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Abstract

New paleomagnetic investigation was carried out on the late Neogene fluviolacustrine sequence of the Yuanmou Basin, located near the southeastern margin of the Tibetan Plateau. Magnetostratigraphic results indicate nine reverse magnetozones (R1 to R9) and eight normal magnetozones (N1 to N8) in the sedimentary profile, which can be correlated to the geomagnetic polarity timescale from C3n.3r to C1r.1r. The age of the sedimentary sequence of the Yuanmou Basin can thus be paleomagnetically constrained to an interval from early Pliocene to Pleistocene, with sedimentation rates varying from 12.5 to 55 cm/kyr. In addition to its highly resolved magnetostratigraphic sequence, the Yuanmou Basin provides a record of Plio-Pleistocene tectono- and climato-sedimentary processes. The mean declinations of the seventeen polarity units (excluding samples with transitional directions) can be grouped into three distinct directional intervals, Group I (2.58–1.37 Ma), Group II (4.29–2.58 Ma) and Group III (4.91–4.29 Ma). These directions indicate that the Yuanmou Basin has probably experienced vertical-axis clockwise rotation of about 12° from 1.4 Ma to 4.9 Ma, which may be related to slip activity of the Red River fault to the southwest and the Xianshuihe-Xiaojiang fault to the east.

Keywords: Yuanmou Basin; magnetostratigraphy; vertical-axis rotation; late Neogene
1. Introduction

The knowledge of the Cenozoic tectonic evolution of the Tibetan Plateau and its adjacent area is important to understand the physical properties of the lithosphere during the process of continent-continent collisions (see reviews by Yin and Harrison, 2000; Tapponnier et al., 2001) (Fig. 1). A poorly understood question about the Himalayan-Tibetan orogeny is whether the penetration of India into Asia is accommodated through distributed crust thickening or localized deformation at major lithospheric faults with high slip rates and that bound quasi-rigid blocks (England and Houseman, 1988; Peltzer and Tapponnier, 1988; Avouac and Tapponnier, 1993; Chen et al., 2002; Dupont-Nivet et al., 2002, 2003, 2004; Huang et al., 2004). Moreover, the phased uplifts of the Tibetan Plateau have had significant impact on late Cenozoic climatic change in East Asia (e.g., Chung et al., 1998; Rea et al., 1998; An et al., 1999, 2001; Guo et al., 2002; Clark et al., 2005).

The eastern margin of the Tibetan Plateau is one of its most active tectonic region with features of Tertiary Indochina extrusion to southeast and clockwise rotations around the eastern Himalayan syntaxis (England and Molnar, 1990; Leloup et al., 1995; Wang et al., 1998; Wang and Burchfiel, 2000; Tapponnier et al., 2001). Earlier paleomagnetic studies revealed clockwise rotation of the Qiangtang terrane (e.g., Zhu et al., 1988; Ototuji et al., 1990; Huang et al., 1992) and the Simao Terrane (Sato et al., 2007). Some counterclockwise rotations of the Cretaceous and Tertiary rocks from southeast China, possibly linked to motion related to the Red River fault was also reported by workers (e.g., Gilder et al., 1993). However, paleomagnetic constraints on
the deformation ages and rotations in this region are still sparse, and, therefore, more
data are needed.

The Yuanmou Basin in northern Yunnan Province, located in the east of the
eastern Himalayan syntaxis (Fig. 1), preserves late Cenozoic fluviolacustrine deposits
with a thickness of ≥850 m. In an attempt to determine age of the two hominin
incisors found in the upper section of this basin in 1965 (Hu, 1973; Qian et al., 1984),
which were attributed to *Homo [Sinanthropus] erectus yuanmouensis* (Hu, 1973; Wu
and Poirier, 1995), magnetostratigraphic studies were carried out by Li et al. (1976)
and Hyodo et al. (2002). However, in Li et al.’s study, only 76 samples in total were
collected and were not analyzed by stepwise thermal demagnetization, which is now
standard practice in evaluating sediments that contain hematite as a principal
remanence carrier. Their paleomagnetic results suggested an age of ~1.7 Ma for the
hominin incisors. In the work of Hyodo et al. (2002), paleomagnetic sampling
intervals were too sparse and unevenly distributed with depth. Four to five samples
were collected at each of 78 sites. Moreover, in their studies, the majority of samples
were demagnetized by alternating field (AF) demagnetization technique and thermal
treatments were done only at sites where a normal polarity magnetization was
obtained by AF demagnetization. They identified four normal and four reverse
polarity chron based on 183 samples from 75 sites (including 29 sites with large $\alpha_{95}$
values between 15° and 37.6°), by which they revised the age of the hominin incisors
to the early Brunhes chron (~0.7 Ma), 1 myr younger than the age reported by Li et al.
(1976), and obtained an age of ~3.6 Ma (Gilbert-Gauss geomagnetic reversal) for the
bottom of the Shagou Formation.

Here we present new paleomagnetic results from the Yuanmou Basin with aims to (1) establish high-resolution magnetostratigraphy for the entire Yuanmou fluviolacustrine sequence; and (2) examine the tectonic rotation history of the basin back to late Neogene time.

2. Geological setting and sampling

The Yuanmou Basin is geologically located in the northern Yunnan terrane bounded by two major fault zones, on the southwest by the NW-SE trending Red River fault zone and on the northeast by the curved Xianshuihe-Xiaojiang fault zone (Fig. 1). The Red River fault zone, which extends over a length of >1,000 km, has been regarded as the suture zone between the South China block and Indochina block (Zhang et al., 1983). The curved Xianshuihe-Xiaojiang fault is nearly NS-trending in northern Yunnan with a width of about 150 km. Eastwardly, it consists of the Yuanmou fault, Yimen fault, Pudu River fault, West Xiaojiang fault, and East Xiaojiang fault. The Xianshuihe-Xiaojiang fault merged with the Red River fault at southern Yunnan. A series of Cenozoic north-south-trending half-graben basins were also developed along these faults, namely the Yuanmou Basin, Lufeng Basin, Dianchi Basin, Fuxian Basin, and Yiliang Basin (Fig. 1).

The N-S elongated Yuanmou Basin with an altitude of 1050 to 1400 m is bounded in its eastern side by the Yuanmou fault and a mountain consisting of the Jurassic Fengjiahe Formation and the Cretaceous Matoushan Formation, and in the western
side by a range of the Precambrian Julin Group (Jiang et al., 1989). The late Neogene deposits were particularly well preserved in the southern part of the Yuanmou Basin with a thickness of ≥850 m. The beds tilt slightly eastward with a mean dip of ~9°. From bottom to top, the whole sedimentary sequence can be divided into four lithologic members: lacustrine and fluviolacustrine silty clay, silts and fine-grained sands (M1); fluvial and fluviolacustrine peaty clays, silts, silty clays and fine-grained sands (M2); fluvial silty clays interbedded with silts and fine-grained sands (M3); and fluvial and alluvial silty clays interbedded with sandy conglomerates (M4) (Pu and Qian, 1977; Qian and Zhou, 1991). The fluviolacustrine deposits also contain abundant Pleistocene mammalian, including hominin, fossils (Bien, 1940; Pei, 1961; Hu, 1973). Neither soil formation, which would indicate slowing or cessation of sedimentation, nor any significant depositional hiatus was observed in any part of the sequence in the field.

In this study, oriented paleomagnetic samples covering M4 to M1 were collected from the entire 260-m-thick Dapoqing (DPQ: 25.69°N, 101.92°E) section and the 644-m-thick Gantangmaoyi (GM: 25.65°N, 101.89°E) section. Block samples were orientated in situ using a magnetic compass. Differences between the 2000 China Geomagnetic Reference Field (CGRF) and the solar compass declination is less than 2°. Cubic samples with 2-cm edge length were cut in the laboratory for paleomagnetic measurements. The DPQ and GM sections (3 km apart) were correlated by using marker layers, a field traceable yellow sand layer and the highest peaty clay layer (HPCL). This field correlation was checked by sampling a ~60-m interval above and
below the HPCL at GM where it overlaps the lower part of the DPQ section.

Sampling intervals in both sections were 0.2–0.5 m, which provided a total of 1633 sampling levels.

3. Rock magnetic investigation

Anisotropy of magnetic susceptibility (AMS) was measured using a KLY-3s Kappabridge. The susceptibility tensor for each sample was calculated by a described method (Jelinek, 1978). To avoid potential problems associated with heating (Rochette et al., 1992), we completed the AMS measurements before any thermal demagnetization was conducted. In the 529 (DQP) and 1208 (GM) samples studied, most minimum susceptibility axes ($K_{\text{min}}$) are close to the vertical, perpendicular to the bedding plane, whereas the inclinations of the maximum axes ($K_{\text{max}}$) are very shallow (Fig. 2a). These results are typical for a normal sedimentary magnetic fabric that has been unperturbed since deposition.

Using the KLY-3s Kappabridge with a CS-3 high-temperature furnace, we performed magnetic susceptibility versus temperature ($\chi-T$) analyses of the bulk sediment. Clear decreases in susceptibility at ~680°C in most $\chi-T$ curves indicate that hematite is the main magnetic carrier with small amount of magnetite ($T_{c}=585°C$) in the studied samples (Fig. 2b). Stepwise isothermal remanent magnetization (IRM) acquisition behaviors show that samples have two magnetic components, one saturated at fields of 0.2–0.3 T but another unsaturated up to 1 T (Fig. 2c). The S-ratio (defined as $\text{IRM}_{0.3T}/\text{IRM}_{1T}$) is consistently low with a mean of 0.53±0.08 (N=543)
Considering all the rock magnetic evidence together, we conclude that hematite is the dominant magnetic carrier in the Yuanmou Basin sediments. These observations question the consideration by Hyodo et al. (2002) that magnetite is the dominant magnetic carrier and AF demagnetization technique was applied to the major part of their collection.

4. Paleomagnetic analyses

In this study, total 1545 samples were subjected to progressive thermal demagnetization up to 680°C, with a 25–50°C interval below 585°C and a 10°C interval above, using a Magnetic Measurement Thermal Demagnetizer (MMTD Model 80). Remanence was measured using 2G cryogenic magnetometers (Models 755 and 760), which were installed in a magnetically shielded space (<300 nT). Representative demagnetization behaviors are presented in Fig. 3. A total of 88 peaty clay samples were subjected to a 150°C thermal demagnetization followed by AF demagnetization at peak fields up to 60 mT. Both methods were capable of isolating the characteristic remanent magnetization (ChRM) after removal of one or two soft secondary components of magnetization. The principal components direction was computed by a "least-squares fitting" technique (Kirschvink, 1980). Based on the rock magnetic analyses (i.e., hematite as the main remanence carrier), we determined the ChRM using high-temperature components (≥610°C) with at least four demagnetization steps trending towards the origin (Fig. 3). For AF demagnetized peaty clay samples we used a component ≥30 mT. Samples with maximum angular
deviation larger than 15° were rejected for further analyses. Based on these criteria, 892 samples (~55%) had reliable ChRM directions. The virtual geomagnetic poles (VGPs) were determined from the ChRM vectors of those samples, and then their corresponding VGP latitudes were subsequently used to define the succession of magnetostratigraphic polarity (Fig. 4).

As mentioned above, Hyodo et al. (2002) have used the inadequate demagnetization technique to their collection. Moreover, they adopted ChRM directions of about 16% samples with a higher coercivity component from the center of a cluster instead of the principal component analysis method as the remanence carried by hematite can’t be totally cleaned by AF demagnetization. Therefore, our new findings presented in this study supercede the previous ones.

As shown in Figure 4, nine reverse magnetozones (R1 to R9) and eight normal magnetozones (N1 to N8) are recognized in the DPQ and GM sections. Specifically, five magnetozones occur at DPQ: three with reverse polarity, R1 (0–113.5 m), R2 (164.85–218.85 m) and R3 (224.25–260.1 m); and two with normal polarity, N1 (113.5–164.85 m) and N2 (218.85–224.25 m). Below the HPCL marker layer at GM, there are six reverse magnetozones: R4 (258.1–272.55 m), R5 (332.8–353.95 m), R6 (387.05–443.8 m), R7 (459.05–481.4 m), R8 (507.4–606.7 m) and R9 (637.05–644.3 m); and six normal magnetozones: N3 (141.8–258.1 m), N4 (272.55–332.8 m), N5 (353.95–387.05 m), N6 (443.8–459.05 m), N7 (481.4–507.4 m) and N8 (606.7–637.05 m).
5. Discussion

5.1. Age constraints on the Yuanmou Basin sediments

Slight changes in bedding attitudes prevent this study from a meaningful local fold test. Instead, we calculated the mean ChRM directions and then performed the reversal test (McFadden and McElhinny, 1990) on sample levels. To do the test we rejected 186 samples with transitional directions (here designated polarity transition as having VGP latitudes less than 60°). The remaining 706 samples have a mean normal direction of $D/I = 1.6°/27.1° (\alpha_{95}=1.8°, N=254)$ and reversed direction of $D/I = 181.3°/-28.2° (\alpha_{95}=1.4°, N=452)$; they positively pass the reversal test with A classification (McFadden and McElhinny, 1990). The overall mean direction is $D/I = 1.4°/27.8° (\alpha_{95}=1.1°)$, corresponding to the paleomagnetic pole at 79.1°N/266.7°E ($A_{95}=2.8°$). Thus, from this point of view we conclude that the observed paleomagnetic results are reliable. Although paleomagnetic results passed the reversal test, we noted an inclination shallowing of $\sim19°$ with respect to the synthetic European apparent polar wander path (APWP) of the same age proposed by Besse and Courtillot (2002). The low inclination may have been caused by syndepositional shallowing of the remanent inclination (Gilder et al., 2001). Several earlier studies revealed that inclination shallowing is a common phenomenon for sedimentary magnetism in Central Asia (e.g., Cogné et al., 1999; Gilder et al., 2001; Dupont-Nivet et al., 2002; Huang et al., 2004). The inclination shallowing seems to have equally affected both the normal and reversed directions for the Yuanmou data. Detailed discussion of the shallowing is beyond the scope of this paper.
Earlier studies have demonstrated that M4 is rich in mammalian fossils, known as the Yuanmou Fauna (Bien, 1940), which is similar taxonomically to the early Pleistocene Nihewan fauna in North China and the Villafranchian fauna in Europe (Bien, 1940; Hu, 1973; Pei, 1961; Qiu, 2000; Deng et al., 2008). By combining biochronological data and magnetostratigraphic results, the magnetozones determined for DPQ can readily be correlated to the geomagnetic polarity timescale (GPTS) (Berggren et al., 1995; Cande and Kent, 1995). DPQ magnetozones R1, R2 and R3 correspond to the Matuyama reverse chron; and N1 and N2, respectively to the Olduvai and Reunion normal subchrons of the GPTS (Fig. 4). GM magnetozones N3–N5 are correlated to the Gauss normal chron and its two reverse subchrons (the Kaena and the Mammoth), and magnetozones R6–R9, to the Gilbert reverse chron and its three normal subchrons (the Cochiti, the Nunivak and the Sidufjall). Therefore, by extrapolating the sedimentation rates of magnetozones N1–R2, we estimate the termination age of M4 to be ~1.37 Ma, instead of the Brunhes chron age estimated by Hyodo et al. (2002).

There was another major drawback of Hyodo et al.’s work besides incomplete removal of viscous remanence, they sampled only 78 sites for a 1300-m-thick section. Both the incomplete demagnetization and very coarse sampling can lead to missing or incorrect interpretation of polarities of this magnetostratigraphic sequence. In Hyodo et al.’s study there were only six paleomagnetic sampling sites in the Yuanmou Formation, corresponding to the M4 in this study; among them they claimed one normal magnetozone (represented by 14 samples of four sampling sites) with two
reversal events (represented by 6 samples of two sampling sites). Their correlation of this normal magnetozone to the Brunhes chron is obviously incorrect. Magnetostratigraphic age of the Yuanmou hominin incisors will be detailed elsewhere (Zhu et al., 2008, manuscript submitted to Journal of Human Evolution).

On the basis of GPTS correlations of our densely sampled sequence, we estimate the base age of M1 to be ~4.9 Ma, which is significantly older than that of 3.6 Ma for the bottom of the Shagou Formation suggested by Hyodo et al. (2002). This suggests that the Yuanmou Basin subsided, possibly due to reactivation of the western branch of the Xianshuihe-Xiaojiang fault (Yuanmou fault), and started to accumulate sediments at the early Pliocene.

5.2. Sedimentary accumulation of the Yuanmou sequence

The built magnetochronology has provided an insight into the infilling process of the Yuanmou Basin. The variability in sedimentary accumulation of the Yuanmou Basin sequence is shown in Figure 5a. There exists high variability in sedimentation rates of the continental fluvial lacustrine sequences in the Yuanmou Basin since ~4.9 Ma, which reveals four distinct stages during the infilling process of the basin. The first stage is from ~4.9 to 4.6 Ma, and has an accumulation rate of ~48 cm/kyr. The second, between 4.6 and 3.3 Ma, has a lower accumulation rate of ~12.5 cm/kyr. Nevertheless, we note that this accumulation rate is estimated based on only one point. The third stage, an interval of 3.2–3.1 Ma, has a very high accumulation rate of ~55 cm/kyr. And, the fourth stage from 3.1 to 1.4 Ma has an accumulation rate
of ~26 cm/kyr. The variation of sedimentation rates can be attributed to either tectonics and/or environmental change. For example, during the early Pliocene (i.e., between 4.9 and 4.6 Ma), the development of the Yuanmou paleolake was initiated due to fault-controlled subsidence, and sediments rich in conglomerates were accumulated. The high sedimentation rate during this stage was associated with the initial formation of the basin and was very likely due to rapid tectonic subsidence. The lower sedimentation rate during 4.6–3.3 Ma was probably mainly related to climate change, when tectonics imparted weak control on basin infilling and numerous peaty clay layers were deposited under warm and wet conditions. The substantially higher sedimentation rate during 3.2–3.1 Ma is also probably indicative of an episode of rapid tectonic subsidence, which was followed by a significant decrease in sedimentation rate during 3.1–1.4 Ma, when a distinctive sequence of floodplain silty clay and silts was developed.

5.3. Possible vertical-axis tectonic rotation

According to modern observations on the deformation in Tibet and its surrounding areas, England and Molnar (1990) proposed that the crustal blocks between the east-striking faults in the eastern part of the Tibetan Plateau rotated clockwise at 1–2°/myr. Based on the sedimentological study, Wang and Burchfiel (2000) proposed that crust in the southeastern part of the Tibetan Plateau has internally deformed and clockwisely rotated. Importantly, our new paleomagnetic data provide an opportunity to discuss the timing of possible vertical-axis rotations, which
were lacking in most previous paleomagnetic studies. To this end, we calculated the mean directions of each of the seventeen polarity units (excluding samples with transitional directions). Results are shown in Table 1 and Figure 5b. These declination means may be paleomagnetically combined into three distinct groups (I to III) with overlaps between neighbor groups if the errors are taken into consideration. Specifically, the Fisher mean declinations of Group I (polarities R1 to R3, 2.58–1.37 Ma), Group II (polarities N3 to N6, 4.29–2.58 Ma) and Group III (polarities R7 to R9, 4.91–4.29 Ma) are -2.8°±1.6°, 2.0°±1.8° and 9.2°±2.1°, respectively, strongly suggesting a progressive vertical-axis clockwise rotation of about 12° from 1.4 Ma to 4.9 Ma for the Yuanmou Basin. Because of the sufficient time intervals used (> 600 kyr), the paleosecular variation influence on these mean directions should be averaged out. Considering the number of samples used in statistics (N=174 to 338), the measurement error potentially related to the imprecision of sampling orientation most likely had an insignificant effect. Moreover, the slight tilting of beds has been corrected and the field observation of the sampled sections does not show any significant internal deformation, such as faulting. Therefore, we tend to interpret these grouped means of declinations to be the resultant of progressive vertical-axis clockwise tectonic rotations of the studied basin.

Understanding of these progressive vertical-axis tectonic rotations may enhance the debate on the consequence of the India-Eurasia collision. Because of lack of paleomagnetic data of the same timing resolution from the neighbor blocks, we discuss them in the geographic (absolute) frame and compare them with stable Europe
reference (Besse and Courtillot, 2002). Groups I and II show slight differences of -2.8°±1.6° and 2.0°±1.8° at the 95% confidence level with respect to the geographic pole, respectively. If the 2σ statistic probability is taken into account, these differences become insignificant. However, Group III presents significant difference of mean declination in clockwise with geographic north at 95% confidence level. That may interpret that the Yuanmou Basin has experienced a progressive clockwise rotation in the geographic (absolute) frame. If compared to the expected declination calculated from the synthetic European APWP of 3 Ma (λp=86.3°N, φp=172.0°E, A95=2.6°; Table 1) proposed by Besse and Courtillot (2002), we note that Group I apparently rotated -6.7°±2.8° counterclockwise, Group II -1.9°±2.8° in the same sense, however, and Group III rotated 5.3°±3.0° clockwise (Table 1). In other words, an earlier clockwise rotation of the Yuanmou Basin was followed by a later counterclockwise rotation relative to the expected direction determined from reference European APWP. An accumulated relative rotation of about 12° occurred, therefore, for the studied section from 1.4 to 4.9 Ma, which indicates an apparent rapid relative rotation of about 4°/myr. Of course, we have noticed that this comparison and its consequent tectonic interpretation may be obscured due to the following reasons: 1) Several active tectonic structures are located from stable Europe and the studied area, such as Altay, Tianshan, Altyn Tagh; 2) The process of India-Eurasia collision presents a continuous nature in the time scale of this study (Patriat and Achache, 1984), and no obvious tectonic evidence to rotate the Yuanmou Basin in different senses from such a short interval from 4.9 to 1.4 Ma.
The clockwise rotation of the Yuanmou Basin obtained from this study is coherent with field observations and GPS measurement carried out around the eastern Himalayan syntaxis (England and Molnar, 1990; Leloup et al., 1995; Wang et al., 1998; Tapponnier et al., 2001). This rotation could be interpreted as evidence for the transformation of the Red River fault from left-lateral to right-lateral (e.g., Leloup et al. 1995). In brief, the regional clockwise rotation of the Yuanmou Basin could be linked to the displacement on the Xianshuihe-Xiaojiang left-lateral strike-slip fault and motion associated with the Red River fault.

6. Conclusions

This paleomagnetic study has shown that the Yuanmou Basin near the southeastern margin of the Tibetan Plateau began to accumulate sediments in the early Pliocene. Seventeen polarity units (9 reverse and 8 normal) were determined for the 850-m thick sequence, the corresponding age spanned from 4.9 to 1.4 Ma. The sedimentation rate varied from 12.5 to 55 cm/kyr, possibly related to tectonics and/or climate changes. Importantly, the observed discordant declinations suggest significant clockwise vertical-axis tectonic rotations of the Yuanmou Basin since the early Pliocene time, which provides constraints on activities of major fault systems in the adjacent region during the past ~4.9 Ma. In summary, the magnetochronology of the Yuanmou sequence chronicles the late Neogene infilling process in the Yuanmou Basin and tectonic rotations in the southeastern Tibetan Plateau.
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FIGURE CAPTIONS

Fig. 1. Sketch tectonic map (a) and detailed geological map (b) showing sedimentary basins (the numbers 1–5 in (a)) and major fault systems in the eastern Tibetan Plateau and Yunnan. 1, Yuanmou Basin; 2, Lufeng Basin; 3, Dianchi Lake; 4, Fuxian Lake; 5, Yiliang Basin. The filled square in (a) is the location of a Global Positioning System station named DLH shown in King et al. (1997).

Fig. 2. Rock magnetic results. (a) Anisotropy of magnetic susceptibility (AMS) diagram. Squares (circles) stand for $K_{\text{max}}$ ($K_{\text{min}}$). (b) Representative $\chi-T$ curves (heating curves only). (c) Representative normalized IRM acquisition curves. (d) Variation of the $S$ ratio ($\text{IRM}_{0.3T}/\text{IRM}_{1T}$) with depth (upper 647 m, correlation between two sections, see text).

Fig. 3. Representative orthogonal plots of the Dapoqing, DPQ (a–d) and Gantangmaoyi, GM (e–l) sections. All directions are tilt-corrected. Open (solid) circles are plotted on vertical (horizontal) plane. Thermal treatment levels are marked in degree Celsius. See Figure 4 for depths of the samples.

Fig. 4. Lithostratigraphy and magnetic polarity stratigraphy at Dapoqing, DPQ (a–c) and Gantangmaoyi, GM (e–g) and their correlation with the geomagnetic polarity timescale, GPTS (d) (Cande and Kent, 1995; Berggren et al., 1995). The highest peaty
clay maker layer (HPCL) and the lithologic member (M) boundaries are shown. VGP
Lat, latitude of virtual geomagnetic pole; R, reverse polarity; and N, normal polarity.
The stars show the GPS points.

Fig. 5. (a) Magnetic polarities identified in the DPQ and GM sections of the Yuanmou Basin. (b) Variation of the sedimentation rates of polarity units as a function of ages. The empty and solid circles represent data of the DPQ and GM sections, respectively. The solid line shows the averaged sedimentation rates of the four stages during the infilling process of the Yuanmou Basin. (c) Variation of the Fisher mean declinations of polarity units as a function of ages. The diamonds show data of the DPQ section; the squares, of the combined DPQ and GM sections; and the triangles, of the GM section. Numbers next to the symbols are sample numbers of the polarity unit that were used for the calculation of the mean. The vertical bars represent the age intervals. The horizontal error bars are the 95% confidence limit of the declinations. These declination means can be paleomagnetically combined into three distinct groups (I, II and III). The dashed line shows the expected declination from the referenced European paleomagnetic pole of 3 Myr.
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<th>( D_i )</th>
<th>( I_i )</th>
<th>( \alpha_{95} )</th>
<th>( \lambda_p )</th>
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<td>0-644.3</td>
<td>1.37-4.91</td>
<td>17</td>
<td>1.4</td>
<td>27.8</td>
<td>1.1</td>
<td>79.1</td>
<td>266.7</td>
<td>2.8</td>
<td>-2.5±2.5</td>
<td></td>
</tr>
</tbody>
</table>

\(^a\) \( N \), the numbers of polarities. \( D_i \), \( I_i \) and \( \alpha_{95} \) are mean declination, inclination and 95% confidence limit, respectively. \( \lambda_p \) and \( \varphi_p \) are latitude and longitude of paleomagnetic pole from this study, respectively. \( A_{95} \) is the radius of 95% confidence region of paleomagnetic poles. \( D_{exp} \) and \( \Delta D_{exp} \) are the expected declination and its confidence limit at the coeval referenced pole, respectively. The referenced European paleomagnetic pole of 3 Myr is at \( \lambda_p = 86.3^\circ \text{N}, \varphi_p = 172.0^\circ \text{E} \) (\( A_{95} = 2.6^\circ \)) (data from Besse and Courtillot, 2002). The vertical-axis rotation with 95% confidence limit, \( R \pm \Delta R \), were calculated after Butler (1992).
Fig. 1
Fig. 2
Fig. 3
Fig. 5