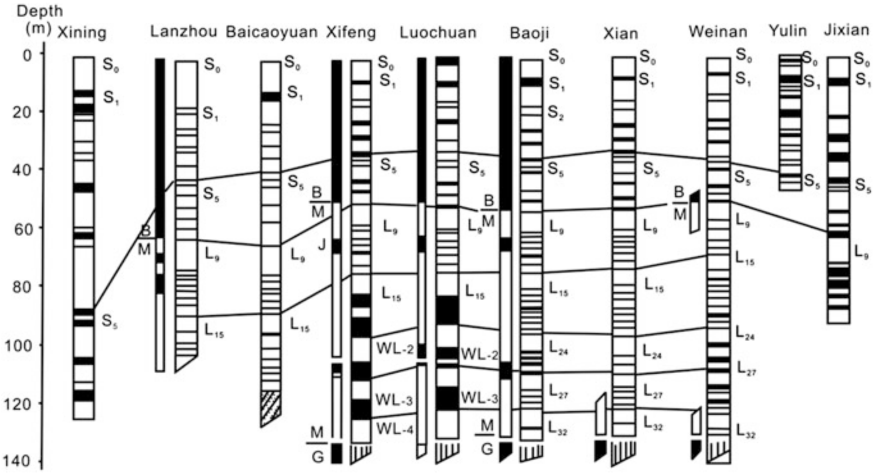


Fig. 4 Correlation of the loess stratigaphy on the Loess Plateau (After Liu 1996)

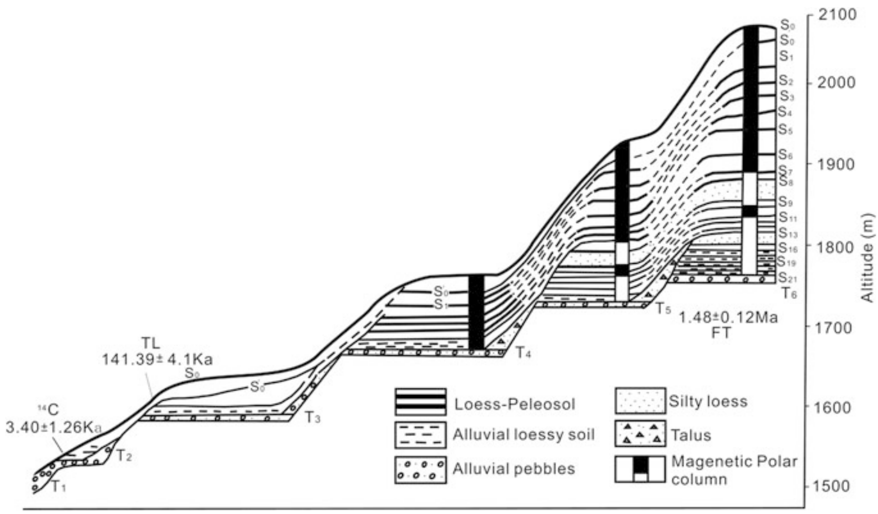


Fig. 5 Loess section on the terraces of the Yellow river (After Zhang 1989)

L_0 to S_5 or S_6, 100–200 m in thickness, and dated at about 0.62 MaBP. Loess on terrace III consists of L_0 to S_1, about 40–60 m in thickness, and dated at about 0.12 MaBP. Loess on terrace II is a layer of loessial soil with thickness of 20–35 m and dating at about 0.03 MaBP. Loess on terrace I consist of present loess L_0 and black loam S_0, about 2.0 m in thickness, and dated at about 0.01 MaBP. Figure 5 is a typical section of the Yellow River terrace near Lanzhou city, which represent the loess on terrace six in the west region.

In the west region, there are generally 5 terraces covered by loess, but loess thickness is thinner than that in the west. Loess on terrace V consists of L_0 to S_{11}–S_{16} (Varied in places), about 70–90 m in thickness, and dated at 1.23 MaBP. Loess on terrace IV consists of L_0 to S_8 or S_9, about 40–70 m in thickness, and dated at about 0.80 MaBP. Loess on terrace III consists of L_0 to S_6, about 25–45 m in thickness, and dated at about 0.62 MaBP. Loess on terrace II consists of L_0 to S_1, 10–17 m, dated at about 0.12 MaBP. Loess on terrace I consists of present loess L_0 and black loam S_0, about 2.0 m in thickness, and dated at about 0.01 MaBP.

The processes of a terrace consist of two episodes: lateral erosion and down-cut. In the tectonic static period, a river has lateral erosion and the riverbed is widened, while during the uplift period, it cut down vertically to form a new narrow riverbed and the original riverbed and floodplain becomes a terrace. The new riverbed would be the next terrace in the forth coming static-uplift cycle. Therefore, on the record of river terraces, the Loess Plateau have experienced at least six cycles of uplift which implies the 6 periods of down erosion at the same time. The erosion cases can also be demonstrated by the interaction among some new loess bed with the old ones.

3 The Effects for Landslide Initiation on the Loess Plateau

Loess has typical landforms like vertical joints and loose textures, as well as special physical and mechanical properties, such as low water content, strong structural strength, loose textures and weaker water resistance, high compressive strength which reduced the shear strength of the material.

3.1 Typical Topographies

Loess mainly forms three characteristic types of geomorphic structures. These are loess platform, loess ridge and loess dome, as showing in Figs. 6, 7, 8. Another form of geomorphic structure, loess Karst is not common.

It could be seen that on the sides of the platforms, ridges and domes are the steep slopes which could easily slide in favorable conditions, such as infiltration of rain water, irrigation water and earthquake effects. Generally, loess landslides occur on the slopes steeper than 35° and higher than 40 m. Our investigation in the northern Shaanxi Province shows that 80 % of loess landslides occurred in slopes with dip angles exceeding 35°. As the slope angle becomes greater than 50°, failure style is normally collapse-sliding or purely collapse; the slopes are stable for slope angles lower or close to 35°. The sliding is more preferable to occur in concaves slopes. The landslides are often continuously distributed on the sides of the loess valleys as the side being the rims of loess platforms, ridges and domes, hence forms the so-called “slide-skirts” or “slide-zone”. The loess slides on the southern part of the valley with strike direction trending East–West are more than those on the north because of its less sunshine effect and higher moisture content.

Fig. 6 Loess platform

Fig. 7 Loess ridges

3.2 Vertical Joint Structure

One unique structural feature of the Loess Plateau is the existence of vertical joints (Fig. 9), which is both primary in origin due to loess formation by wind-blown processes and tectonic in origin due to neo-tectonic movement (Wang 1985). Vertical joints in the loess deposits constitute weak planes along which rainfall easily infiltrate into the loess. The joints are the main erosion path in the loess slopes especially on the margins of the platforms and ridges; the joints generally connect the upper and the lower part of the slopes. Rainfall infiltrates into the slope through the joints and moves down along the joint planes as meet a relative impermeable bed as paleosol, the water would move horizontally out on the impermeable bed. As a result, a lot of sinkholes (Fig. 10) form on the slope surface with outlets appears on the slope toe (Fig. 11). The process enlarges the joints into wide fissures which allow more water to flow in and form temporary waterfall during rainy periods. Erosion along the joints not only affects the slopes, but also allows more water to flow into the slope which essentially affects the stability of the slope.

Fig. 8 Loess domes

Fig. 9 Loess joints

3.3 *Loose Texture*

Loess materials have a characteristic porous texture. The upper Q_2 and Q_3 loesses, L_1 to L_2 generally have void ratios of 0.8–1.1, that means the ratio of pores to solid particles is about 1:1, so it is a very loose material. As viewing on Scan Electric Micrograph photos, the micro-holes can be identified clearly (Figs. 12, 13). The particles are mainly aggregation of silts around the holes contacting at points with weak connection by clay minerals. The connection is water-sensible. As soaked in water, the particles will lose their connection and also disintegrate. At last, they become more fine granules and fall in the holes (Figs. 14, 15). This typical texture make loess has a special quality of collapsibility, which means as the loess has consolidated under given load, if soaked by water, it will creates an additional depression.

Fig. 10 Sinkholes on the ground

Fig. 11 Erosion along loess joints

The skeleton-porous texture of loess formed in arid climate, which has a relative high structural strength in general condition. But the strength decreases obviously as it is saturated. Therefore, continuous raining or irrigation always causes large numbers of loess slides.

Fig. 12 Micro-texture of undisturbed loess, rounded particles of aggregation of silts support each other, pores are among them

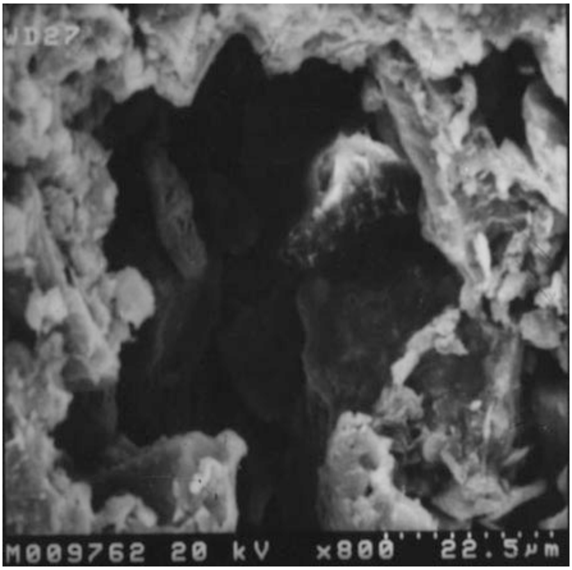


Fig. 13 Micro-texture of undisturbed loess, a single pore

Fig. 14 Micro-texture after water soaked loess, the rounded aggregations disintegrate, parts of them fall in the pores

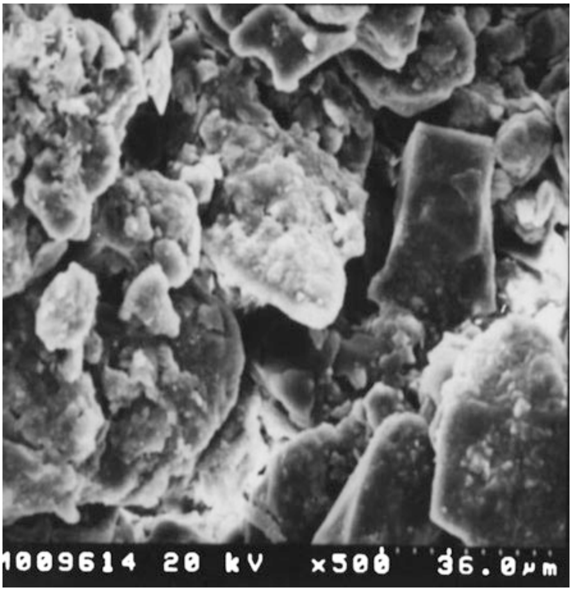


Fig. 15 Micro-texture after water soaked loess, pores were filled up

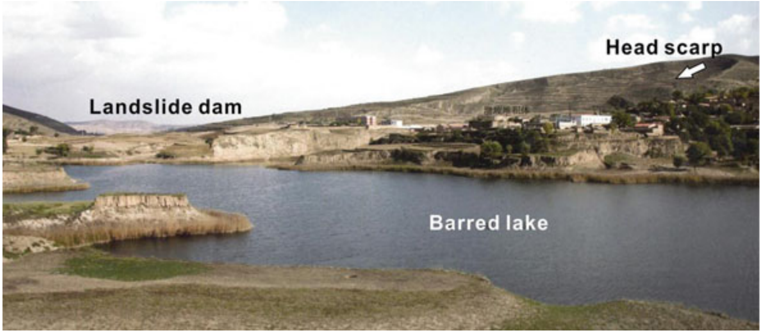


Fig. 16 Landslide dam and barrier lake formed in 1920 Haiyuan 8.5 Ms earthquake. (Subao Village, Xiji County, Ningxia autonomous Region, Photo by Yin YP)

4 Triggering Factors of the Loess Landslides

The loess landslides are initiated by four triggering factors. They are earthquakes, rainfalls, irrigation and civil engineering activities (Li and Li 1997).

4.1 Earthquakes

The eastern part of the Loess Plateau is surrounded by a major active zone. The eastern and southern part lies next to the Fenhe and Weihe Rifts respectively, the north is the Hetao rift, the west is the Yingchuan rift and the southwest is the Liupanshan thrust structure. Five earthquakes with magnitude of equal or larger than 8.0 Ms degree occurred in these active zones. They are: the 1303 Hongtong 8.0 Ms in the Fenhe rift, the 1556 Huaxian 8.0 Ms in Weihe rift, the 1695 Linfen 8.0 Ms in Fenhe rift, the 1739 Pingluo 8.0 Ms in Yinchuan rift, the 1920 Haiyuan 8.5 Ms in the liupanshan thrust zone (Fig. 3).

The latest and most catastrophic is the 8.5 Ms Haiyuan earthquake, which triggered 675 loess landslides and killed more than 100,000 lives. The landslides formed 40 huge barrier lakes, with 27 of them still very active (Fig. 16) Extensive earthquake vibrations and liquefaction have been considered to be the main triggering factors which initiated the landslides. After the 2008 Wenchuan earthquake, the area around the Loess Plateau has been considered to be a potential region of strong earthquakes.

4.2 Rainfalls

Rainfall is a common triggering factor of landslides. The Loess Plateau has an annual precipitation between 450 and 720 mm, which is not really high. High rainfalls are recorded between June and September and often occur as storms. Most of the loess landslides are related to rainfall effect, but loess has a very low

Fig. 17 Ground saturated zone after decades of intermittent rainfall, the observed site is located in Ganquan County, Shaanxi Province

permeability. The coefficient of permeability of loess is generally lower than 10^{-4} cm/s. In situ observation and test indicates that the depth of the saturated zone at the loess ground generally no more than 1 m even after a long term of raining, as Fig. 17 shows. However, the vertical joints on the tops of loess slopes are the main for the rainfall down moving. Erosion along the joints forms sink holes and opened fissures to permit much rain water flowing in (Fig. 18). As the water encountering a relative impermeable bed, such as paleosol, Tertiary red clay or bed rock, it would accumulate on the bed to soften the soil and induce landslide.

4.3 Irrigations

With developing of the irrigation systems in the loess region in recent 40 years, agricultural irrigation has become a prominent agent to induce landslides. Hei-Fang platform in Gansu province is a typical area for this case. The platform is composed of two high flat lands with the total irrigation area of 13.4 km^2. Since the irrigation system began to run in 1968, the loess landslides around the platform occurred frequently. Investigation revealed that in the 15 years between 1968 and 1983, 15 landslides occurred with average 1 one a year which are relative small in dimension and short in run distance with run-out length between 20–50 m, in the 6 years between 1984 and 1989, 15 cases occurred with average 1.5 ones a year which are larger in dimension and longer in run distance with run-out length between 50–100 m, in the 9 years between 1990 to 1998, 31 cases occurred with average ones a year which are large in dimension and far in run distance with run-out length between 250–400 m. According recently investigation, the 10 km long margin of the Hei-Fang platform has 72 landslides (Fig. 19).

Fig. 18 The flow of rain water along vertical joint in the loess, root also grows along the joint

The landslides caused reduction of farmland and loss of lives and properties. In about 40 years, more than 1 km^2 area of the top land of the platform slid away, caused 20 more person death and injured.

In the Guanzhong irrigation area of central Shaanxi province, there is the same problems. Guanzhong irrigation area is accords with the Weihe rift area. There are many pieces of highlands among the branches and the trunk of the Weihe River in the rift area, those highlands are the dissected loess platforms. The surfaces of the most loess platforms are irrigating farmlands. The area has a long history of irrigation and now has a very dense canal system. Leakage of the canals and free-flow irrigations induced a large number of landslides at the side slopes of the loess platforms, such as the north sides of the loess platforms at the south of the Jinghe river (Fig. 20), Bahe river, and Weihe river.

4.4 Engineering Activities

Engineering cut mainly carried out in highway and railway infractions, as well as dwelling sites.

There are 4 main national highways and many other provincial roads as well as 3 railways rendering on the Loess Plateau connecting this region to the around of

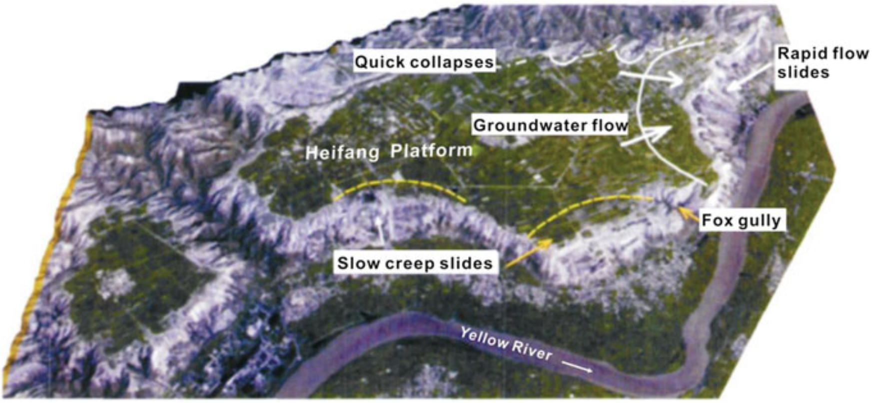


Fig. 19 The landscape of Hei-Fang platform

Fig. 20 The topography of the south bank of Jinghe River and the north side of a loess platform with the slope height of 70–90 m and slope angle of 50–70°. The top is an irrigation farmland, which often induces landslides at the side

the country. Construction of the roads induced a large number of landslides and caused a huge loss. Tongchuan-Huanglin highway is the first high grade road constructed on the Loess Plateau. In the period of design, the landslide problem was far low estimated; only 3 landslides were designed to stabilize. While the highway being constructing, there were 27 landslides occurred actually. More than 200 million yuan RMB was added to control the landslides. Almost all kinds of measures, such as piles, pile-anchors, block-anchors, frame-anchors, beam-anchors and retaining walls, were practiced in the landslides (Fig. 21).

Fig. 21 The piles applied to stabilizing a landslide on the Tongchuan-Huanglin highway

Fig. 22 The living caves (Abandoned) in the top and the foot of the loess slope

In addition, the people in the loess area have a tradition from ancient time to live in digging caves (Fig. 22), which also induced slides to cause a large number of casualities as not properly worked out. The living caves mostly dig either on the top or on the foot of a slope around platforms or ridges. As there are a good drainage ways around living caves to get rid of water penetration, and the thermos released by living activity to keep the soil of the inner wall always dry, the living caves are solid enough to living.

Fig. 23 A new excavated building site located in Longshou village, Huanglin County, Shaanxi. The west side has a shearing plane at the top by unloading (**a**); the toe of the north side was spited to slices by the concentrated stress (**b**)

But people often neglect some potential or unseen intakes of water, so landslides often damage living caves and kill peoples in loess area. In recent years, the living caves destroyed and people killed by loess slides every year, especially in autumn.

Our investigation revealed that about 380 were killed and 70 injured in the collapse of 400 living caves during 1985 to 2010. Figure 23 shows a new excavated site for digging living caves. It can be seen that the toe of the north side has been split to slices by the concentrated stress, the west side has a shearing plane at the top by unloading, and the east side has dug caves at the toe. All the traces imply that the slope close to equilibrium state, digging of the caves would cause damage without reinforcement.

5 The Hazards of Loess Landslide on the Loess Plateau

Loess landslide is a prominent geological disaster in the Loess Plateau, which caused deaths of lives, damage to lifelines, transportation routes and destruction of farmlands.

5.1 Causing Direct Death of Lives

The reports of the loess landslides caused causalities are released almost every year. Of which, the Saleshan landslide in Gansu Province broken in 1983 is the well known one, which is a high rapid long run-out slide with the run distance of 1600 m in a few minutes. The landslide destroyed four villages, took about 200 and 77 lives and 300 domestic animals, and filled up two small reservoirs. In 2005, another loess landslide occurred in Shuidonggou village, Jingxian County, Shanxi Province on May 9th killing 24 people. In 2006, the loess flow-slide occurred in Gaolou village, Huaxian County, Shaanxi Province on October 6 killing 12 people. In 2009, a loess landslide occurred in Lanzhou city, Gansu Province on May 16th killing seven people. In 2010,

Fig. 24 Collapse and slide occurred in the opening as the tunnel being driven after a heavy rain

another geodisaster occurred in Shigou village, Zizhou County, Shaanxi Province on January 10 killed 27 people. In 2010, the accident occurred in Baqiao district, Xi'an city on September 17 killed 32 workers of two factories located at the foot of a slope.

The population in loess area is relatively dense. Before 1980's, almost all peasants, even rich ones, lived in living caves, but now most of them move out to live in houses, even buildings, which did not reduced the casualties by landslide. Because of house land limitation, most of the new houses were built on the foot of slopes. Cutting of slopes for enlarging sites and keeping the wasted living caves still open often make the houses in front the slope in danger.

5.2 Damage of Lifeline

There are plenty of gas and oil transfer routes entombed underground on the Loess Plateau, such as the West-East Gas Transfer Route, Jingbian–Beijing and Jingbian–Xi'an Gas Transfer Routes, Jingbian–Xianyang oil Transfer Route and many other oil Transfer Routes between gathering wells and oil refining plants. Landslides are the most headache problems in the route lines.

Figure 24 shows a tunnel crossing a loess ridge in the West-east Gas Transfer Route. As the tunnel was driving in June 2002, after 30 h continuously raining of 60 mm rain fall from June 8 to 9, a collapse fell down to cover half of the opening of the tunnel, further more, a 60 m high, 100 m width slide was appeared on the slope. The cracks bordering the slide opened 10–30 cm, and the top part of the sliding mass fell down 60–80 cm. The steel supports and the inner line were seriously twisted (Fig. 25). At last, the tunnel was abandoned; instead of entombing along the river valley beside, more than 10 millions Yuan RMB was added for the revision.

Another big accident being gotten rid of is that a landslide on the Jingbian–Xianyang oil Transfer Route which crosses the whole Loess Plateau with 460 km long. To the north of Xianyang City, the route was designed crossing beneath the

Fig. 25 Steel supports were twisted by deformation of the inner wall of the tunnel

Jinghe River and then climbing up a 90 m high slope which is the north side of Jingyang Plantform. A series of linear distributed sinkholes and cracks developing on the top of the slope told us a potential huge landslide was there. Then we persuaded the designer move the route a kilometer away on a stable old landslide, even though the route should be elongates 3 km and costs 6 millions Yuan additional money. The oil route was completed and put into work in the beginning of year 2002 (Fig. 26), while the slope slipped in March 2002, with irrigating on the top of the platform. The slide not only fell 50 m down, but also squeezed the Jinghe River bed to thrust up (Fig. 27). It would be a disaster as the oil route was entombed on the original site.

5.3 Obstruction of Transportation

The Loess Plateau is located in the central of China. The 4 main national highways and the 3 railways of Long-Hai, Bao-Zhong and Xi-Tai connecting this region to others around the country. Because of the complicated landforms and rapid highway and railway development, construction of the road induced a large number of landslides and caused huge loss. On Tongchuan-Huanglin highway, there were 27 landslides occurred during construction in 1990 s. Almost all kinds of possible measures, such as piles, pile-anchors, block-anchors, frame-anchors, beam-anchors and walls for anti-sliding, were practiced in the slides. Unfortunately, part of the control structures was invalid at last. Since the road was completed to utilize on May 2001, it has troubles in every rain season, some of the piles were broken down, and some of the anchors were pulled out, and the slides were still moving foreword. The reason of the failures is that drainage system is not sufficiently available, both ground and underground. In any cases, drainage of water is the most necessary, but simple and less cost measure in loess sliding control because of its sensibility to water. After of all, all the roads passing the Loess Plateau face the problems of landslides which either large or small (Figs. 28, 29).

Fig. 26 The landslide on the north side of Jingyang loess platform occurred in March 2002

Fig. 27 The Jinghe river bed was squeezed up by the landslide

Fig. 28 The damaged beam-anchors for stabilizing the landslide

Fig. 29 A loess slide in No.309 National Road (K2075 + 100)

Railway has the same problem. The 150 km length of Baoji-Tianshui railway has 22 landslides, of which 13 ones are loess slides. Wolongsi landslide, slipped on August 8,1955 near Baoji City, is the largest one on the railway line. It is primary an old landslide, re-slipping after several days rainstorm. The slipping process continued half an hour. The railway on the foot of the slide was pushed forward 110 m, and all the living caves, houses and farmland on the slide were destroyed. The slide has size of 20 million cubic meters and area of 3.3 million square meters. In addition, landslides often cause railway accidents on the Loess Plateau.

5.4 Deduction of Farmland

Land-slipping is a kind of gravity erosive process, which not only moves away the good land on the top of the slope, but also covers that on out of the slope foot. With the landslide progressively developing, the cultivable land is decreasing, which is so-called “worm-eating” of the farmland. The process is more severe on the side slope of loess platforms. Generally the top of the loess platform is gentle and suitable for irrigation, while the foot of the side slope is first terrace of river, which has very loose deposits and shallow ground water. The slides in such a condition have a high rate and a long run distance. Landslides along the platform are almost continuously distributed, forming slide zones along the sides of platforms. There several such slide zones around Xi’an city, such as North bank of Weihe River slides zone; South bank of Jinghe River slides zone, South bank of Bahe River slides zone, North bank of Chanhe River slides zone

Take the South bank of Jinghe River slides zone as example. This slides zone extends 45 km long east to west. Because of side erosion of Jinghe River, the slope has dip angle of 45–70° and 70–90 m high. The top is the gentle Jingyang Platform, a good irrigating farmland. Since the irrigation system was built up in 1976, large amount of water penetration caused hundred of slides along this zone, of which the large slides with size of greater than 30 thousands cubic meters are 30 more. Until present, the total size of the sliding mass is 45 million cubic meters, 30 persons dead, 240 living caves damaged and nearly 1000 mu farmland on the top slipped, 2500 mu farmland on the foot of the slope covered.

Fig. 30 A loess slide in South bank of Jinghe River sliding on May, 2003. Slipped away 80 mu, and covered 200 mu farmland

Fig. 31 A loess slide in South bank of Jinghe River sliding on April, 2006. Covered 5 mu farmland

Now there are still 20 potential landslides creeping in dangerous state. Because local government pays much attention to the slide zone and set ones on duty to observe the change of the slope. They gave alarm to the villagers on time, so relative few people dead in the slipping along this zone. In recent years, Large slides almost happens every year in the fall, the follow photos (Figs. 30, 31) shows the ones in 2002 and 2006.

6 Countermeasures for the Loess Landslides

6.1 Hazard Risk Management

Now we pay too much attention to the engineering countermeasures and skills to control landslides when the hazards of landslide coming. However, as investigating origins of the hazards, it is not surprised that most of them were related to human activities. So, "A Great Debate" on the topic of "Disaster Mitigation Is A Waste of Money" was conducted at the end of the 2010 11th IAEG conference. I agree with the point of view because "People are the main problem" just as some delegates argued (Sergio 2010; Kalsnes et al. 2010). We make the disaster today with a little money; we cure them tomorrow with great money. Is it a waste of money? Therefore, hazard risk management should be more essential than hazard mitigation, which means we should control the action of ourselves to keep from producing new hazards in the long run. So reasonable planning of land use, immigration of the people out of hazard threatening, improvement of ecological environment, innovation of irrigation skill may be more significant. The government has stepped going on but far more from the necessity of economic development.

Since 1990 s, the government has been prohibited to herd on the loess slope of steeper than 25° on the Loess Plateau instead of planting trees. Now the north of Loess Plateau is greener than before. Covering of vegetations would obstruct erosion of loess to improve stability of slope.

Since 2008 Wenchuan 8.1 Ms earthquake and thereafter 2010 Zhouqu huge debris flow, the government has appropriated special funds for immigrating the people suffering inclement geological conditions to the new planned site. But some planned sites were still unsuitable for residence, hazards triggered by construction at the new site made the problems severe. Because the land resources are owned by government, but held by privates, which limits the choice of reasonable sites in a broad range. So the problems may be solved under further reformation of the land policy.

The present overflow irrigation way applying in most farmland on the Loess Plateau not only wastes water resource, but also induces landslides. Replacement by dropping or spraying irrigation could create more social and economic benefits.

That Large amount of cutting for road construction can be replaced by under ground tunnels, cutting for leveling house foundation by littlie cutting and more filling may reduce the risk of landslide in a large extent.

6.2 Monitoring and Pre-alarm

For landslides which have potential risk to the residents but not confident for their stability, monitoring and pre-alarm is a practical way to reducing their risk as much as possible. There are many successful experiences on this way. In the remote areas, the heads of the local government were trained to respond to any observation on the slope movement. People could be alarmed before slipping which saved many lives. As to slides related to some important project such as highways, railways and reservoirs, besides periodical observation, monitoring by equipments such as total station is often applied. Some equipment were fixed in the sites, such as extension meter, incline meter and rainfall meter. The monitoring

Fig. 32 An extensometer installed at a landslide in Heifangtai, Gansu province

Fig. 33 A borehole inclinometer installed at a landslide in Heifangtai, Gansu province

data were obtained on real time with remote controlled unit from the field. Figures 32 and 33 shows the monitoring system of surface extensometer and borehole inclinometer installed at the landslides in Heifangtai, Gansu province.

7 Conclusions

1. Loess is a wind blown deposit which is best developed in the Chinese Loess Plateau. The loess highlands of the Plateau have a continuous stratigraphy in the whole Quaternary which reflects the climatic change in the geological record of the deposits, while loess on the river terraces reflect the intermittent uplift of the Plateau and consequent lateral and downward erosion.
2. Loess landslide occurred extensively on the Loess Plateau due to the topographic effect, vertical joint structures, loose texture and water sensibility.
3. Loess landslides are triggered by earthquakes, rainfalls, irrigations and engineering activities. Most of the landslide hazards are caused by human activities.

4. The countermeasures for landslide hazards should be hazard risk management for controlling man-made hazards, such as reasonable planning of land use, immigration of the people out of hazard threatening, improvement of ecological environment, innovation of irrigation skills and best design for constructions.

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