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ESR DATING STUDIES OF PALAEO-DEBRIS-FLOW DEPOSITS IN DONGCHUAN, YUNNAN PROVINCE, CHINA

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Abstract — The ages of palaeo-debris-flow deposits in Dongchuan, Yunnan Province were determined by ESR dating. They are consistent with a ^{14}C age estimate. The results suggest that the debris-flow deposits were formed during humid periods of the Late Pleistocene. Simulation experiments and SEM analysis show that the resetting of Ge centres in quartz is most likely due to collisions of the quartz grains during the process of rapid deposition. © 1998 Elsevier Science Ltd. All rights reserved.

INTRODUCTION

Electron spin resonance (ESR) age determinations of fault clays were reported by various researchers (e.g. Fukuchi *et al.*, 1986, 1989; Buhay *et al.*, 1989; Grün, 1992). So far, ESR dating for debris flow deposits has never been attempted. The area of Dongchuan, Yunnan Province, China contains many recent debris flows. However, it is difficult to estimate their ages by isotopic dating methods because of a lack of organic materials in these loose sediments. This paper aims to present our attempts to date debris-flow deposits by the ESR method and to discuss the reliability of the method, the dating mechanism and the geological meaning of the ESR ages obtained.

GEOLOGICAL SETING AND SAMPLING SITES

The Jiangjia Ravine in the northwest of Yunnan Province is a typical area where debris flows are active in China. A comprehensive survey in this district shows that debris flows in modern times have been widespread and frequent, and clear evidence of older debris flow activities can be found everywhere. Due to a lack of precise dating, the ancient debris flow deposits could only be subdivided into three groups: early ancient, middle ancient and later ones. This situation is clearly unsatisfactory.

The profile of the debris flow deposit at Laotianliangzi is representative for early flows (Fig. 1a). It is a set of a densely packed, unstratified melange accumulation with drift boulders and is more than 100 m thick. A red weathering crust (2–3 m thick) is developed at the top of this profile. The surface is a red loam of about 0.5 m thickness. The sediments lie unconformably on the basement of epimetamorphic rocks. Sample Yn-2 was collected from this profile (Fig. 1a). The middle ancient debris flow deposits are represented by the profile at Nideping (Fig. 1c). It contains muddy gravel sediments with a thickness of about 100–150 m.

A red weathering crust of about 2.5 m caps the sediments, the surface is red loam of about 0.5 m thickness. The top of the profile at Xianyuantian has been strongly eroded, and the thickness of relict sediments is about 50 m (Fig. 1a). Sample Yn-3 was collected from the profile at Xianyuantian and sample Yn-4 from the profile at Nideping. The profile of debris flow deposits at Dawazhigoukou is a representative of the later flow and is a set of unconsolidated material. The thickness of the outcropping at Dawazhigoukou is only 18.0 m due to the influence of newer debris flow deposits. Sample Yn-5 was collected from the profile at Dawazhigoukou (Fig. 1b).

EXPERIMENTAL AND RESULTS

Samples were washed in water and then sieved to obtain the 0.06–0.25 mm grain fraction which was treated with H_2O_2 to remove organic material. The grains were soaked in 6 M HCl to dissolve carbonate and subsequently etched with concentrated HF for about 1 h to remove the outer layers of the quartz grains. The samples were thoroughly washed in water and dried at 40°C. Finally, magnetic minerals in these samples were removed by a magnetic separator.

Samples were divided into eight aliquots (about 250 mg each) and irradiated with a ^{60}Co-source. The doses were monitored with alanine/ESR dosimeters. The irradiated samples were kept untouched for more than one week and then measured with a JES-FEIXG ESR spectrometer with the following measurement conditions: room temperature, X-band, microwave power: 2 mW, modulation amplitude: 0.08 mT and magnetic field scanning range 337 $\pm$ 5 mT. A typical ESR spectrum of the quartz samples is shown in Fig. 2 and a dose–response curve in Fig. 3. We selected Ge centre as the dating signal.

The concentrations of radioactive elements, U, Th, K_2O, were determined by laser fluorescence, colorimetric spectrophotometry and atomic absorption techniques, respectively. The contributions of α-radiation were neglected because most of outer layers of the quartz grain had been removed by HF. We could not measure the water content in the samples because sample collection had been carried out several years ago. Because of the high concentrations of radioactive elements, we neglected the contribution of cosmic rays. Considering all parameters, we estimate the total error of the ESR ages is in the range of 15–20%. In order to test and verify the reliability of ESR dating, we carried out ^{14}C dating on organic material in sample Yn-5. The dating results and related parameters are shown in Table 1.

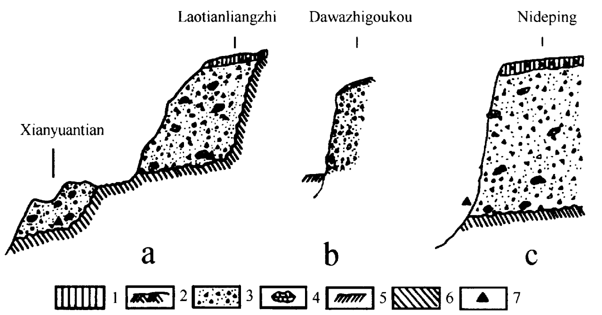

FIG. 1 Profiles of debris flow depositions in Dongchuan, Yunnan Province, China. 1: red weathering crust; 2 red loam; 3: debris flow deposits; 4: limestone drift boulders. 5: river bed deposits; 6: basement, epimetamorphic rock; 7: sampling site.

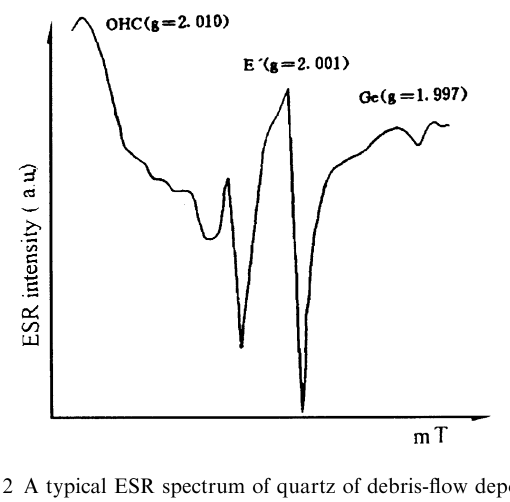

FIG. 2 A typical ESR spectrum of quartz of debris-flow deposits.

DISCUSSION

Mechanism of ESR dating

Resetting of ESR centres occurs if the samples are heated, exposed to light or other geologic agents act on them (e.g. pressure in fault planes). After resetting the ESR signals grow again due to environmental radiation (for the basic principles of ESR dating, see e.g. Grün, 1989; Ikeya, 1993). Ge centres of quartz in sediments show no ESR signals after being exposed to sunlight for 1 hr. The question is whether other mechanisms may contribute to the resetting of the Ge centres in quartz in debris-flow deposits.

Influence of grain collision on resetting of ESR centers

Observations of grain shapes and surface structures under SEM show that the quartz grains from ancient debris-flow deposits are irregular with sharp edges and corners. Conchoidal fractures on the surfaces of quartz

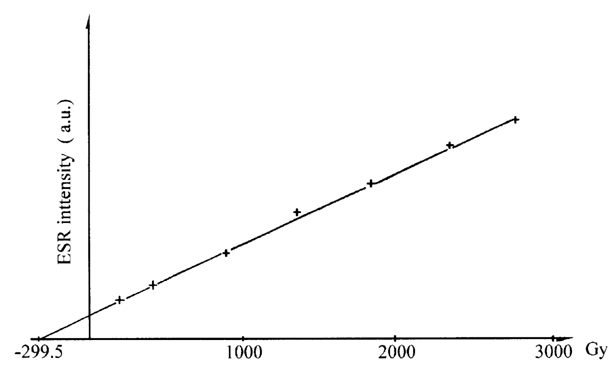

FIG. 3. Dose response of ESR intensity.

TABLE 1. Sampling site, ESR ages and related parameter

Sample number	Sampling site	Stratigraphic level (m)	U ppm	Th ppm	K_2O ppm	Dose (Gy)	ESR age (ka)	^{14}C age (ka)
Yn-2	Laotianliangzhi	120	2.21	11.6	4.08	497.2	98.3	
Yn-3	Xianyuantian	48	2.44	13.3	4.20	299.5	56.1	
Yn-4	Nideping	90	2.58	10.7	4.06	307.5	63.1	
Yn-5	Dawazhigoukou	18	2.58	12.6	4.38	124.6	22.7	20.13 $\pm$ 1.48

grains are well developed, occurring on 88% of the grains (n = 250); 10% show cleavage faces, 12% pits and 18% scratches. These observations indicate that the debris flows had high kinetic energy and that quartz grains in the deposits collided each other, producing the various mechanical structures on their surfaces (Fig. 4).

In order to verify whether collision contributes to the resetting of the Ge-centre we devised the following experiments: first, samples were put into a glass tube and vibrated on a varied gearshift vibrator for 5 min. The subsequent ESR measurements showed little variation in the intensities of the E' and Ge centres, indicating that the energy produced by the vibration was far smaller than of the debris flows. Second, samples were ground in a glazed mortar for 1 min. We found that the ESR intensity of E' centres hardly changes after grinding, however, intensity of the Ge centres decreased by 38% (Table 2). Although we cannot measure the kinetic energy in the debris flows, the energy released during grinding for one minute is most likely smaller than the energy released during the deposition of the debris flows. Modern debris flows in Jiangjia Ravine are dense anisotropic fluids which move very quickly

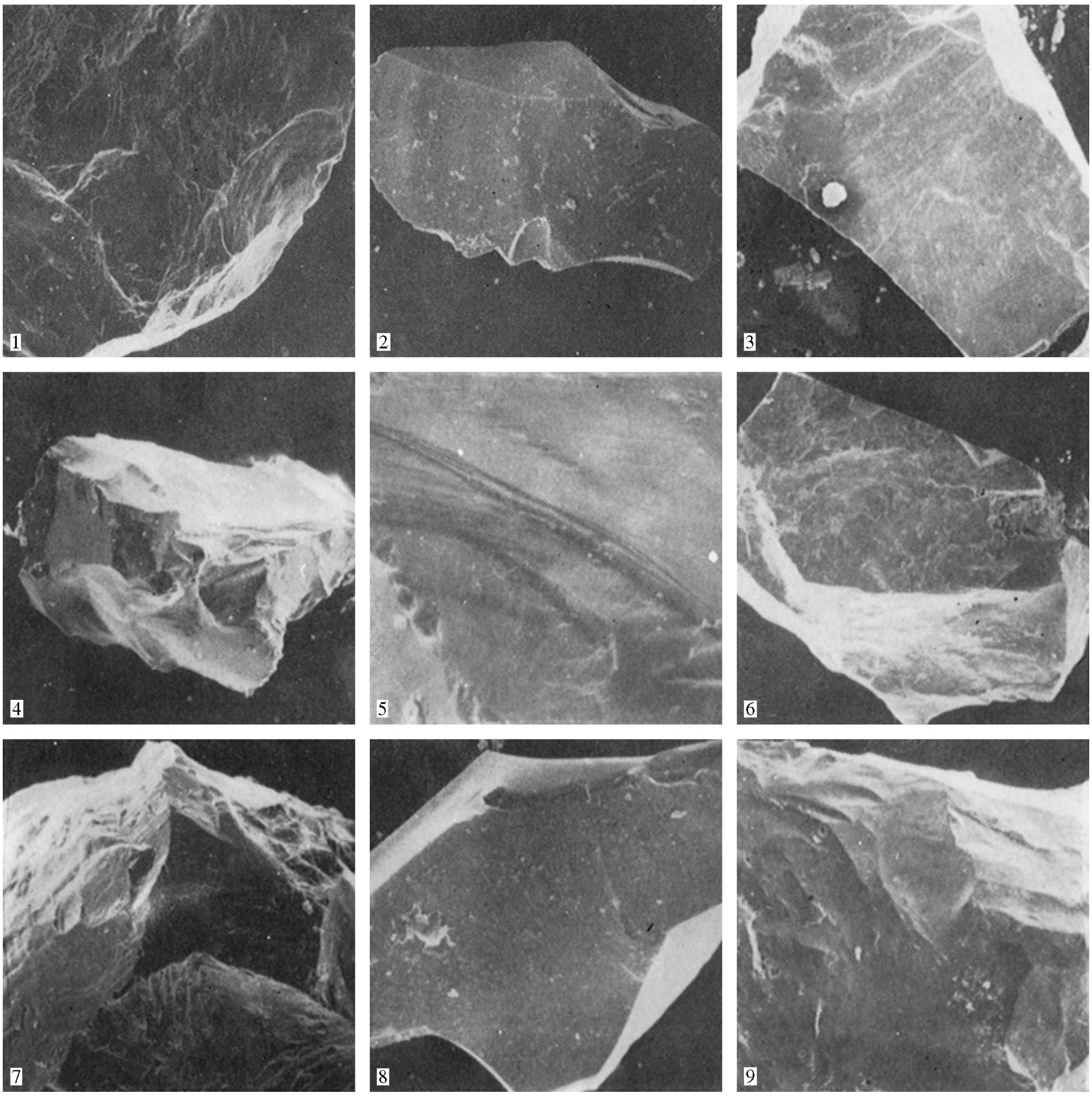

FIG. 4. 1. Saw-toothed at the border of grain, conchoidal fracture, ×800.
2. Saw-toothed at the border of grain, conchoidal fracture, scratch (upper right hand corner), ×400.
3. Cleavage face, conchoidal fractures (lower left hand corner), morel basin, ×400.
4. Conchoidal fractures, ×300.
5. Conchoidal fractures, scratches, morel basins (left) ×300.
6. Cleavage face, V shaped basin, ×400.
7. Basin, ×800.
8. Conchoidal fracture and scratch, ×400.
9. Scratch and morel basin, ×800.

TABLE 2. ESR results of grinding experiment

centre	ESR intensity (a.u) Before grinding	After grinding
E'	11,271	11,264
Ge	1345	825

with an average velocity in the range of 7–8 m s^{-1} and highest velocities in the range of 15 m s^{-1} indicating very high energies. The second experiment suggests that the Ge centres in quartz may be completely reset when the grains collide with each other in the rapidly moving debris flows. However, the E' centres are almost not affected by this process. It cannot be excluded that sunlight contributes to the resetting of the Ge-centre (see e.g. Tanaka *et al*.,. 1985; Grün, 1989). Considering the short possible exposure of the grains to light, this effect should be minor.

Reliability of ESR dating

Since the ESR dating studies of debris-flow sediments had never been carried out before, we have checked our ESR results with a ^{14}C analysis on organic matter in sample Yn-5 (the other samples did not contain enough organic matter for ^{14}C analysis). The results of both dating techniques are virtually the same (see Table 1). Because ^{14}C analyses are completely independent of ESR, we conclude the ESR age estimates presented in this paper are reliable.

Geological interpretation

Based on the ESR ages, the three stages of debris-flow deposits in Jiangjia Ravine have the following ages: the ancient stage took place around 98 ka; the middle stage is in the range of 63–56 ka and the late stage is in the range of 23–20 ka. The periods can be correlated to pluvial interstadial periods of the Late Pleistocene.

SUMMARY

The SEM observations on the structures of the surfaces of the quartz grains as well as our experiments indicate that much of the resetting of the Ge centre can be attributed to the collision of quartz grains during the deposition of the fast moving debris flows. The ESR dates which have been confirmed by a radiocarbon age estimate, allow the establishment of a chronological framework for the debris-flow deposits in Dongchuan, Yunnan Province.

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