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Early Pleistocene Debris-Flow Deposits in the Upper Jinsha River, Sw China and their Paleoenvironmental Implications

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Abstract

Large fan shaped debris-flow deposits occur at the piedmont west of Benzilan, in the upper stream of the Jinsha River, southwest China. The accumulation is composed of alternation of debris-flow units and reddish gravel soil units, seemly showing a binary structure. The debris-flow deposit has a mean thickness of 100 m. We did analysis on particle size, major element, clay mineral, pollen and electronic spin resonance (ESR) dating for samples from the debris-flow accumulation. Our study shows that the reddish gravel soil was in fact the debris flow material and its apparent differences from the debris flow material, especially color, was due to weathering. It was a relative dry-hot climate to weather the upper part of the debris flow body into the reddish gravel soil. Evident chemical difference between the soil and debris-flow units was caused essentially by carbonate dissolution from soils. The debris-flow sequences indicate that the climate of the upper Jinsha River valley during the Early Pleistocene was characterized by a remarkable wet-dry alternation and would be warmer than today. The study area would be uplifted by 1300 m since the Early Pleistocene.

Keywords: Debris flow; Reddish gravel soil; Jinsha river; Tibetan plateau; Climate

Introduction

According to previous studies [1-6], we have known that there occur many Quaternary debris-flow deposits in the southeastern (SE) marginal area of the Tibetan Plateau (TP), especially in valleys of the upper reach of the Jinsha River and that they can provide rich information for geomorphic evolution, tectonic movement or climate change and others. In valleys of the upper reach of the Jinsha River, Zhang [7] identified one planation surface, two erosion surfaces and seven levels of alluvial terraces. The elevation of the planation surface is 4200-4400 m. The elevation of the higher erosion surface is 3200-3400 m; the elevation of the lower erosion surface is 2500-2600 m. The terraces are seen mainly in the gorges, while alluvial deposits and debris-flow accumulations are distributed in the broader river valleys. Also, it can be noted in some places that the debris-flow accumulations, probably coming from tributaries, rest commonly on fluvial terraces or erosion surfaces at different elevations, indicating that they would form at different ages.

What triggered debris flows and other mass movements in this area? Previous researches thought that the occurrence of large scale debris flows being closely related to heavy precipitation during the interglacial periods [8] or the strengthening summer monsoon periods [1,9,10].

In this area the precipitation is mainly subjected to influence of the southwest monsoon, showing very significant spatial and temporal differences. It is concentrated between June and September, accounting for 80% of the total annual precipitation. The valley areas, located in the rain shadow between two high mountain ranges, generally receive a less rainfall (~300 mm yr^{-1}). Therefore, such valleys areas are relatively dry and hot. The vegetation in the dry valley areas below 2700 m is chiefly composed of shrubs and grass with few trees.

In this paper, one large debris-flow accumulation in the upper Jinsha River is reported. It is expected to keep good records of the environmental information, which helps to understand the environmental evolution in the valley areas of the upper Jinsha River.

Observations

The debris-flow accumulation we studied occurs in the piedmont west of Benzilan Town, Deqin County, northwestern Yunnan Province, Southwest China and about 2 km away from the Jinsha River (Figure 1).

The debris-flow accumulation is ~700 meters wide and averages 100 meters thick. The outcropping elevation of its bottom is 2600 m. Its bedrock mainly consists of slate and limestone belonging to the Middle Devonian Formation.

The debris-flow accumulation looks to be composed of debris-flow material and reddish gravel soils (Figure 2). Both seem to constitute a clear binary structure. The similar structure can be also seen in old fluvial terraces along the upper reach of the Jinsha River. The debris-flow accumulation is generally exposed along highway cut slopes and gullies. We selected two profiles to observe, describe, sample and analyze (Figure 3).

Profile I

The profile is located at the west part of the debris-flow accumulation. It is around 10 meters long and shows part of the upper of the debris-flow accumulation. It is composed of two continuous segments, which both have a clear binary structure composed of debris-flow material and reddish gravel soils. The first segment contains eight units, of which four are reddish gravel soil units and four are debris-flow units. They are numbered units1-8 (Figure 4). The second segment, located near the

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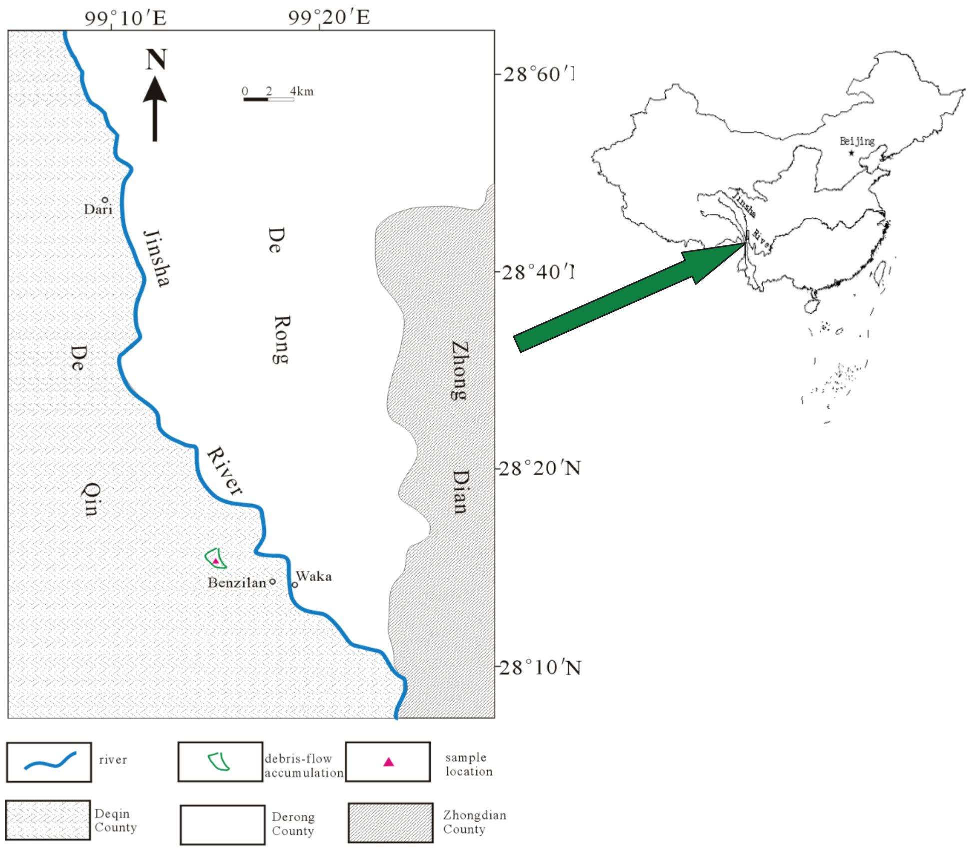

Figure 1: Map of the study area showing the location of the sample site.

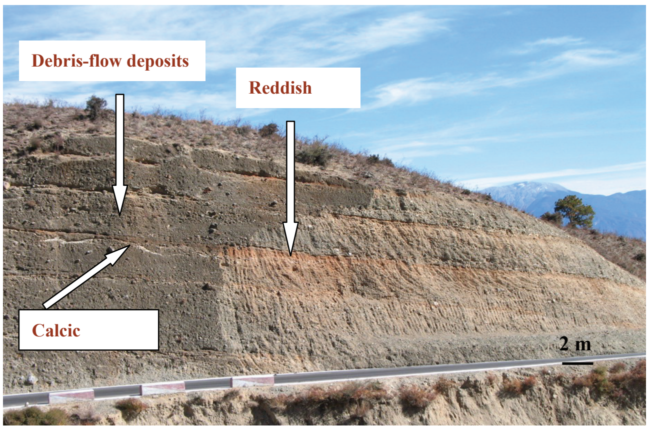

Figure 2: Section showing the alternation of debris flow and reddish gravel soil. The gray color unit denotes the debris flow, the red color unit denotes the reddish gravel soil, and the white color strip denotes the calcic illuvium.

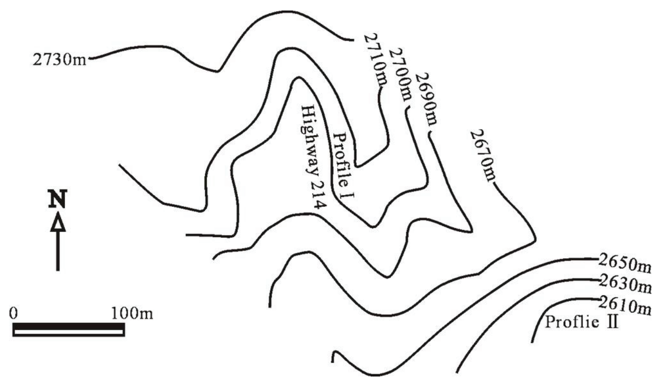

Figure 3: Map showing the studied profiles at Benzilan. The profile I is exposed along highway cut slopes. The profile II is on a side of a deep gully and shows the bottom of the debris-flow accumulation.

first segment, contains three reddish gravel soil units and three debris-flow units, which are numbered units 9-14. Each reddish gravel soil unit is around 10-25 cm thick, composed of fine to coarse gravels and silty clay. Each debris-flow unit is 50-250 cm thick. It contains angle to sub-rounded gravels of limestone and slate. The gravels are unstratified, matrix-supported, and poorly sorted.

Profile II

The profile is on a side of a deep gully and shows the bottom of the debris-flow accumulation. It is 6 m thick and contains three reddish gravel soil units and three debris-flow units. They are numbered 15-20 (Figure 5). Massive matrix-supported gravels in the reddish gravel soil units are more distinct than those in profile I. Gravels in the debris-flow units are of quartz porphyry, which is similar to the base rock outcropped. The mean thickness of the debris-flow units is 100-200 cm, while that of reddish gravel soil units is 20-40 cm. The whole accumulation is very compact. It can be seen near the section that old alluvial deposits rest on the debris-flow accumulation. The alluvial

Figure 4A: Profile I at Benzilan.
Part of the profile, showing Units 1-8 (Scale rule is 2m long).

Figure 5A: Profile II at Benzilan.
(A) Part of the profile, showing Units 15-20.

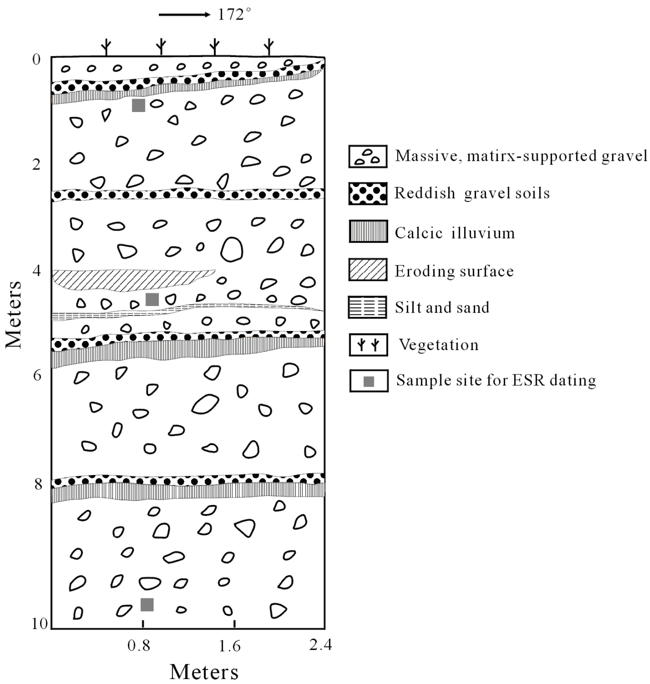

Figure 4B: Profile I at Benzilan.
Cross-section showing units in central part of Profile.

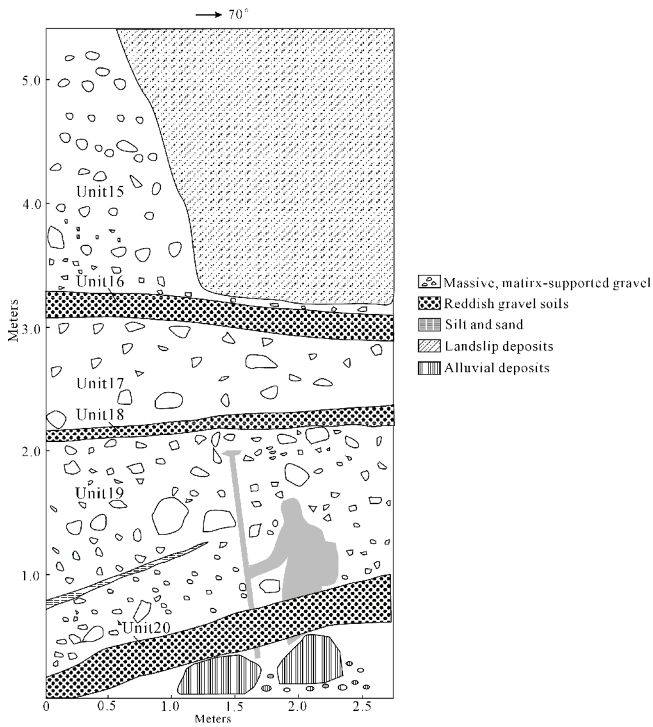

Figure 5B: Profile II at Benzilan.
Cross-section showing units in central part of Profile II.

deposits are dominantly composed of cobble and coarse gravels. Also, there occurs local rock fall at the top of the profile.

In the two profiles we have seen that except their color, thickness and debris content, the two kinds of units seem not to have significant differences. The reddish gravel soil has obvious weathering features and looks the weathered debris-flow. Moreover, a sequence of soil genesis can be observed in the two profiles, that is, Ah-B-C from top to bottom.

Analyses

The profiles were excavated down 40 cm deep to collect fresh samples. We made the following analyses for the collected samples: particle size, clay content, major element, pollen, and electronic-spin-resonance (ESR) dating. The major element analysis was carried out using an X-ray fluorescence spectrometer (XRF-1500) in Institute of Geology and Geophysics, CAS. The ESR dating was carried out using an EMX –type instrument in the Key Laboratory of Qingdao Institute of Marine Geology.

Grain size

The grain size analyzing results for the debris-flow units and the reddish gravel soil units are listed (Table 1). In the debris-flow units, gravel ranges from 71.9% to 84.0%, sand from 11.0% to 21.3%, and silt and clay from 4.6% to 8.5%. In the reddish gravel soil units, gravel ranges from 36.8% to 71.8%, sand from 17.9% to 48.9%, and silt and clay from 10.3% to 19.7%. It can be seen from these data that the grain size distribution of the debris-flow units and the reddish gravel soil units is similar. The difference in the order of magnitude is only in the silt and clay content (Figure 6). This seems further to show that the reddish gravel soil should be the weathered debris-flow material and that a relatively weak weathering environment should exist during the formation of the debris-flow accumulation.

Major elements

A common method of addressing the conditions under which a paleosol formed is to look at molar ratios of major elements that are related to soil formational processes [11-13]. The analyzing results of the major elements for the debris-flow units and the reddish gravel soil units are listed in Table 2. Figure 7 gives a comparison of element ratios between the debris-flow units and the reddish gravel soil units.

The ratio of Al_2O_3/ SiO_2 for the reddish gravel soil units generally is in a range of 0.16-0.22 (Figure 7) and little more than that for the debris flow units. This shows that the reddish gravel soil units would form in a low energy and weak weathering condition, that is, the early weathering of the debris flow accumulation- the mother material of the weathered debris flow would take place in such a condition. Under this condition, the leaching out of SiO_2 was very weak and the enrichment of aluminum was very low. Perhaps, the low aluminum might be due to the leaching out of aluminum oxides.

The ratio of Ti/Al is an index to reflect whether the mother materials of sediments are consistent or not. In profile I, the ratios of Ti/Al for individual reddish gravel soil units are in a range of 0.16-0.18 (Figure 7). Moreover, they have only a little difference from those for the debris flow units, 0.11-0.14. This shows that the mother material of the reddish gravel soils should be the debris flow materials.

The ratios of FeO/Fe_2O_3 for the reddish gravel soil units are relatively lower, 0.3-0.75 (Figure 7), suggesting that the debris flow material should be weathered into the reddish gravel soil in an exposed oxidation environment.

CIA is an index to reflect the weathering degree and its calculation

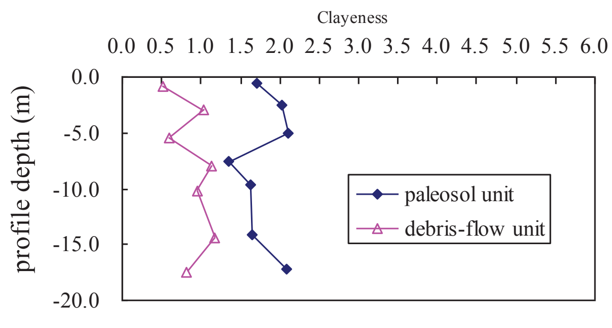

Figure 6: Clayeness of the debris-flow units and reddish soil units,

Unit	Grain sizes by wt %							
Code	Cobbles	Coarse-very coarse gravel	Medium gravel	Fine-very fine gravel	Coarse-very coarse sand	Medium sand	Fine very fine sand	Silt + clay
S.No	(>60 mm)	(20-60mm)	(5-20mm)	(2-5 mm)	(0.5-2 mm)	(0.25-0.50mm)	(0.075-0.25 mm)	(<0.075 mm)
1	0.0	7.9	24.6	5.1	12.5	10.7	19.5	19.7
3	0.0	8.1	19.5	13.2	16.4	7.1	18.3	17.3
5	0.0	10.9	38.4	16.5	8.0	3.0	7.3	16.0
7	0.0	15.7	41.5	14.6	7.2	3.3	7.4	10.3
9	0.0	9.0	38.4	20.3	7.0	3.8	8.4	13.3
11	0.0	14.2	36.3	14.1	12.5	3.6	6.9	12.4
13	0.0	9.3	16.7	10.8	15.4	16.1	17.4	14.3
2	0.0	34.9	39.5	9.6	6.2	1.5	3.7	4.6
4	0.0	35.7	30.7	10.2	7.3	2.4	5.3	8.5
6	18.5	28.2	27.1	8.6	5.3	1.9	3.8	6.6
8	0.0	25.9	36.6	10.1	8.3	3.2	7.7	8.2
10	6.0	42.8	20.5	8.0	7.9	2.6	5.9	6.3
12	0.0	34.8	26.8	10.3	8.6	3.5	9.2	6.8
14	0.0	19.7	38.6	16.5	8.9	2.7	6.4	7.2

Table 1: Grain-size analyses of the debris flow units and the reddish soil units.

Unit code	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MnO (%)	MgO (%)	TiO_2 (%)	CaO (%)	Na_2O (%)	K_2O (%)	P_2O_5 (%)	FeO (%)	LOI (%)	Sum (%)
1	51.84	14.28	8.30	0.17	4.54	1.30	4.88	1.52	2.63	0.38	1.40	8.59	99.83
2	33.32	11.62	7.59	0.15	5.84	1.61	15.56	1.53	1.31	0.60	4.52	16.13	99.78
3	51.73	15.03	9.70	0.22	4.55	1.58	3.97	1.72	2.49	0.28	1.62	6.99	99.88
4	31.39	11.33	7.08	0.15	5.29	1.45	18.00	1.36	1.37	0.54	4.00	17.99	99.95
5	51.90	16.37	10.54	0.21	4.22	1.71	2.26	1.74	2.53	0.40	1.44	6.46	99.78
6	39.98	13.56	10.03	0.21	5.86	1.70	9.47	1.78	1.82	0.55	3.42	11.73	100.11
7	42.85	13.89	8.43	0.15	4.26	1.53	10.87	1.72	1.95	0.53	1.66	12.09	99.93
8	27.76	9.91	6.09	0.12	4.75	1.22	22.17	1.15	1.16	0.48	3.40	21.02	99.23
9	51.45	17.04	8.53	0.19	4.43	1.52	2.26	1.51	2.79	0.38	2.80	6.64	99.55
10	33.52	11.96	7.65	0.14	6.17	1.53	15.12	1.56	1.32	0.55	4.39	15.71	99.63
11	44.66	15.08	9.64	0.23	6.44	1.62	5.53	1.78	2.27	0.51	3.24	8.79	99.78
12	22.15	8.55	4.52	0.12	4.92	1.08	26.90	0.88	0.87	0.48	3.84	24.72	99.03
13	45.93	17.52	12.50	0.30	5.95	1.87	2.15	1.58	2.22	0.37	1.70	7.48	99.57
14	32.98	11.79	8.42	0.13	5.53	1.44	16.20	1.34	1.39	0.57	3.45	16.76	99.99
15	57.51	17.39	3.24	0.17	3.23	0.72	5.48	3.35	0.78	0.19	4.47	3.29	99.82
16	57.45	18.36	8.75	0.14	2.30	0.82	0.89	0.84	2.98	0.32	0.48	6.57	99.99
17	59.35	16.97	2.80	0.15	3.31	0.66	4.95	3.74	0.61	0.16	4.23	2.88	99.43
18	57.53	18.17	8.84	0.13	2.21	0.83	0.93	0.83	2.98	0.34	0.35	6.79	99.93
19	60.28	16.59	2.72	0.14	3.19	0.65	4.76	3.88	0.50	0.15	3.99	2.76	99.61
20	57.98	18.09	8.56	0.13	2.17	0.82	0.95	0.84	2.99	0.31	0.20	6.61	99.65
Upper continental crust*	65.9	15.19	_	0.08	2.21	0.50	4.20	3.90	3.37	0.16	_	_	[illegible]

* Data from Taylor and McLennan (1985).

Table 2: Geochemical analysis based on XRF (X-ray fluorescence).

Unit number	Unit1		Unit2		Unit3		Unit4		Unit5		Unit6		Unit7		Unit8	
	Grain	%	Grain	%	Grain	%	Grain	%	Grain	%	Grain	%	Grain	%	Grain	%
pollen in total	115	100	124	00	125	100	120	100	80	100	116	100	109	100	115	100
Trees	99	86.1	67	54.0	107	85.6	72	60.0	64	80.0	74	63.8	79	72.5	69	60.0
Shrubs & Herbs	14	12.2	53	42.8	16	12.8	43	35.8	11	13.7	37	31.9	21	19.3	38	33.0
Ferns	9	7.9	4	3.2	12	8.9	5	4.2	8	6.9	5	4.3	14	10.8	8	7.0
Abies	6	5.2	5	4.0	9	7.2	3	2.5	5	6.2	7	6.0	6	5.5	4	3.5
Picea					1	0.8							1	0.9		
eteleeria	1	0.9											1	0.9		
Pinus	81	70.4	53	42.8	75	60.0	56	46.7	55	68.8	58	50.0	65	59.6	46	40.0
Betula	9	7.8	9	7.3	13	10.4	9	7.5	4	5.0	6	5.2	6	5.5	16	13.9
Alnus					1	0.8									2	1.7
Juglans	1	0.9			1	0.8	2	1.7							1	0.9
Ulmus					1	0.8	1	0.8			1	0.9				
Tilia	1	0.9			4	3.2	1	0.8	1	0.9	2	1.7	1	0.9		
Corylus	1	0.9	1	0.8	1	0.8	1	0.8								
Ephedra			1	0.8	1	0.8	3	2.5			1	0.9	1	0.9	1	0.9
Artemisia	7	6.1	32	25.8	8	6.4	23	19.2	6	7.5	21	8.1	10	9.2	21	18.3
Compositae	1	0.9	1	0.8			1	0.8			2	1.7	1	0.9		
Chenopodiaceae	4	3.5	10	8.1	2	1.6	11	9.2	2	2.5	9	7.8	4	3.7	9	7.9
Polygonum			1	0.8			2	1.7	2	1.6						
Caperaceae			5	4.0			1	0.8	1	1.3	2	1.7	3	2.8	5	4.4
Gramineae	1	0.9	2	1.6	2	1.6	1	0.8	2	2.5	2	1.7	2	1.8	2	1.7
Lycopodium					1	0.8										
Selaginella	1	0.9	2	1.6			3	2.5	1	1.3	2	1.7	2	1.8	4	3.5
Polypodium			3	2.3					1	1.3			4	3.7	1	0.9
Polypodiaceae	1	0.9	2	1.6	1	0.8	2	1.7	3	3.7	3	2.6	1	0.9	3	2.6
Adiantum													1	0.9		
Pteris													1	0.9		

Table 3: Pollen characteristics of the debris-flow units and reddish soil units in Profile I.

formula is $[Al_2O_3/(Al_2O_3+CaO+Na_2O+K_2O)]\times 100$. The CIA for the reddish gravel soil units is in a range of 64-75, suggesting that these units should be weak weathered.

The ratios of CaO/Al_2O_3 for the reddish gravel soil units are significantly lower than those for the debris flow units, suggesting that the reddish gravel soil should be at the decalcareous stage of the early time of weathering and belong to the reddish soil weathering crust.

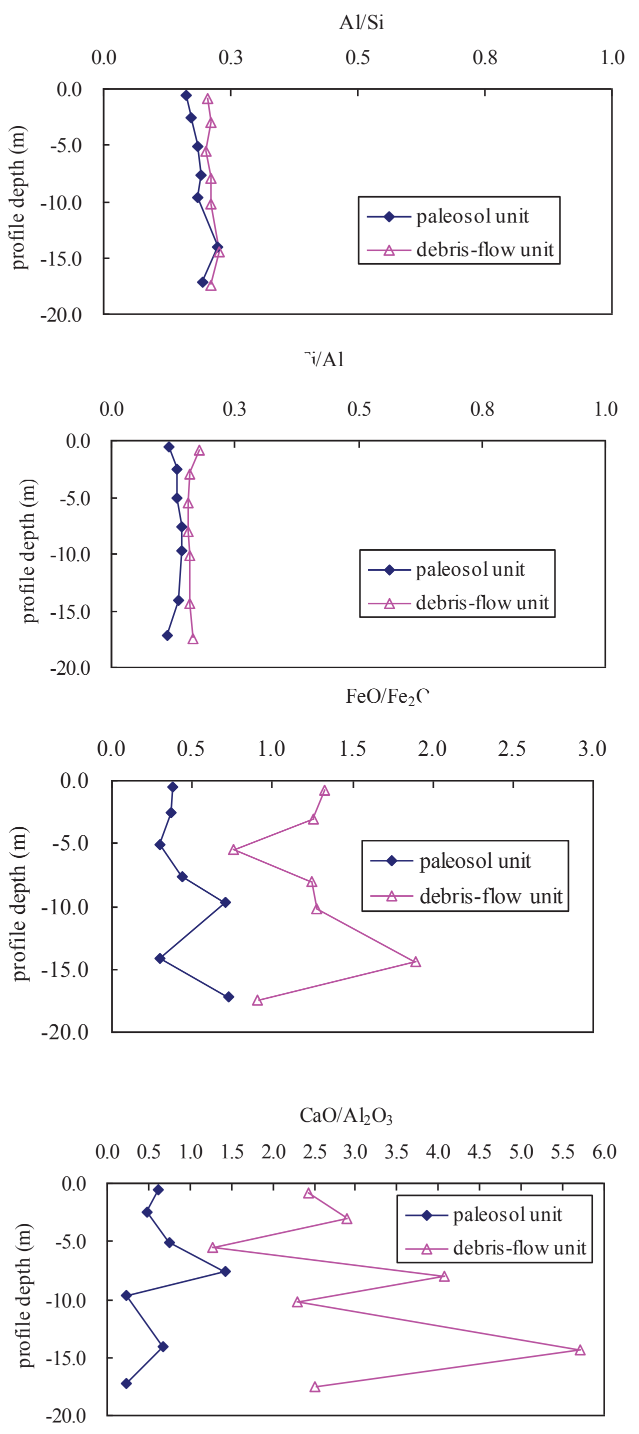

Figure 7: Major element chemistry of debris-flow units and reddish soil units.

Clay minerals

We did the semi-quantitative clay mineral analysis for the soil units and debris-flow units in both profiles. The clay minerals in the debris-flow units are firstly chlorite (33% - 65%) and secondly hydromica (5% - 20%). The quartz ranges from 2%-5%. The chlorite content in the soil units decreases by 20% - 30% compared with that in the debris-flow units, (Figure 8). No kaolinite was found in both types of the units. Such a clay mineral assemblage means that the reddish gravel soil should form in a relatively dry climate and be lower in weathering degree.

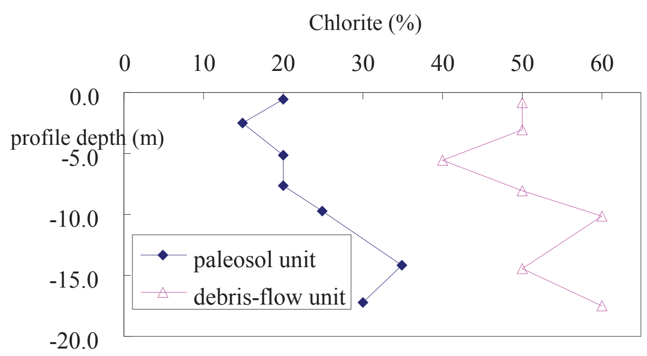

Figure 8: Comparison of chlorite content in the debris-flow units with that in the reddish soil units.

Sampling number	Buried Depth (m)	U (10^{-6})	Th (10^{-6})	K_2O (%)	AD (Gy)	Age* (Ma B.P.)
BZL1	0.8	0.97	2.47	0.70	2680	2.48
BZL2	4.8	1.06	3.12	0.73	1812	1.54
BZL3	9.7	1.02	2.3	0.85	2140	1.77
* Error estimates are about 15.0%.						

Table 4: ESR dating results of the sandy samples from the debris-flow units.

Pollen analysis

We did the pollen analysis only for the samples collected from profile, including its debris flow units and reddish gravel soil units. In the reddish gravel soil units, the tree pollens account for 79.2% of the total, the shrub and herb pollens for 16.7%, the fern pollens for 4.1% (Table 3). In the debris-flow units, the tree pollens accounts for 58.6% of the total, the shrub and herb pollens for 37.6%, the fern pollens for 2.7%. In all of the samples analyzed, the pollen grain numbers all are in a range of 80-125. There are 23 species to be identified, of which 9 correspond to trees, 2 to shrub species, 6 to herbaceous species and 6 to ferny species. The 23 species of plants sketch a mixed forest community, in which Pinus and Betula are dominant, but there are some humid-tolerant tree species such as Juglans, Betula and Alnus.

The Artemisia pollens in the debris flow units (18.1-25.8%) are more than those in the reddish gravel soil units (6.1-9.2%), which suggests that the debris flow should form in a warmer and more humid climate.

Also, according to Weng et al., the ratio of A/C (Artemisia / Chenopodiaceae) can be used to denote climate: If the ratio is more than 1, it indicates a relatively humid climate. All of the ratios of A/C for the debris flow units are more than 1, so these units should be accumulated in a relatively humid climate environment.

ESR dating

Three sandy samples from the debris-flow units in Profile I were used in electronic-spin-resonance (ESR) dating. The dating errors are estimated to be about 15.0%. The ESR dating results listed in Table 4 indicate that the debris-flow accumulation should form at least prior to 1.54Ma B.P. On the basis of paleomagnetic studies [7], the lower erosional surface with 2500-2600 m a.s.l. in the study area formed in 2.00 ± 0.20 Ma B.P. On the other hand, the elevation of the bottom of the debris flow accumulation studied is 2600 m, about equal to the elevation of the lower erosional surface in the study area. This shows that the debris flow accumulation and the lower erosional surface might have some internal relation and that the ESR dating results for the debris-flow units should be credible. Therefore, the debris flow accumulation containing debris-flow material and reddish gravel soil should form in the Early Pleistocene.

Discussions and Conclusions

The above analyses are enough to prove that the reddish gravel soil was in fact the debris flow material and its apparent differences from the debris flow material, especially color, was due to weathering. Therefore, a debris flow unit and a reddish gravel soil unit should be regarded as a debris flow body. The debris flow accumulation we studied at Benzilan is the superposition of many debris flow bodies.

The SE margin of the Tibetan Plateau has experienced an intense tectonic uplift since the Early Pleistocene [7,9,14,15]. The elevation of the debris flow accumulation studied supports this opinion. The mean annual temperature to form the modern reddish soils is between 22-25°C [16]. The elevation of the debris flow accumulation studied is 2600 m where the mean annual temperature today is 12.2°C. This means that the debris flow accumulation should form at a much lower elevation than its present elevation. The elevation where the modern reddish soils are distributed on the SE margin of the TP is between 1000-1300 m [17]. Supposing the perpendicular declining rate of the mean temperature is $0.7°C \cdot 100m^{-1}$, the elevation to the reddish gravel soil should be 1300 m and the uplift magnitude of the study area since the Early Pleistocene should approximate to 1300 m.

Weathering crusts in southern China can be divided in terms of the degree of weathering into three types: reddish soil weathering crust, red soil weathering crust, and laterite weathering crust. The reddish gravel soil units in the debris flow accumulation studied should belong to the reddish soil weathering crust, i.e., in the early period of the red soil growth [15,18] The reddish soils have been well developed in the Hengduan Mountains [16]. The special landform on the SE margin of the Tibetan Plateau has helped the development of debris flows. It was a relative dry-hot climate that made the upper part of the debris flow body weathered into the reddish gravel soil [19-21].

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