Reconnaissance magnetostratigraphy of the Precambrian-Cambrian boundary section at Meishucun, Southwest China

F. WU (1); R. VAN DER VOO (1) and Q. Z. LIANG (2)
(1) Department of Geological Sciences. The University of Michigan. Ann Arbor MI. 48109-1063, USA
(2) Yunnan Institute of Geological Sciences Kunming, Yunnan, People's Republic of China

ABSTRACT

A sequence of platform carbonates and phosphorites in southwest China, near Kunming, contains the Precambrian-Cambrian boundary and is well studied in terms of lithologies and faunal content. The sequence, called the Meishucun section, has been proposed as a global stratotype for the boundary. In this paper we report preliminary paleomagnetic data which reveal eight reversals. The data yield a paleopole which is unlike any paleopoles obtained for younger Phanerozoic rocks from the South China block; this pole falls at 68.8°N, 270.7°E, and is based on 57 samples (Decl./Incl. = 4.2°/+7.1°, $k = 9$, $\alpha_{95} = 6.6°$). A comparison of our preliminary magnetostratigraphy with records obtained from Siberia, Australia and the western USA shows that all sections are characterized by frequent reversals, but that detailed correlations are not yet possible.

INTRODUCTION

The Precambrian-Cambrian boundary is associated with the first appearance of diverse shelly fossil assemblages and is thus a feature of primary importance in stratigraphy and earth history. It is the subject of study by the IUGS-IGCP Project 29 Working Group, in attempts to correlate the important Precambrian-Cambrian sections of the world, such as those in Siberia, Mongolia, Australia, Newfoundland, the western US and Canada, China and Morocco (Cowie, 1984).

In China, where the Late Precambrian comprises the Sinian system, an apparently complete and fossiliferous Sinian to Lower Cambrian section exists in Yunnan province. About 45 km south-southwest of Kunming, to the south of Dianchi Lake, the large Kunyang phosphorite mine in Jinning County exposes a complete sequence over a wide area (Fig. 1). This sequence is called the Meishucun section (pronounced May'shoo-

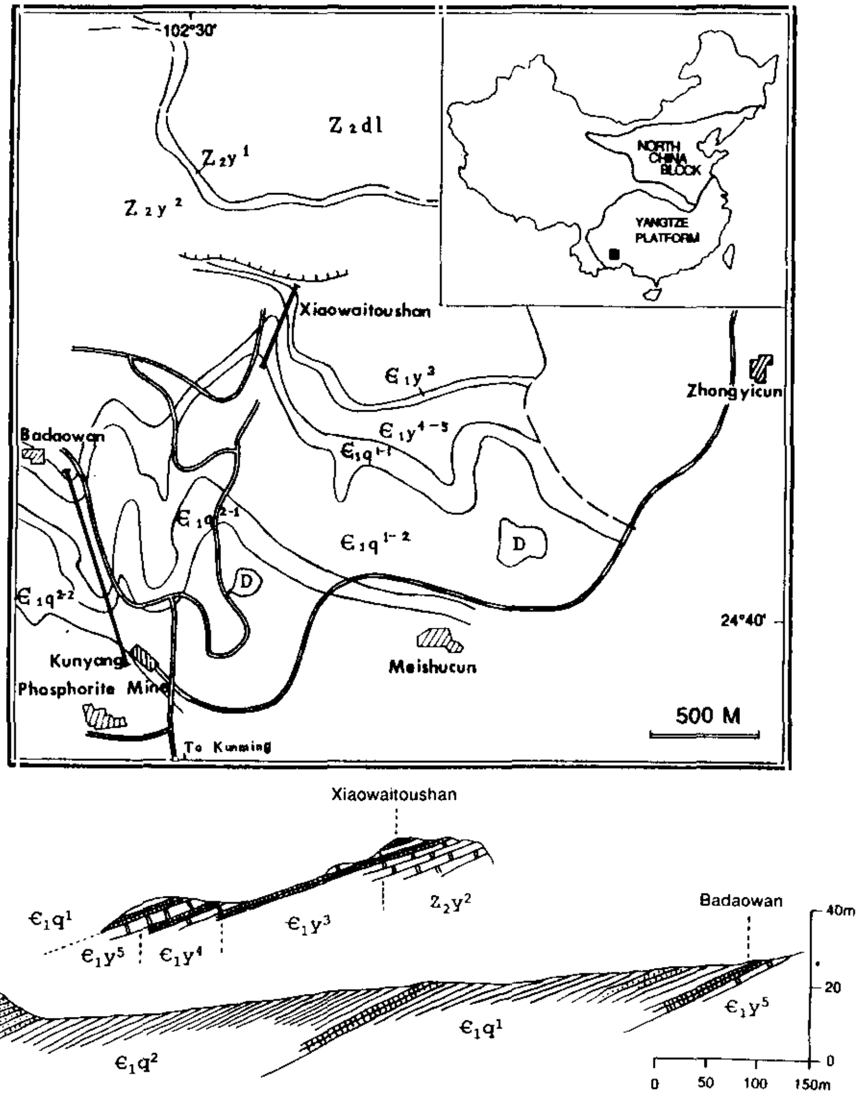

Fig. 1.—Geological sketch map of the Kunyang mine area (extending more or less over the whole map area) in Yunnan province, and schematic cross section of the sampled section (top diagram: lower Meishucun section, bottom: upper Meishucun section; only the lower section yielded paleomagnetic results). Note the vertical exaggeration of these cross-sections. The inset map provides the location in southwest China. The formation symbols are explained in the righthand column of Fig. 2. Figure adapted from Luo Huilin et al. (1984).

tsoon), and we have obtained preliminary but promising magnetostratigraphic data in a pilot study of the uppermost Sinian and lower Cambrian (Tommotian) formations.

The Meishucun section represents a national stratotype in China and has been proposed as a Chinese candidate for a global stratotype section that contains the Precambrian-Cambrian boundary (Xing Yusheng and Luo Huilin, 1984). Thus the importance of the Meishucun section lies in its significance for global stratigraphic correlation of the first order, even if it is eventually not selected as a global stratotype. A monograph has recently been publised (Luo Huilin et al., 1984) with chapters devoted to lithologic description, stratigraphic relationships, paleontology, isotopic ages, and regional to international correlations.

Despite this wealth of information now accumulated about the Meishucun section, the precise location of the Precambrian-Cambrian boundary is still a matter of some dispute. The classical stratigraphic subdivisions of the section (Fig. 2) placed the boundary at the base of the Xiaowaitoushan Member (ϵ1y3) of the Yuhucun Formation (position A in Fig. 2), but a second important fossil occurrence (position B) near the top of the Zhongyicun Member (ϵ1y4) of the Yuhucun Formation is currently preferred as marking the Precambrian-Cambrian boundary, on the basis of a vote by the members of the IUGS-IGCP Working Group # 29. The reasons for placing the boundary higher in the section are partly based on isotopic (Rb-Sr isochron) dating of the overlying black shales from the Badaowan Member (ϵ1q1) of the Cambrian Qiongzhusi Formation, which gave an age of 579.7 ± 8.2 Ma, in addition to previously reported ages of 587 ± 17, 584.7 ± 15.2 and 588 ± 13 Ma for similar strata in the area

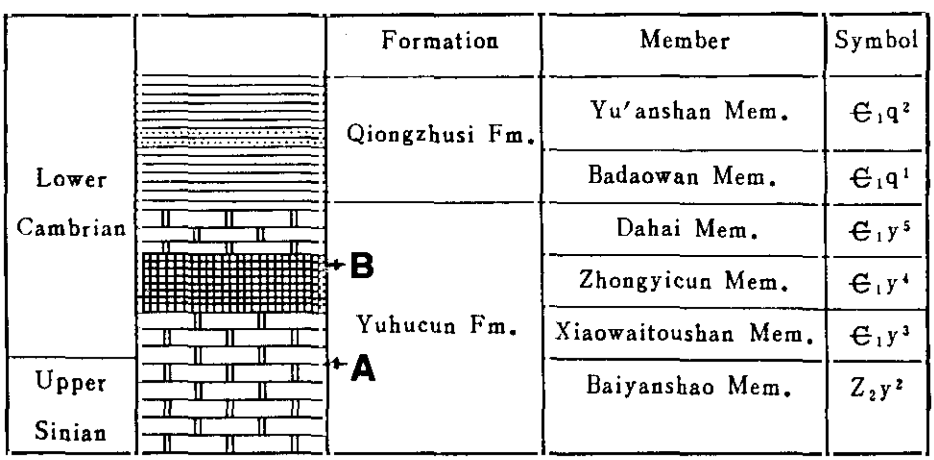

Fig. 2.—Late Precambrian (Sinian) to Cambrian stratigraphy of the Meishucun area (from Luo Huilin et al., 1984). Positions A and B are possible Precambrian-Cambrian boundary locations discussed in the text.

(Luo Huilin et al., 1984, p. 120-123). It is just above this Badaowan Member that the oldest trilobite in China (and perhaps the oldest in the world; Luo Huilin et al., 1984, p. 118) makes its appearance *(Parabadiella yunnanensis)*. However, the B position for the Precambrian-Cambrian boundary is underlain by the lower Meishucun section (Zhongyicun and Xiaowaitoushan members, ∈ ly3-4 in which several shelly fossil species are already abundant: this *Anabarites-Circotheca-Protohertzina* (A-C-P) Zone of diverse shelly fossils would then be Precambrian, a choice which is somewhat dependent on what is preferred as the definition of the Precambrian-Cambrian boundary.

The two choices for the boundary (A and B) now co-exist in the literature and the figures in Luo Huilin et al. (1984) use one or the other with little explanation of the underlying rationale; see for instance Fig. 3, which presents the monograph's attempt at international stratigraphic correlation of the Meishucun section with those from other countries. In this figure, the Precambrian-Cambrian boundary is placed at position A, below the A-C-P Zone.

Our preliminary paleomagnetic results from the Meishucun section suggest that it may be possible to establish an excellent reversal record for this section. This would be of the greatest importance for a choice of

Upper Sinian	Lower Cambrian					Series	
Dengyingxia'an	A B Meishucunian			Qiongzhusian		Stage	
	A.–C.–P.	P.–S.	S.–E.	P.	E.*	Shelly f.	Fossli Zone
	S. C.	D.	P.*			Trace f.	
Yuhucun Fm.			Qiongzhusi Fm.			China (Yunnan)	
Tsaganolom Fm.		Bayangol Fm.		Salanygol Fm.		Mongolia	
Yudoma Fm.		Pestrotsvet Fm. (Tommotian)		Fumuldur Fm. (Atdabanian)		Siberian Platform	U.S.S.R.
Valdai Group	Baltic Group			Liukati Horizon		E. European Platform	
Taliwinian (Lie de Vin)	Upper Limestones			Tioutian	Amouslekian	Morocco	
Charnian		Hartshill Fm.		Stokingford Fm.		U. K.	
Reed Dolomite	Deep Spring Fm.			Campito Fm.		U.S.A.	
	Grand Bank Fm.	Miguelon View Fm.	Random Fm.	Brigus Fm.		Neufoundland	Canada
Map Unit 10b	Map Unit 11	Map Units 12, 8, 13,		Sekwi Fm.		Machenzi	
Pound Quartzite	Uratanna Fm.	Parachilina Fm.		Ajiax Limestone		Australia	

Fig. 3.—International correlation of the Precambrian-Cambrian boundary section of various parts of the world (from Luo Huilin et al., 1984). Shelly fossil zones include: A.-C.-P., the *Annabarites-Circotheca-Protohertzina* zone; P.-S. the *Paragloborilus-Siphogonuchites* zone; S.-E., the *Sinosachites-Eonovitatus* zone; P., the *Parabadiella* (trilobite) zone; and E. the *Eoredlichia* zone. Trace fossil zones include: S., the *Sellaulichnus meishucunensis* zone; and P. the *Plagiogmus arcuatus* zone.

the global stratotype for the boundary and for international correlations of sections, because of the global synchroneity of reversals and the possibility to match «fingerprint»-type reversal records. From our preliminary data, it appears that reversals are frequent and irregularly spaced, a prerequisite for such correlation.

GEOLOGICAL SETTING AND PALEOMAGNETIC SAMPLING

Meishucun is located at 24.7N, 102.5E at the southwestern margin of the Yangtze Platform (S. China block). The Sinian-Cambrian sequence consists of platform dolomites and phosphorites in the Baiyanshao (Z2y2), Xiaowaitoushan (∈1y3), Zhongyicun (∈1y4), and Dahai (∈1y5) members of the Yuhucun Formation, and also in the lower part of the Badaowan (∈1q1) member of the Qiongzhusi Formation (Fig. 2). The overlying portion of the Qiongzhusi Formation consists of shales and silt- or sandstone. The strata dip gently to the south (about 15 degrees) and are unmetamorphosed.

The total thickness of the Yuhucun and Qiongzhusi formations is 332 m, of which 139 m was sampled for paleomagnetic study. Parts not sampled include the lowermost 177 m of the Yuhucun Formation and the uppermost 16 m of the Qiongzhusi Formation (in the Yuanshan Member, ∈1q2). A total of 159 individually oriented samples were collected from 112 horizons, using a portable gasoline-powered drill and a Brunton compass. Distances between the horizons generally were on the order of 0.4 m in the dolomites and phosphorites, while in the highly fissile shales of the Badaowan and Yuanshan members (∈1q1-2) of the Qiongzhusi Formation, distances between horizons ranged up to 18 m. We will call the sampled dolomite-phosphorite part of the Yuhucun Formation (32 m thick) the «lower Meishucun section»; this lower section yielded 106 samples. The remaining part of the section in the Qiongzhusi Formation (107 m thick) yielded only 53 samples because of the unfavorable lithologies.

PALEOMAGNETIC ANALYSIS

Samples were cut into 2.2 cm high specimens (2.5 cm diameter) in the laboratory and stored in a magnetically shielded room before and during demagnetization treatment (restfield less than 200 nT). Measurements were carried out on a ScT cryogenic magnetometer, and alternating field (AF) and thermal demagnetizations were performed with Schonstedt equipment. Components of magnetization were identified by visual inspection of orthogonal vector diagrams (Zijderveld, 1967), and their directions were determined by principal component analysis (Kirschvink, 1980). Natural Remanent Magnetization (NRM) intensities ranged from 0.1 to 1 mA/m for all rock types; 8 of the 159 samples had NRM intensities that were too low, and these have not been used. The NRM directions are tightly grouped around the present-day field direction (Fig. 4a), indicating that the rocks have generally been heavily overprinted in recent times.

Because in most cases AF demagnetization did not succeed in eliminating a significant part of the NRM (Fig. 5), thermal demagnetization was carried out on all samples with sufficient NRM intensities. Thermal demagnetization of many samples isolated only one component of magnetization (Fig. 6). The directions of those 94 samples which show only one component conform to the present-day field, indicating complete and recent remagnetization. Almost all of the 53 samples of the clastics in the upper section (Badaowan and Yuanshan members) show only this magnetization, called group A; we conclude that the lithologies of the upper section are not suitable for paleomagnetism and magnetostratigraphy, because they have not retained ancient magnetizations.

Many samples from the lower Meishucun section, however, reveal more than one component of magnetization. Although a large part of the total remanence in these samples is removed by 200-300°C with a direction conforming to that of the present-day field, the direction of the magnetization remaining above 300° is clearly different from the group A direction. In the samples of the top row in Fig. 7, the higher-temperature magnetization is northerly and shallowly upward (group B directions), whereas in the samples of the bottom row of Fig. 7 the direction is southerly and shallowly downwards (group C directions). There are 29 group

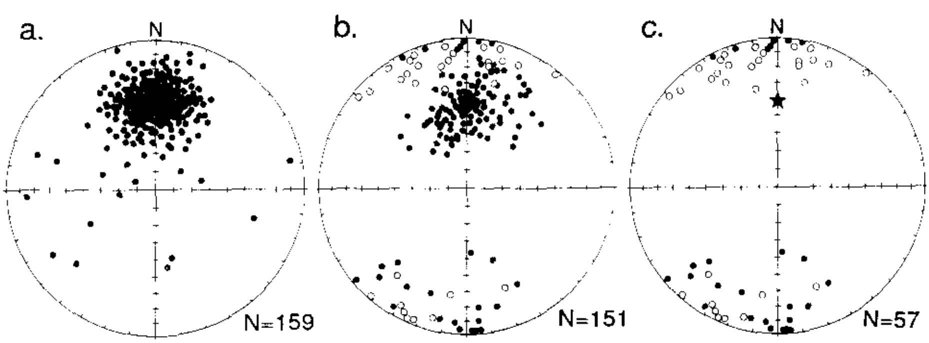

Fig. 4.—Equal-area projections of (a) the Natural Remanent Magnetization directions before demagnetization, (b) the characteristic directions of groups A, B, and C combined, and (c) the characteristic directions of groups B and C only (all without correction for the tilt of the strata). Full (open) symbols represent projections onto the lower (upper) hemisphere. The star (in c) represents the direction of the present-day geomagnetic field.

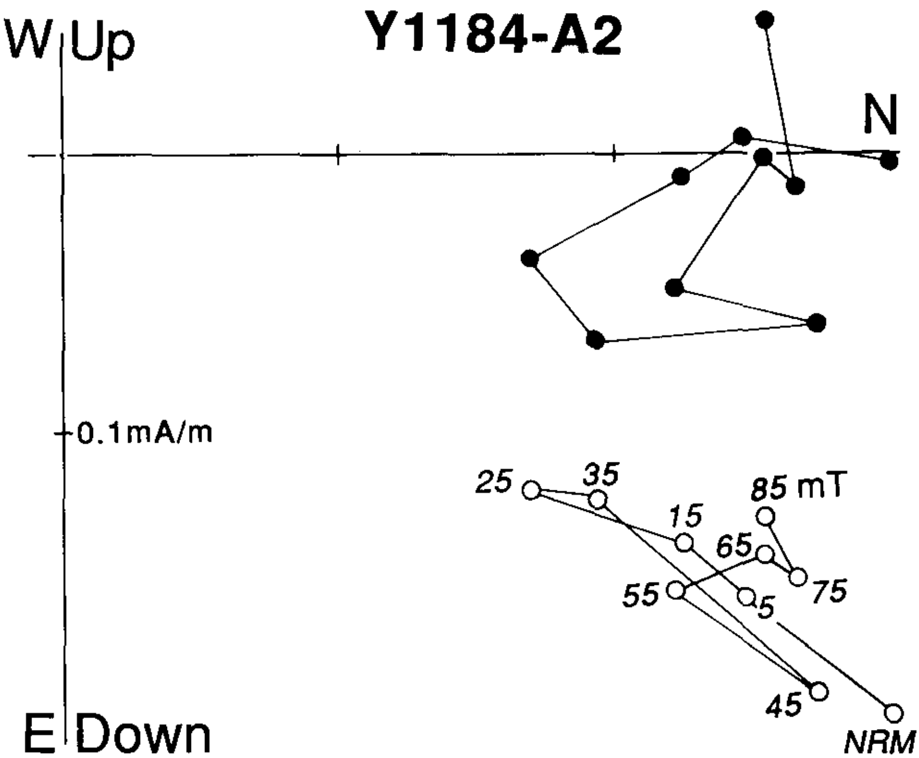

Fig. 5.—Orthogonal vector diagram (Zijderveld, 1967) of a sample treated with alternating fields, illustrating that this technique does not succeed in removing the remanence. Plotted points represent the in-situ endpoints of the magnetization vector measured after each treatment step (in mT); full (open) symbols are projections onto the horizontal (vertical) plane; intensity of remanence is indicated along the axes.

B directions and 28 group C directions in our collection (of the Group B directions 26 are in the lower Meishucun section and only 3 in the upper section; all group C directions are in the lower section).

In Fig. 4b all directions thus determined (groups A, B, and C) are shown, whereas in Figure 4c only the B and C directions are plotted. The group B and group C directions are antipodal and represent reversals of an ancient magnetic field. In a subsequent section we will discuss the polarity record that can be constructed from the B and C directions.

Because the intensity of the remanence above treatment of 300° becomes rather low (0.08 – 0.4 mA/m) the precision of the direction determination is frequently rather low also. In some samples it was not possible to determine the direction precisely, although a determination of polarity (group B versus group C direction) could be made without hesitation (Fig. 8). Such samples have been included in the polarity record, but they account for some of the scatter in Fig. 4c.

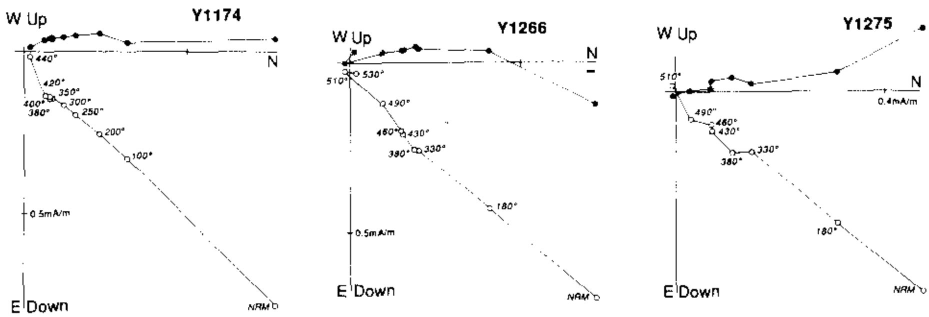

Fig. 6.—Orthogonal vector diagrams, with the same conventions as in Fig. 5, for three samples wich show only one component of magnetization; this direction of magnetization, called the group A direction, conforms to the present-day geomagnetic field.

Blocking temperatures fall between 200 and 500° for group B and C directions, so that magnetite could well be the carrier of the NRM. Fig. 9a shows the acquisition of Isothermal Remanent Magnetization (IRM) of five representative samples. After an initial rapid increase in magnetiza-

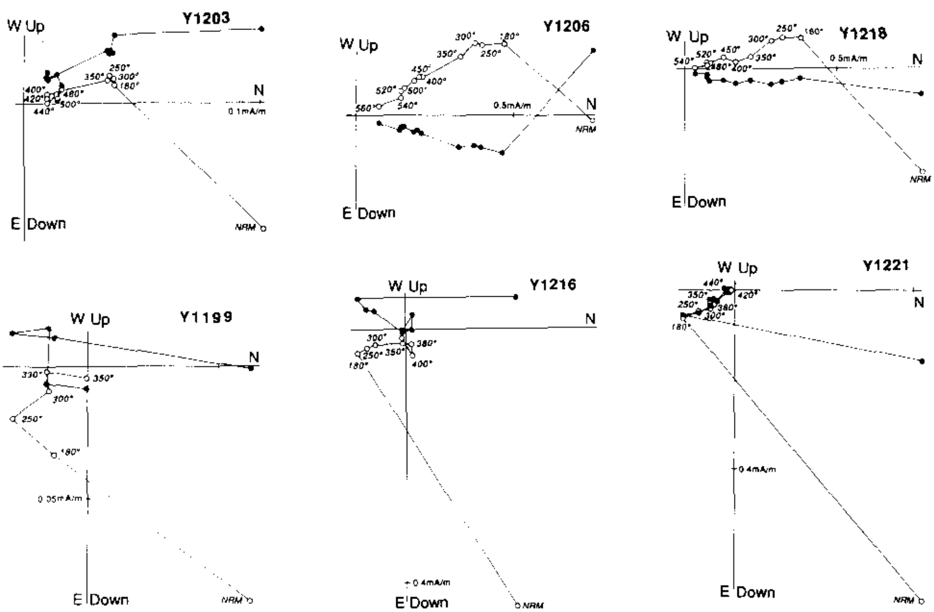

Fig. 7.—Orthogonal vector diagrams, with the same conventions as in Fig. 5, for six samples which show two components of magnetization. The top row shows three samples which contain group A and group B magnetizations, with group B directions being northerly and shallowly upward above temperatures of about 200°C. The botton row shows three samples with group A and group C directions, the latter being southerly and shallowly downward above temperatures of about 200°C. Groups B and C are the characteristic directions for the Meishucun section and are antipodal to each other.

tion acquired below 50 mT, the samples continue to increase their remanence up to fields of 1 T, indicating that a higher-coercivity phase is present, in addition to possibly magnetite. A thermo-magnetic analysis of a powdered dolomite specimen, performed with a horizontal Curie balance, is shown in Fig. 9b. Two Curie temperatures are revealed, on characteristic for magnetite at about 570°C and another with a Curie temperature of 680° characteristic of hematite.

DISCUSSION AND PALEOPOLE POSITION

Almost all of the samples studied contain the group A direction as an overprint and many samples contained only this direction, interpreted as a recent remagnetization. Other collections from China have also yielded such widespread remagnetizations (e.g., Kent et al., 1987). However, a large proportion of the samples from the lower section (54 out of 106 samples) also revealed a significantly different magnetization.

Although we have obtained a dual polarity magnetization representative of an ancient magnetic field (since the group B and C directions are clearly different from the present-day field and the group A overprints), we can not be a priori certain that this magnetization is primary and of

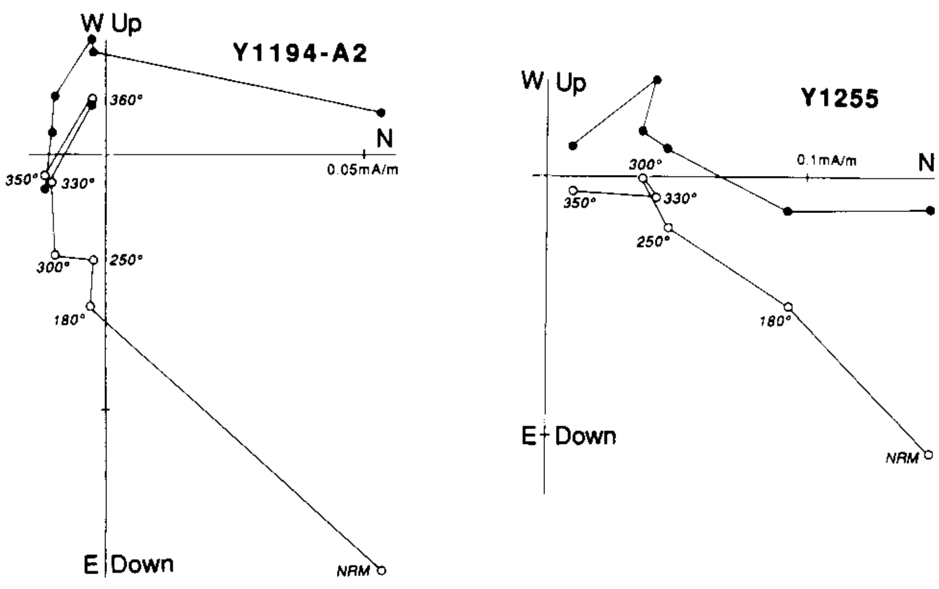

Fig. 8.—Orthogonal vector diagrams, with the same conventions as in Fig. 5, for two samples which show a group B or group C direction (as in Fig. 7), so that the polarity of magnetization can be determined. However, the directions of these samples are less well defined because of the large variations above temperatures of about 300°C.

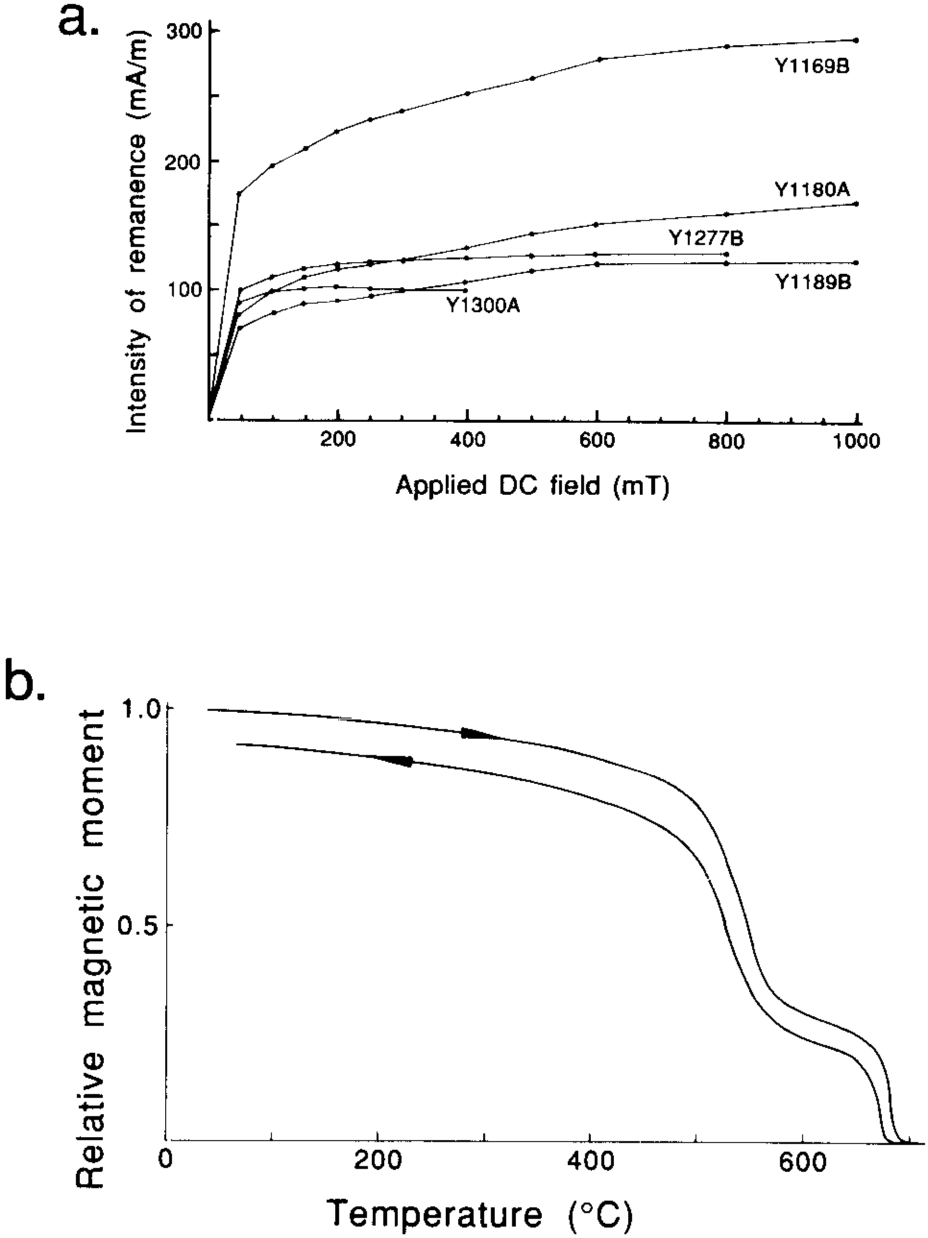

Fig. 9a.—Acquisition of Isothermal Remanent Magnetization of representative Meishucun section samples, indicating a lower coercivity mineral (magnetite) as well as higher coercivity mineral such as hematite.
Fig. 9b.—Thermomagnetic analysis of a powdered dolomite sample, showing Curie temperatures at about 570 and 680°C, indicating the co-existence of magnetite and hematite.

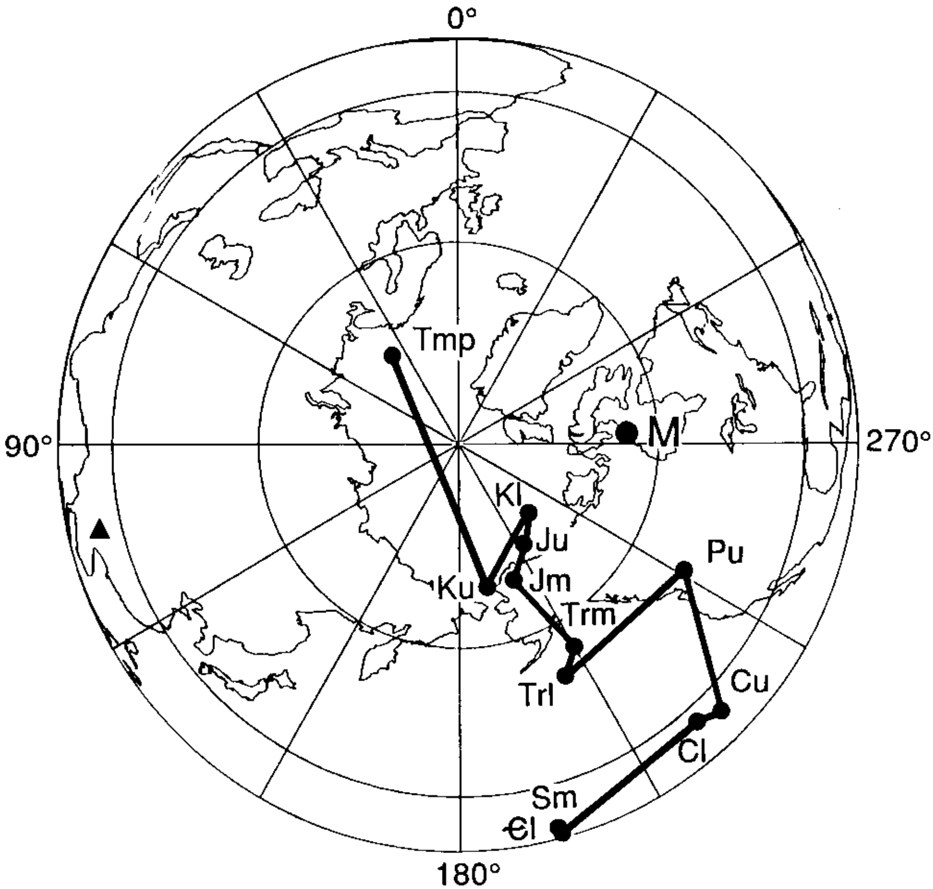

Fig. 10.—Paleopole positions from the Yangtze Platform (South China block). All poles are from Lin et al. (1985), except where indicated otherwise: Tmp, middle to Late Tertiary, Ku, Late Cretaceous, Kl, Early Cretaceous, Ju, Late Jurassic, Jm, Middle Jurassic, Trm, Middle Triassic, Trl, Early Triassic, Pu, Late Permian (Zhao and Coe, 1987), Cu, Late Carboniferous, Cl, Early Carboniferous, Sm, Middle Silurian (Opdyke et al., 1987), ∈l, Early Cambrian, M, pole from this study.

Late Precambrian to Cambrian age. Unfortunately, fold, conglomerate or baked contact tests are not possible with the local geological setting; moreover, folding took place during the Tertiary so that the foldtest would not help much in constraining the age of magnetization. Table 1 lists mean directions in in-situ and tilt-corrected coordinates.

Two considerations, however, may be helpful in determining the age of magnetization. The first involves the direction and its paleopole position in comparison with the Phanerozoic apparent polar wander path. If the B plus C paleopole were to resemble poles determined for younger periods, a strong suspicion of remagnetization would exist. The second consideration, not yet possible with our reconnaissance collection, examines whether the reversals are layer-parallel: in sampling parallel sections, one can determine whether the same reversal record exists and if so, this would strengthen the argument that the magnetization is acquired during the time of deposition.

The paleopole determined from the combined group B and C directions (Table 1) is located at 68.8°N, 270.7°E and is plotted in Fig. 10 together with the Phanerozoic paleopoles available for the South China block. It appears that the paleopole from this study is different from any Phanerozoic paleopoles published thus far (McElhinny et al., 1981; Chan et al., 1984; Lin et al., 1985; Chun et al., 1986; Kainian et al., 1986; Opdyke et al., 1986, 1987; Zhao and Coe, 1987). Our paleopole is also quite different from the Early Cambrian pole (Lin et al., 1985) derived from rocks in Zhejiang and Hubei provinces, which falls at 3.4°N, 195.0°E. It is possible that age differences between our section and those of Lin and co-workers during a time of apparent polar wander can account for the difference in pole location; the alternative of a relative rotation of 80 degrees between the two areas appears to be much less likely, given the platform setting of the sequences. The results of Lin et al. (1985) for the Early Cambrian are not published in detail, so it is impossible to evaluate their results. We note, however, that the pole of Lin and colleagues falls very close to the Silurian pole for the South China block (Opdyke et al., 1987) and that a Silurian remagnetization can not be precluded.

MAGNETIC POLARITIES

If we assume that the magnetizations of groups B and C are primary, a preliminary magnetic polarity record can be constructed for the lower

TABLE 1. Group means of characteristic magnetization

Group	N	K	α_{95}	in-situ		bedding-corrected	
				Decl./Incl.	paleopole	Decl./Incl.	paleopole
A	94	138	3.3	1.4/+45.6	87.1N, 134.0E	356.0/+58.2	75.1N, 90.1E
B	29	12	7.9	355.6/– 9.0	60.8N, 291.3E	356.0/+ 7.0	68.8N, 293.4E
C	28	9	9.6	192.8/+ 8.7	58.6N, 257.2E	193.0/– 7.3	65.8N, 249.1E
B+C*	57	9	6.6	4.0/– 9.1	60.8N, 274.1E	4.2/+ 7.1	68.8N, 270.7E

N is the number of samples used to calculate the means; Decl./Incl. are declination and inclination (in degrees); K and α_{95} are the statistical parameters associated with the means; *group C directions have been inverted to calculate the overall mean.

Meishucun section (Fig. 11). In this figure we can compare the sample numbers and position, the identification of group A, B or C directions, the Virtual Geomagnetic Pole (VGP) latitudes (Lowrie et al., 1980) constructed from group B and C directions, and a magnetic polarity zonation with the lithologies and members of the formations. Also included is the very preliminary magnetostratigraphy obtained by Liang and co-workers (in Luo Huilin et al., 1984), who obtained many fewer group C directions because of the low intensity of their samples measured with a spinner magnetometer and possibly because of less detailed demagnetization.

In the column we have treated the group B directions as normal polarity (black) and the group C directions as reversed. This is at this time a relatively arbitrary decision, because there is no independent evidence to determine whether a paleopole in this study is a northpole or a southpole. It may eventually turn out that the polarity designation used here needs to be switched, but such a reinterpretation would not diminish the stratigraphic value of the reversal record we have begun to document.

On the basis of our directions, there are at least eight reversed zones in the lower Meishucun section. We note that the three reversed zones determined by Liang and co-workers have all been confirmed by our study. In the lowermost part of our section, our sampling density is lower, and it may well be possible that several other polarity zones have yet to be discovered. What is remarkable is that after a period of predominantly reversed (?) polarity in the Xiaowaitoushan and lower Zhongyicun members, there is a period with very frequent reversals in the upper Zhongyicun and Dahai members. The A position for the Precambrian-Cambrian boundary would fall below the predominantly reversed part of the section, whereas the B position would be in the middle of the zone with frequent reversals.

It is worth stressing at this point that our magnetic polarity construction is preliminary and in need of corroboration. Even so, it is tempting to compare this record with records published for other parts of the world (Fig. 12). The Amadeus Basin in Australia (Kirschvink, 1978) has yielded a reversal stratigraphy with predominantly normal polarities in the Late Precambrian, followed by a mixed interval in which the Precambrian-Cambrian boundary is placed. These Australian results pass a foldtest and are thought to be primary on the basis of paleopole location. The Lena River section in Siberia (Kirschvink and Rozanov, 1984) is mostly Tommotian-Atdabanian in age and does not include the Precambrian-Cambrian boundary; this section also contains frequent reversals. The Meishucun, Siberian and Australian polarity zonations are not readily compared to each other, and the Amadeus Basin and the Lena River sections have been interpreted to be of different age (Kirschvink and Rozanov, 1984). Results from Mongolia (Kirschvink et al., 1987) are unpublished at this time, but are also thought to be younger than the Precambrian-

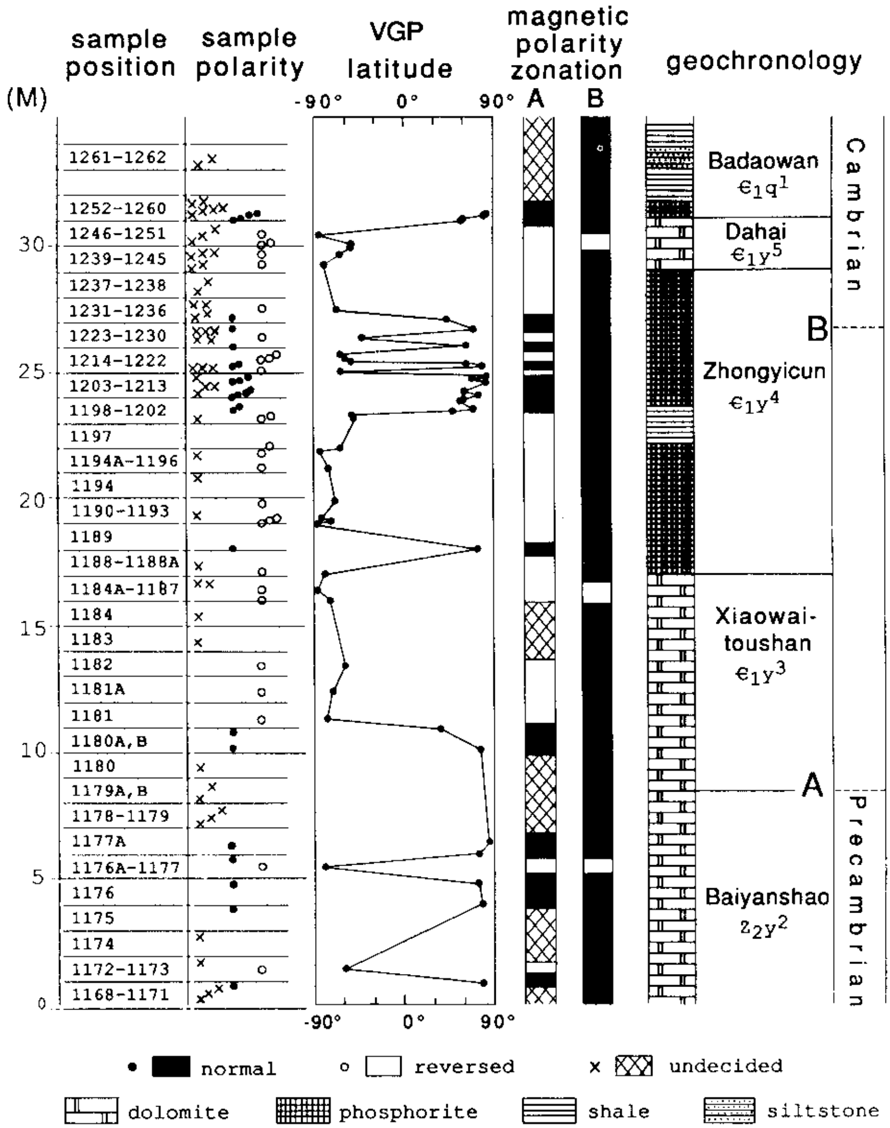

Fig. 11.—Magnetic polarity zonation derived from the characteristic group B and C directions of this study, for the lower Meishucun section. Formation names and positions A and B for the Precambrian-Cambrian boundary are from Luo Huilin et al. (1984) and conform to those in Fig. 2. Stratigraphic position (in m) is indicated on the left, followed by a column with our sample numbers; the sample polarity column contains symbols for group A directions (crosses, not used), group B directions (dots) and group C directions (open circle); the Virtual Geomagnetic Pole (VGP) latitude is plotted according to the method of Lowrie et al. (1980). The Column A magnetic polarity zonation is from this study, whereas column B is based on the very preliminary results of Liang et al. (1984).

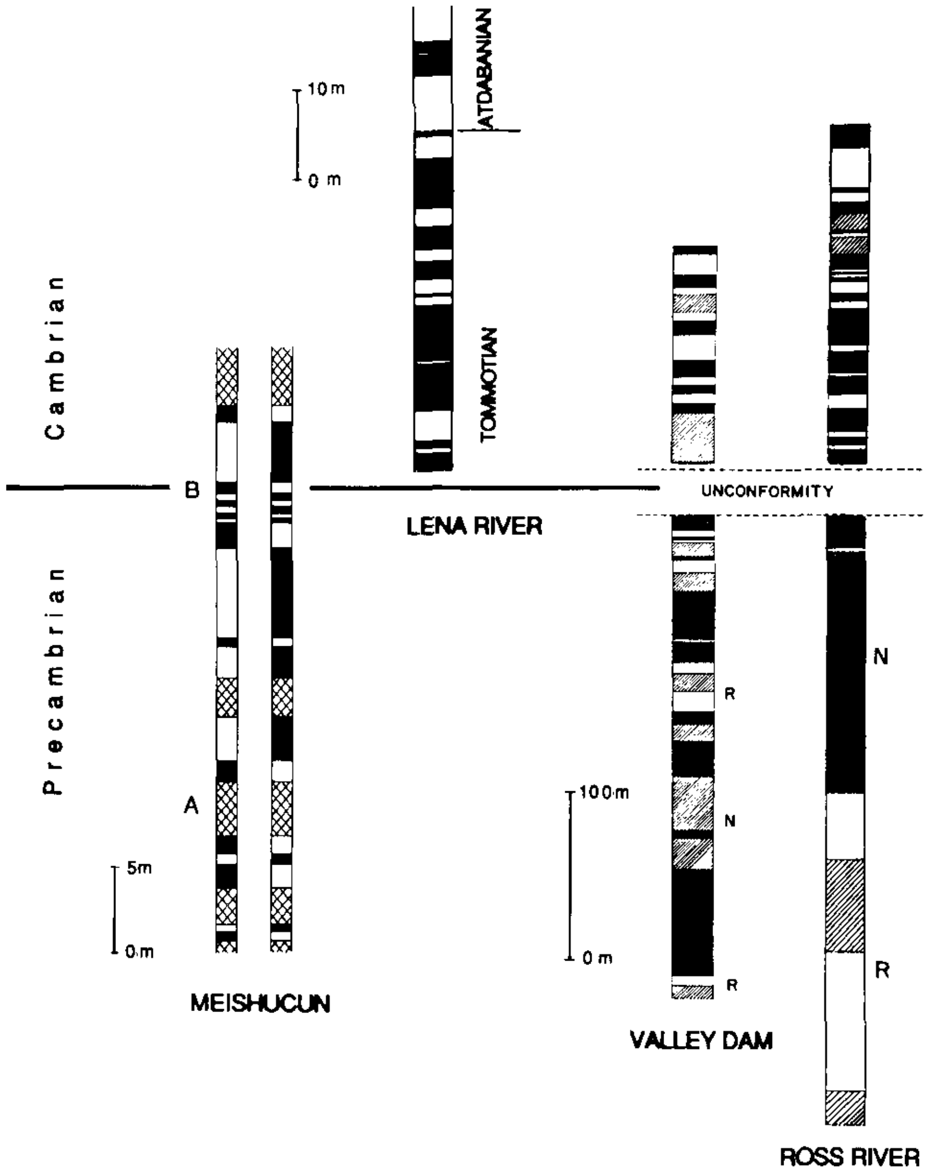

Fig. 12.—Magnetostratigraphic zonations from Meishucun (two polarity options shown, given that we do not know which is reversed and what is normal), from the Lena River section in Siberia, and from two sections, Valley Dam and Ross River, in Australia (Kirschvink, 1978 and Kirschvink and Rozanov, 1984). It appears that at this time it is not possible to make any correlations between these sections, indicating the need for further work.

Cambrian boundary. The possible presence of disconformities and hiatuses in the Amadeus Basin further complicates a successful comparison.

Extensive magnetostratigraphic work has been carried out on Late Precambrian and Lower to Middle Cambrian sections in the Desert Range of Nevada (Gillett and Van Alstine, 1979; Van Alstine and Gillett, 1979). However, the Cambrian results are all reversed and resemble results from younger rocks: it is likely that later Paleozoic remagnetizations have affected these rocks. The Late Precambrian Johnnie Formation, on the other hand, yields a typical latest Precambrian paleopole (10°S, 162°E) and includes frequent reversals.

The Johnnie Formation is likely to be older than the Siberian, Australian and Meishucun sections, so that magnetostratigraphic comparison is not possible.

FUTURE WORK AND CONCLUSIONS

We intend to resample the section and several parallel sections in the Kunyang mine in the near future, concentrating on the lower Meishucun section, in order to establish a reliable magnetostratigraphy.

It is possible, although we do not believe that it is likely, that the group B and C magnetizations reported on above are not primary. However, we believe that if we obtain a reversal stratigraphy that shows correlations between parallel sections, we may be reasonably assured that the magnetization (being layer-parallel) was acquired at the time of deposition or shortly thereafter. While we have in previous studies encountered dual-polarity remagnetizations, we have never observed these to be layer-parallel.

In conclusion, we have obtained a paleopole (at 68.8°N, 270.7°E) unlike any Phanerozoic paleopoles thus far obtained for younger rocks from the South China block. In the lower Meishucun section, eight reversals have been determined and the dual-polarity directions are antipodal within the limits of error. Wherever they have been studied, the Precambrian-Cambrian boundary sections have yielded frequent reversals and this study is no exception. However, a detailed correlation between the Siberian, Australian, western USA and Chinese sections is not yet possible at this time.

Acknowledgements

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