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PALEOMAGNETIC RESULTS FROM THE TRIASSIC OF THE YANGTZE PLATFORM

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Abstract. Two widely separated localities have been sampled from Triassic Formations of the Yangtze platforms. The first is from the border area between Sichuan and Guizhou provinces, where the Early Triassic Yelang Formation was sampled at 15 sites, located on both flanks of an anticline. Characteristic high-temperature components were isolated from nine sites, the remainder were severely overprinted by a recent field. Two polarities are present, one directed toward the northeast with shallow positive inclinations, and the other to the southwest with almost horizontal inclinations. The northeast group passes the fold test at the 95% level. The second area of study was from the city of Nanjing, Jiangsu Province, where 19 sites were drilled from three formations ranging in age from the lower to upper Triassic. The samples are severely overprinted with a component that is almost vertical and whose origin is unclear. However, in 23 of the samples, a high-temperature component was isolated directed to the northeast and positive and to the southwest and negative. The fold test is indeterminate. The pole positions from the two localities are Sichuan 46.3°N, 219.2°E, $\alpha95 = 10.9°$; Nanjing 44.8°N, 223.6°E, $\alpha95 = 9.3°$, which are not significantly different from each other and fall near two other recent studies of Triassic rocks from the Yangtze block. The pole positions given above are significantly different from the Triassic of Europe, Siberia, the North China block, and Thailand, indicating that these different components of eastern Asia were not sutured together in their present configuration until after the Triassic.

Introduction

It has become apparent in the last few years that southeast Asia consists of a collage of small plates that have been sutured onto Eurasia at various times in the past. McElhinny et al. (1981) divide southeast Asia into at least six plates; there are undoubtedly more. The region appears to be a tectonic collage consisting of continental fragments, some of which are of large size, which came together to form Eurasia. The most prominent of these are now known as the Sino-Korea platform, the Yangtze platform, and the most recent addition, the Indian subcontinent.

One of the most important means of studying the tectonic history of these paleoplates is through the determination of paleomagnetic pole positions through time. Such studies yield information on paleolatitudes of the different blocks and provide important constraints concerning the times of accretion of the different blocks (Irving, 1979).

Recent tectonic synthesis in the region has lead to widely differing interpretations of the geological history of the region. Klimetz (1983) believes that the South China block accreted to Eurasia in post-Triassic times, while Zhang et al. (1984) and Mattauer et al. (1985) believe that the North and South China blocks were joined in the Devonian or earlier times. These hypotheses may be tested paleomagnetically, and we attempt to do this in the study reported here.

Triassic formations from two widely separated localities on the Yangtze platform (Figure 1) were sampled during the summer of 1983 as part of a cooperative program between the Institute of Geology of Academia Sinica and the Department of Geology of the University of Florida, and Lamont-Doherty Geological Observatory (LDGO) of Columbia University.

Sichuan and Guizhou Provinces

The first sampling area to be described is located in the border area between Qijiang County, Sichuan Province, and Tongzi County, Guizhou Province. Samples were collected from the Lower Triassic Yelang Formation on both limbs of an anticline whose axis runs NNE-SSW. Cambrian and Ordovician rocks constitute the core of the anticline while, the limbs consist of Silurian, Permian, and Triassic sedimentary rocks. The folding is believed to have taken place at the end of the Cretaceous or at the beginning of the Cenozoic. Beds on the northwest limb dip at angles from 25° to 40° to the NW, while on the southeast limb, the beds are more steeply inclined at angles up to 72° to the SE.

The Yelang Formation, 429 m in thickness, conformably overlies Permian limestones on the southeast limb and is divided from bottom to top into five members. Member 1 is composed of

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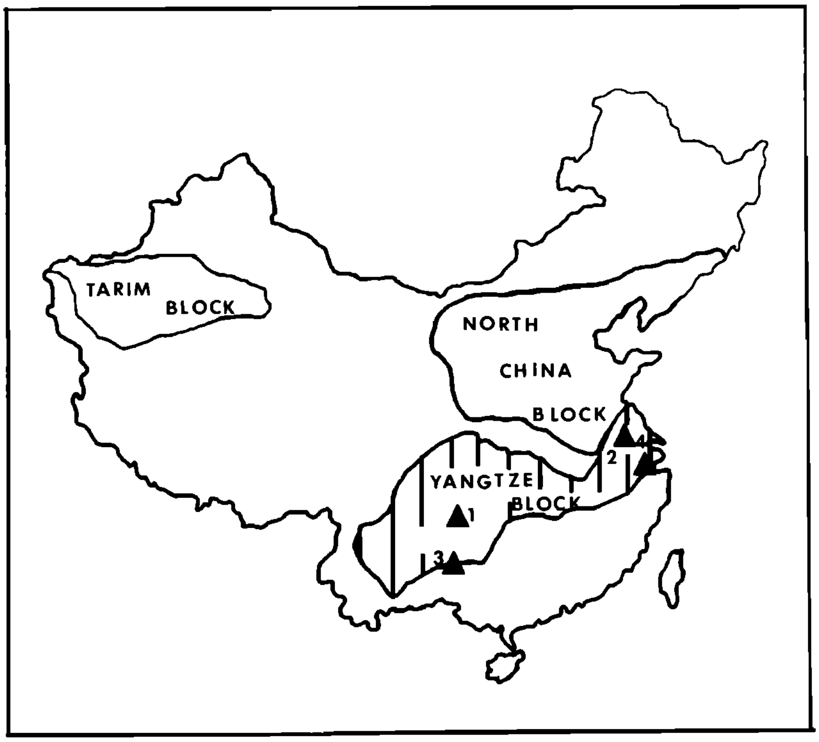

Fig. 1. The triangles indicate localities where Triassic rock formations were studied by the present authors and other workers. 1, Tongzi, North Guizhou; 2, Nanjing, Jiangsu; 3, Guiyang, Guizhou; and 4, Changxing, Zhejiang.

yellowish shales interbedded with gray-yellowish thin-layered argillaceous limestones. Member 2 consists of gray and pale gray argillaceous-laminated limestones. Member 3 is dominantly purplish red calcareous and silty mudstones and siltstones with some interbeds and lenses of argillaceous limestones. Member 4 consists of gray and pale gray argillaceous-laminated limestones, bioclastic limestones, and oolitic limestones. Member 5 is composed of purplish red calcareous mudstones with intercalated argillaceous limestones. Conformably overlying these units are the Lower Triassic Maocaopu Formation and the Middle Triassic Songzikan Formation, both consisting mainly of dolomites and limestones deposited in a marine environment, which are in turn, disconformably overlain by Upper Triassic quartzose sandstones, shales, and siltstones with coal seams (Xujiahe Formation).

The Lower Triassic sediments vary lithologically on a regional basis, from west to east, changing from a proximal clastic facies (Feixiaguan Formation) through a mixed facies of clastics and carbonates (Yelang Formation) to a carbonate marine facies (Daye Formation) (Yang Zunyi et al., 1982). The sampling area is in the transitional facies zone of mixed clastics and limestone. For this reason the Yelang Formation at the northwest limb is thicker and with more clastic beds. Most of our samples are red mudstones or siltstones, with a few limestones. According to regional geological survey data, the pelecypod fossils in the Yelang Formation in the sampling area can be divided into four assemblages, i.e., from bottom to top, *Claraia wangi*, *C. griesbachi*, *C. aurita - C. stachei*, and *Eumorphotis multiformis*.

Paleomagnetic Results

Fifteen sites were sampled in the field using a hand held gasoline powered drill. Five to seven samples 2.5 cm in diameter and up to 6 cm long were drilled at each sampling site, which usually consisted of a competent siltstone bed 0.25 to 0.50 m in thickness. Sampling was carried out in road cuts or streambeds in an attempt to avoid weathered material. The samples were oriented in situ using a commercially available orienting device and a Brunton compass. The samples were returned to the United States where they were sliced into cylinders 2.5 cm in length.

The samples were then measured on a Schonstedt spinner magnetometer or an SCT cyrogenic magnetometer at the paleomagnetic laboratory at the University of Florida. The natural remanet magnetization (NRM) directions (Figure 2) are dominated by a component in the present direction of the earth's magnetic field.

Pilot thermal demagnetization curves were run on one sample from each site at temperature intervals of NRM, 100°, 200°, 300°, 400°, 450°, 500°, 550°, 600°, 625°, 650°, 660°, 670°, and 680°C. Figure 3 illustrates the results from four sites, two of which are from the northwest limb of the anticline, (Figures 3a and 3c) and two from the southwest limb (Figures 3b and 3d). Almost all samples have low-temperature components in the present direction of the earth's field. However, at temperatures above

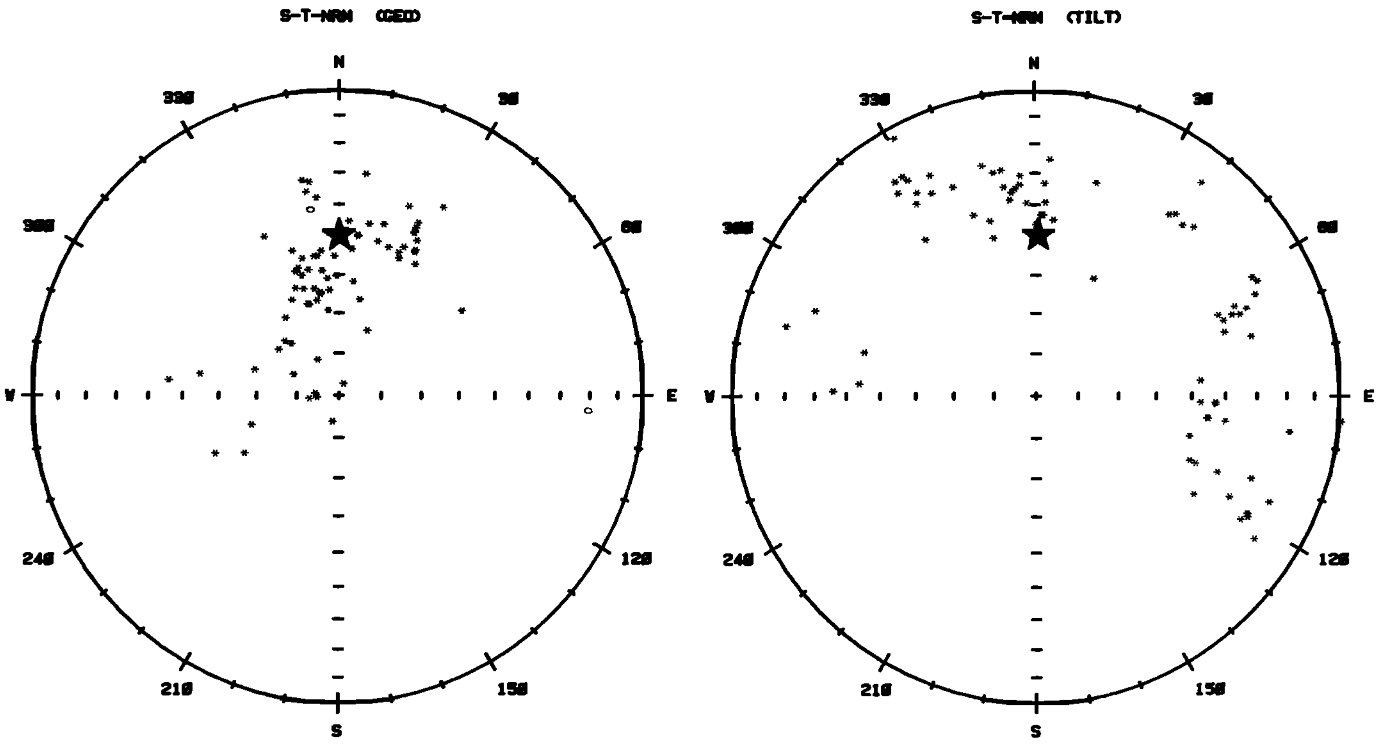

Fig. 2. NRM directions of samples from Tongzi County, Guizhou, before (left) and after (right) correction for bedding tilt. Large star represents the axial geocentric dipole field at the locality. Small stars represent direction in the lower hemisphere; open symbols, upper hemisphere.

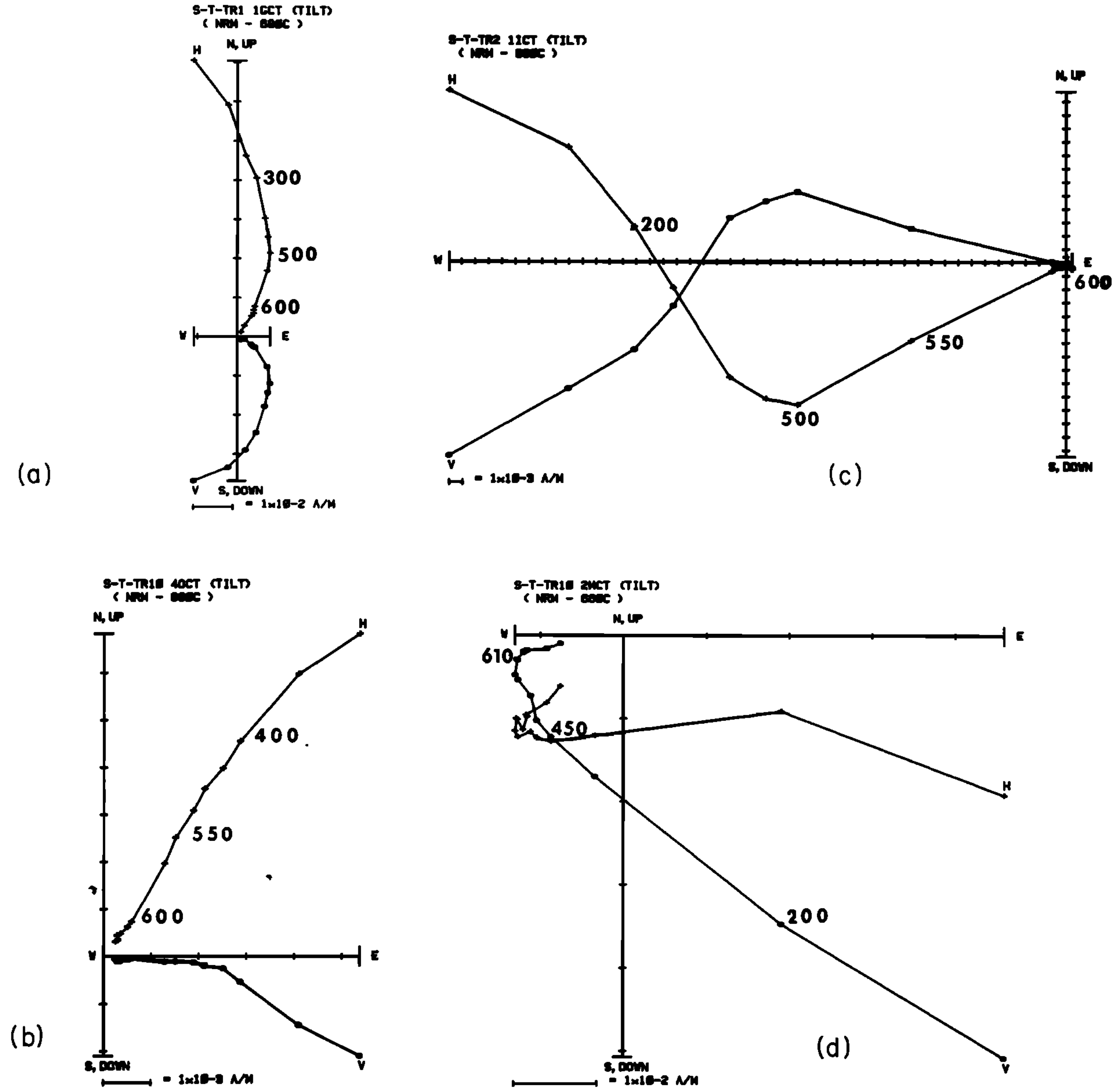

Fig. 3. Orthogonal plots of four samples from both limbs of the syncline in Tongzi County, Guizhou, corrected for bedding tilt.

500° to 600°C (e.g., Figure 4c) a component is resolved that is clearly not in the present direction of the earth's magnetic field. All the vector diagrams have been corrected for tilt, so as to more easily compare results from both sides of the anticline. It can be seen in Figures 3a and 3b that a component directed to the northeast with a shallow positive inclination is resolved from both limbs of the anticline at temperatures exceeding 600°C.

The samples shown in Figures 3c and 3d show different behavior. In one case (Figure 3c) it can be seen that two components of magnetization are present. One is directed to the west-northwest with a shallow positive inclination at blocking temperatures between 100° and 300°C. A second component is resolved between 500° and 600°C that is directed to the southwest with a negative inclination. At temperatures above 625°C, the sample is effectively demagnetized. Figure 3d, on the other hand, has a large low-temperature (NRM to 600°C) component that is directed initially in the direction of the present field. However, at high unblocking temperatures between 610° and 660°C, a characteristic component is resolved that is directed to the southwest with a shallow negative inclination.

The behavior illustrated in Figure 3 is common to 10 of the 15 sites studied. In the orthogonal plots given above, it is difficult to observe the high temperature part of the blocking temperature spectrum. Therefore in Figure 4, orthogonal plots are shown for temperature intervals above 400°C, so that the high-temperature part of the spectrum can be seen.

Figure 5 illustrates the behavior of the remaining sites to progressive thermal

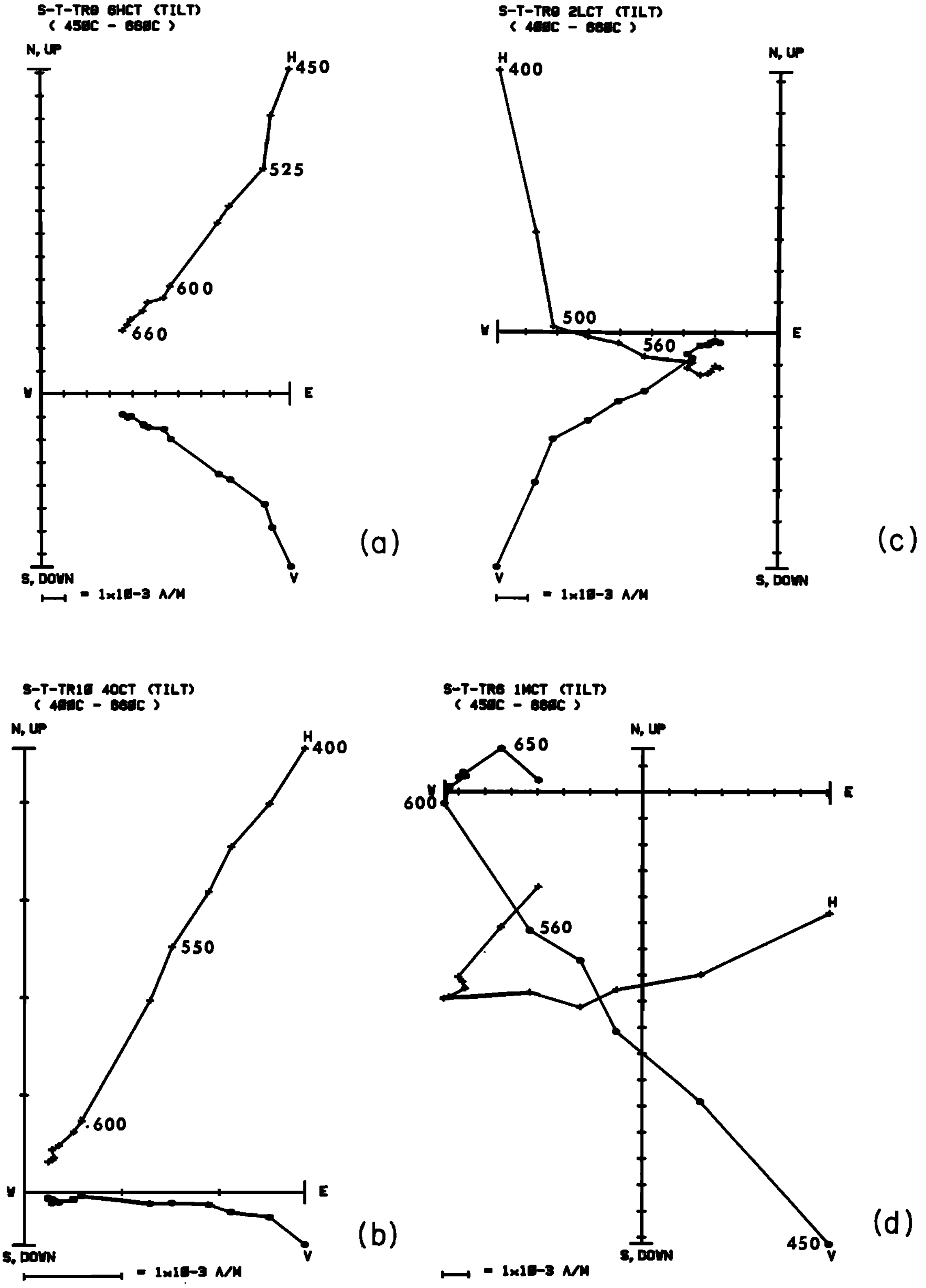

Fig. 4. Orthogonal plots of the high temperature components of samples from both limbs of the syncline, corrected for bedding tilt. Figures 5a and 5b are from the same samples as figures 4a and 4b.

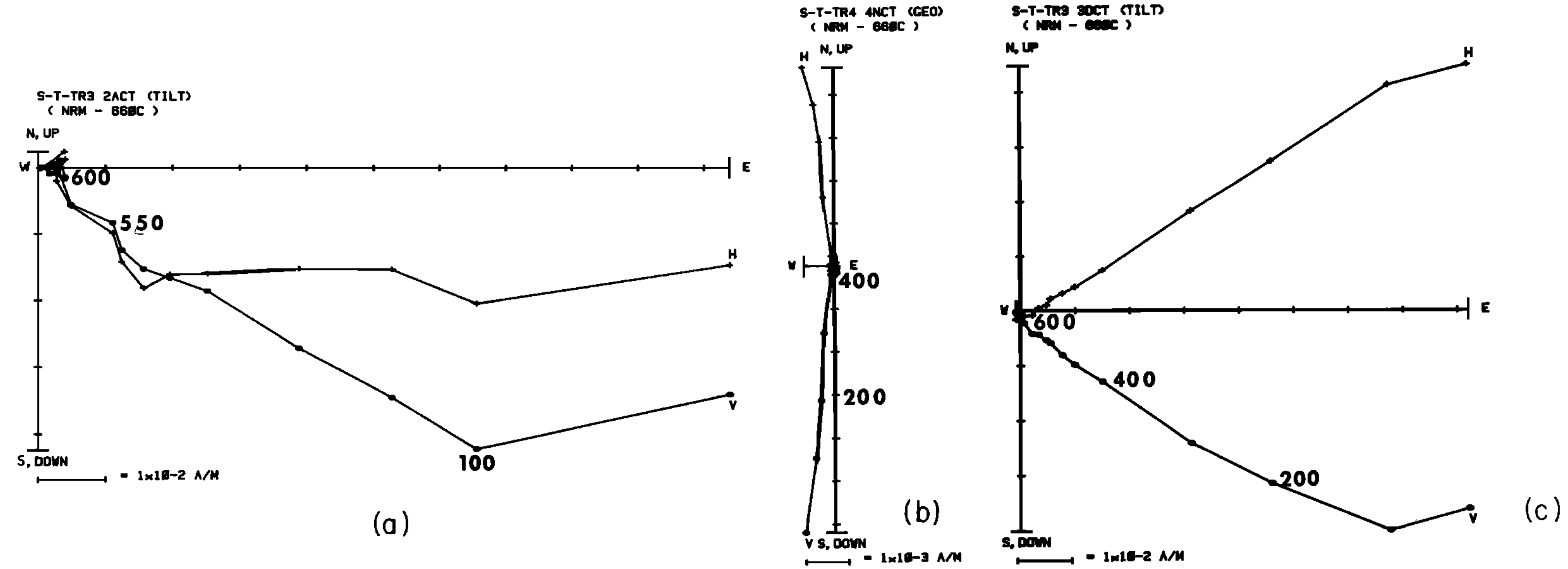

Fig. 5. Examples of orthogonal plots of progressive thermal demagnetization of samples from three sites in a Guizhou Province from which it was not possible to isolate a high-temperature component.

TABLE 1. Triassic Site Statistics From Tongzi, North Guizhou (28.58°N, 106.85°E)

									Pole Position	
Site	N	D	I	Dc	Ic	α95	K	Temperature Range, °C	Latitude	Longitude
A*	5	71.1	70.2	102.8	3.8	21.7	13.5	600-660	-10.3	188.9
B*	5	90.6	73.5	109.7	3.1	31.8	6.7	600-660	-16.5	185.7
C	5	214.0	-3.6	215.1	1.9	4.7	271.2	600-660	-45.3	52.1
D*	5	228.8	18.6	186.5	29.8	27.8	8.5	610-670	-45.1	98.0
E*	4	235.1	7.7	203.0	38.4	8.8	109.0	600-660	-35.1	80.5
F*	5	9.2	54.5	349.8	37.2	48.1	3.5	610-660	77.9	339.0
G	5	42.0	15.9	32.8	18.4	6.6	135.8	600-660	53.8	222.2
H	6	60.4	5.4	56.6	17.0	15.4	20.0	600-660	33.4	205.6
I	5	229.6	1.6	229.3	-2.7	21.1	14.2	525-600	-35.8	37.9
J	4	40.2	28.5	24.6	28.7	8.5	116.7	525-600	63.7	222.0
K	5	41.6	15.5	35.2	32.3	9.3	68.8	600-660	56.0	208.0
L	7	224.9	2.2	225.6	-0.2	10.2	35.8	600-660	-38.0	41.8
M	5	220.5	-9.8	223.5	4.7	6.3	147.6	600-660	-38.1	46.0
O	5	354.8	28.3	35.0	24.0	12.9	36.3	600-660	53.7	215.8
FM	9	40.8	11.9	40.0	13.1	11.0	23.1		46.3	219.2

*Not involved in the calculation of the formation mean (FM).

demagnetization. In Figure 5a the behavior of two of the remaining sites reveals that there are several components present, generally directed toward the southeast. One site has blocking temperatures ranging from 100°to 500°C and a second with steeper inclinations from 500° to 625°C. It was not possible to resolve any component with a blocking temperature above 600°C. The low-temperature component at these two sites is enigmatic, since it appears in no other sites. These components, before tilt correction, are westerly with steep inclinations and therefore are not in the present direction of the dipole field.

The sample from the site shown in Figure 5b, on the other hand, reveals that a low blocking temperature component is present in these reddish limestones that is clearly an overprint resulting from the present magnetic field. No component is resolvable at blocking temperatures above 500°C. Figure 5c shows a thermal demagnetization curve that is common to several sites. The samples from these sites all yield vectors that swing into the southwest quadrant and clearly possess a high temperature component that is similar to that illustrated in Figure 4d. However, in these samples, this component is never fully resolved, and the three sites whose samples are characterized by this behavior were rejected.

The thermal demagnetization results were divided into low temperature and high-temperature components, which were analyzed using the principal component techniques of Kirschvink (1980). The values obtained from this analysis were combined in site mean directions using Fisher (1953) statistics. The resulting site statistics are presented in Table 1.

Figure 6 shows that the low temperature components from these samples, in general, fall close to the present dipole field direction before correcting for tilt. Upon applying a tilt correction, the group splits into two parts, a clear indication that this component was acquired after folding.

The mean directions for the high temperature components for the sites that possess northeast and down and southwest and shallow directions are illustrated in Figure 7. It is unfortunate that the shallow characteristic direction of magnetization lies close to fold axis, which makes the application of the fold test difficult (Graham, 1949). However, one of the sites in the northeast group is affected enough by the tilt correction to give a positive fold test. The sites in the southwest quadrant, however, are affected very little by the tilt correction, even though the sites are evenly distributed between the two limbs of the anticline. Nevertheless, the northeasterly directions yield a positive fold test at the 95% confidence level.

A simple visual inspection of the two sets of characteristic directions indicates that those directed toward the southwest have directions that, although the declinations are almost exactly opposed to the northeast grouping, the inclinations are almost horizontal, while those in the northeast are inclined downward at angles greater than 20°. Therefore these two groups do not pass the reversal test.

The reason for this failure is not clear, since we believe that we have successfully resolved the characteristic component as shown by the orthogonal plots. It is true, however, that some of these samples display highly viscous behavior at temperatures above 610°C, which in some cases required a wait upward of 20 min before making a measurement. The mean direction for this locality was calculated giving each site unit weight. If an unremoved component is present in both sets of data, the effect of averaging will tend to nullify this component.

Jiangsu Province

The second set of results reported here are from the samples collected in the vicinity of Zijinshan Hill in the suburb of Nanjing (32°N, 119°E) (Figure 1), the capital of Jiangsu Province, where lower, middle, and upper Triassic rocks are exposed. The early Triassic Xiaqinglong Formation there is composed of gray or grayish yellow interbedded shallow water limestones and shales, 176 m in thickness, and yields such early Triassic fossils as Anasibirites, Pseudosageceras, and Hemiprionities. The middle Triassic Shangqinglong Formation consists of purplish-red limestones with a thickness greater than 170 m and abundant middle Triassic cephalopods and pelecypods. The Late Triassic Huangmaqing Formation, unconformably overlain by the Jurassic Xiangshan Group, is mainly composed of purplish red fine-grained sandstones, siltstones, and shales and is more than 1362 m thick. In the uppermost part of Huangmaqing Formation such members of the late Triassic flora as Phlebopteris cf. polypodiodes Brongn. P. sp. cladophlebis sp. and Equisetites have been found.

Bedding attitudes vary from dipping NW to SW, at 18° to 75°. Three (M-O), four (P-S), and twelve (A-L) sites were drilled in the Xiaqinglong, Shangqinglong, and Huangmaqing formations, respectively, in the manner previously described, and measured in the paleomagnetic laboratory at Lamont-Doherty Geological Observatory.

Paleomagnetic Results

The NRM directions before tilt correction tend to lie along the present field or more commonly near to vertical (Figure 8). Pilot thermal demagnetization curves were run on each site and representative orthogonal plots are illustrated in Figure 9. In every case the blocking temperature spectrum is dominated from NRM to 650°C by a steeply inclined positive component. In two of the samples illustrated (Figures 9a and 9c) it can be seen that at high temperatures, a component is isolated that is directed to the northeast with a positive inclination (Figure 9a) or to the southwest with a negative inclination (Figure 9c). These directions are similar to the direction previously described from Guizhou Province Figure 7. The results illustrated in Figures 9b and 9d are from samples in which a high temperature component is not well isolated, even though northeasterly (Figure 9b) and southwesterly (Figure 9d) high-temperature components are undoubtedly present but of too small magnitude to be resolved.

Unfortunately, this high-temperature component could only be convincingly resolved from 23 red bed samples out of 95 studied. The individual specimen directions are plotted in Figure 10. The directions fall into two groups, one to the northeast with positive inclinations, the other group directed to the southwest with negative inclinations after correction for bedding tilt. This distribution is similar to the results from Tongzi County, Guizhou, in that both normal and reversed directions are present, however, they are not 180 apart, the reversed directions being shallower than the normal magnetizations.

The percentage of samples (24%) in which a characteristic direction of magnetization was isolated is relatively low; therefore site mean directions are not very meaningful. The statistics for the locality are calculated giving each sample unit weight, and the results are presented in Table 2.

The analysis of this locality was made very difficult by the strong vertical component present in all samples. The origin of this component is difficult to understand, since it appears to be of postfolding origin. The possibilities seem to be (1) a complex multicomponent magnetization that yields a vertical resultant, (2) overprinting in a postfolding magnetic field with a steep inclination, and (3) a very stable drilling remanence acquired along the axis of the drill.

Regarding the first possibility, the demagnetization trajectory of the very steep component tends to be linear, which would require closely superposed blocking temperature spectra of two or more components. This cannot be excluded but seems unlikely. The second hypothesis, that a postfolding vertical field caused the magnetization, would require that the Yangtze platform be in the vicinity of the North Pole sometime in the Tertiary, since the folding was Late Cretaceous in age. No steep directions are known from southeast Asia from the Cenozoic, so the possibility seems remote.

The third possibility, that this direction was acquired during drilling, is geometrically possible because most of the cores were drilled close to the vertical. However, it is not at all clear what process would lead to the very high coercivities and relatively high blocking temperatures of such a magnetization, particularly when such effects are not observed in other rock units we sampled (e.g., the Triassic from Ghizhou) with the same drill and techniques. With the present information available, it is not possible to decide between the different possibilities.

Discussion

The pole positions calculated from the two sampling areas are as follows: Guizhou sites, N = 9 sites, latitude 46.3°N, longitude 219.2°E, and $\alpha95 = 10.9°$; Nanjing samples, N = 23 samples, 44.8°N, 223.6°E, and $\alpha95 = 11.5°$. These two studies yield pole positions that have overlapping circles of confidence.

Other Triassic data have recently become available from the Yangtze platform, and these pole positions are listed in Table 2. The first set of data, from the Huachi Formation of middle Triassic age from near the city of Guiyang (Chan et al., 1984), was derived from 10 sample cores taken from both limbs of an open anticline. The specimens were submitted to thermal demagnetization. Although the number of samples is few, both polarities of magnetization were present (two normal, six reversed, two rejected), and the fold test was positive. The

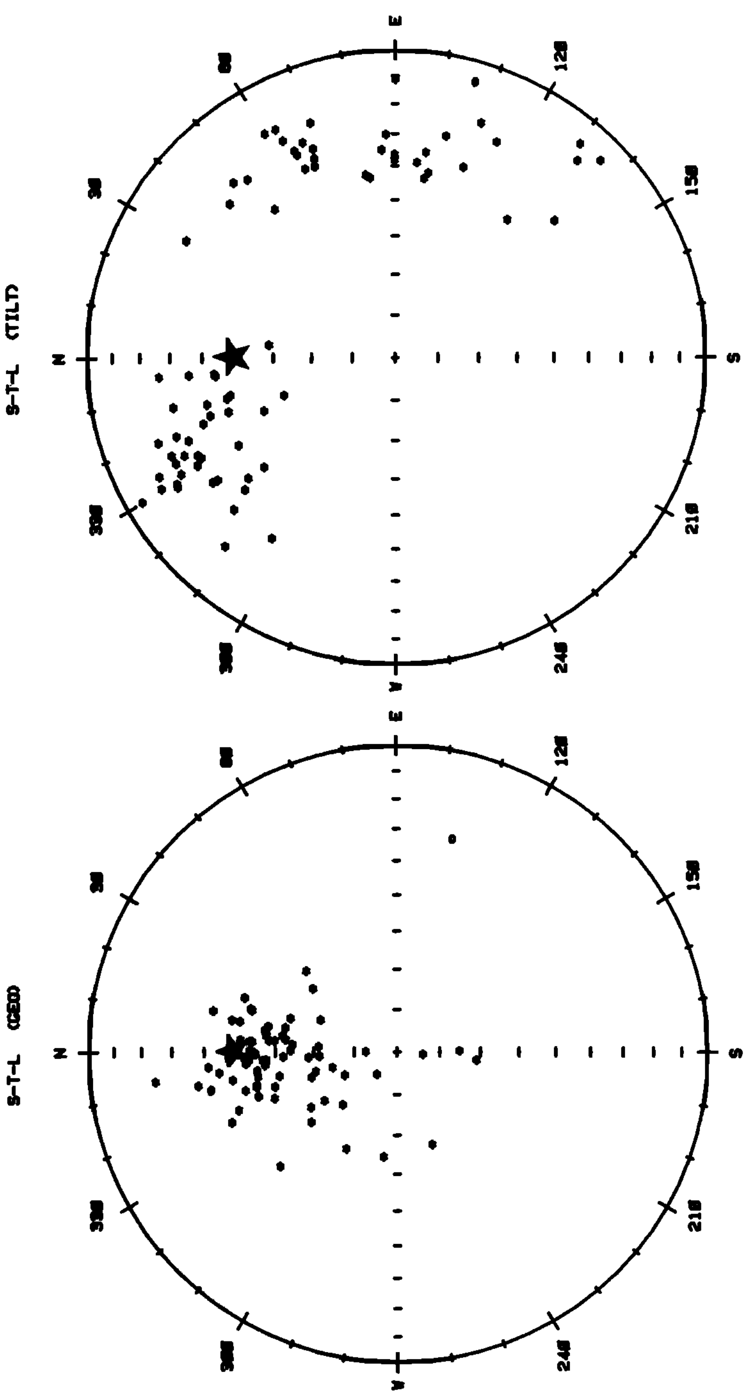

Fig. 6. Plot of low-temperature components from samples from Guizhou Province, before (left) and after (right) bedding tilt correction. Symbols as in Figure 2.

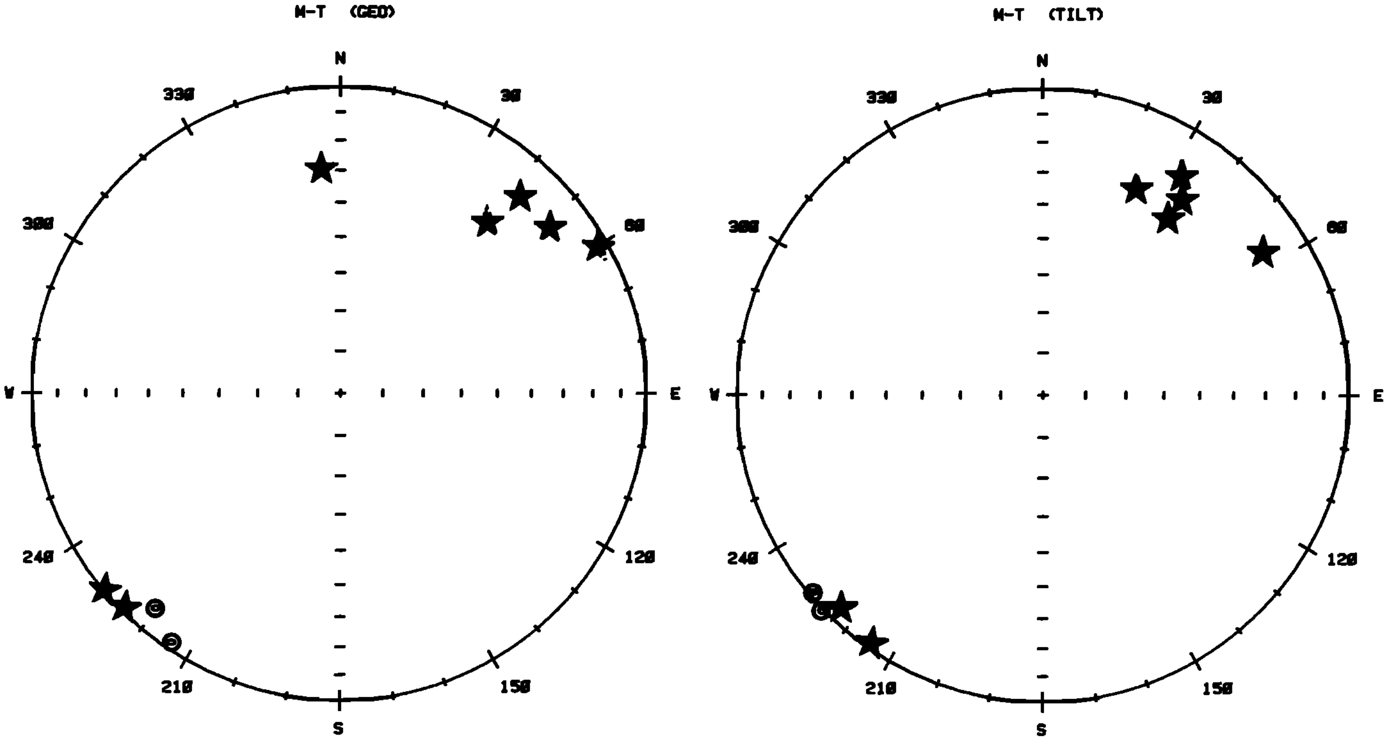

Fig. 7. Site (Guizhou Province) mean directions before (left) and after (right) bedding tilt correction. Symbols as in Figure 2.

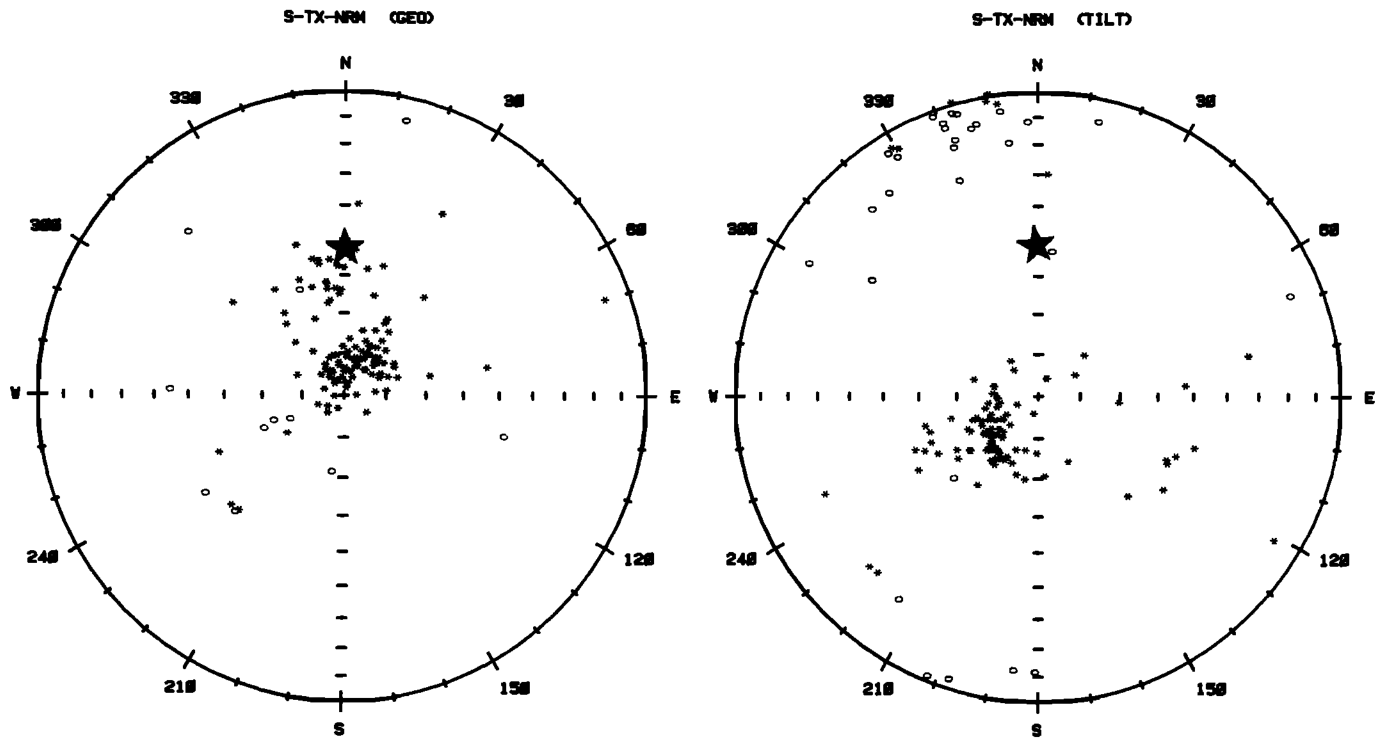

Fig. 8. NRM directions from Nanking area before (left) and after (right) bedding correction. Symbols as in Figure 2.

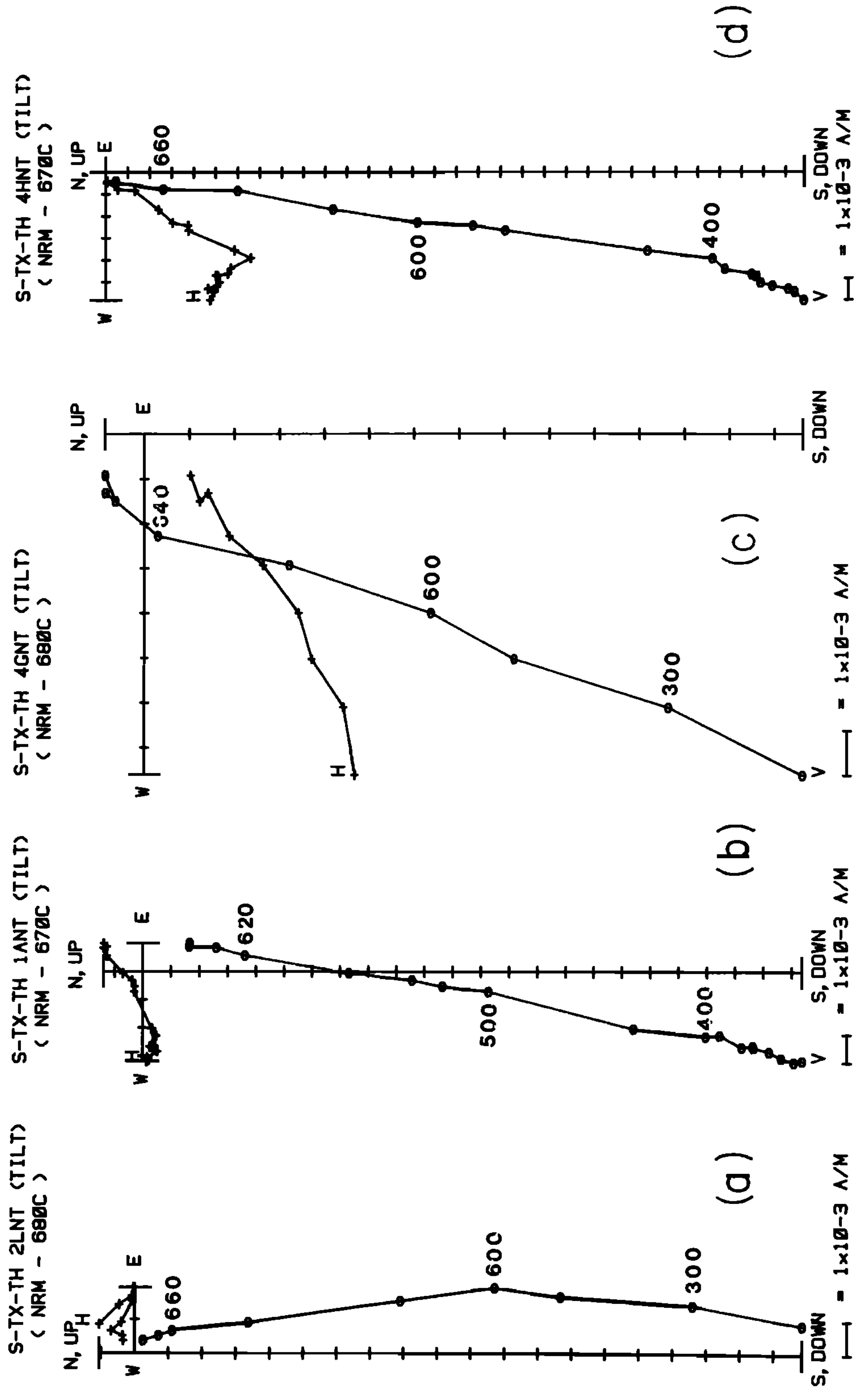

Fig. 9. Orthogonal plots from four samples from the Nanjing area.

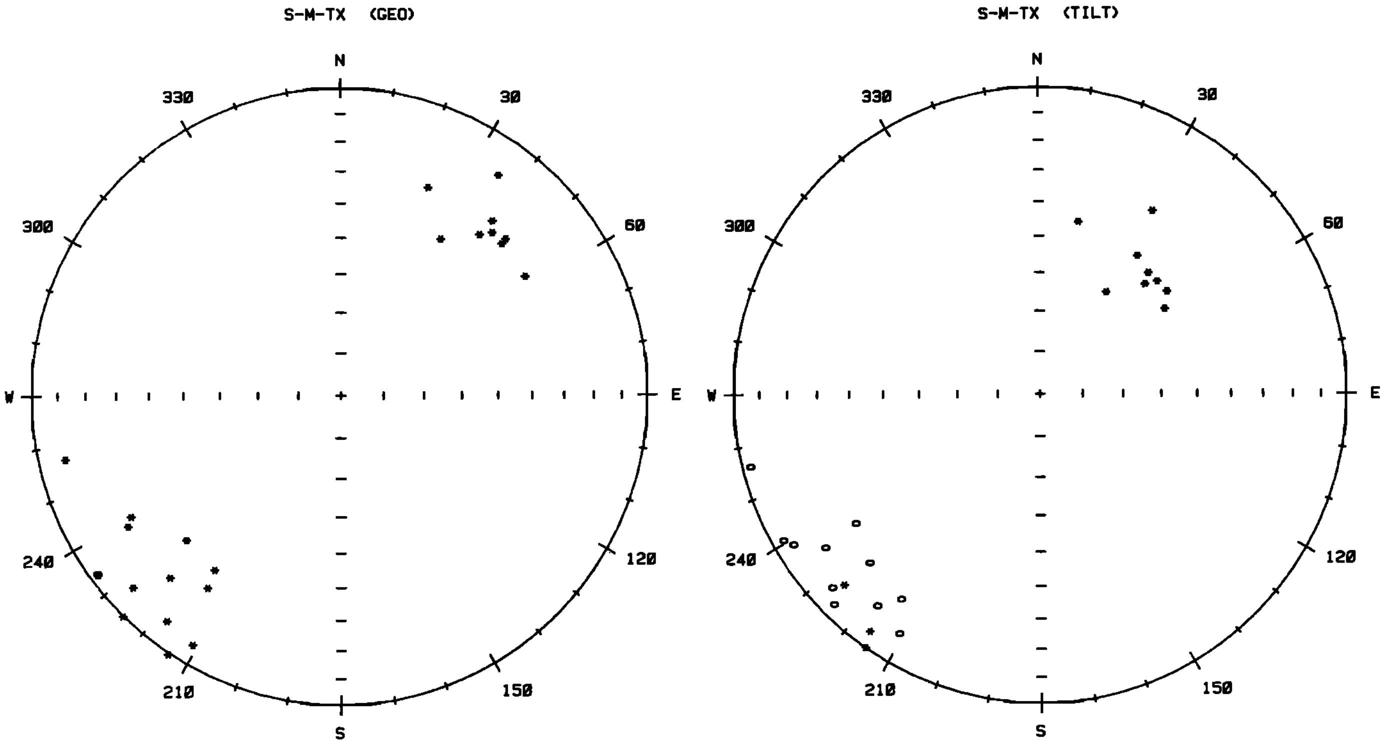

Fig. 10. Stereographic projections of individual high-temperature components from the Nanjing area isolated in this study before (left) and after (right) bedding tilt correction. Symbols as in Figure 2.

TABLE 2. Triassic Formation Means From Different Localities

	Locality					Pole Position					
Rock Unit	North Latitude	East Longitude	N	Dc	Ic	Latitude	Longitude	K	α95	Dp	Dm
			Chan et al. (1984)								
Huachi Fm. Middle Triassic	26.0	106.0	8*	215.7	-26.1	64.0	221.0		7.5		
			Lin et al. (1984)								
Changxing Fm. Upper Permian- Lower Triassic	31.0	119.8	13	44.8	44.9	50.7	204.8	38	6.8	5.4	8.6
			This Study								
Yelang Fm. (Tongzi to Guizhou) Lower Triassic	28.6	106.9	9	40.0	13.1	46.3	219.1	23.1	10.9	5.4	
Huangmaqing Fm. Upper Triassic Nanjing, Jiangen Province	32	119	23*	224.8	-24.4	-44.8	43.6	11.5	9.3	5.4	10

*Number of samples.

paleomagnetic pole position obtained in the study, 54.6°N, 209.7°E, has an oval of 95% confidence, which overlaps the poles determined in the present study.

A second study has recently been completed by Lin et al. (1985) on limestones that span the Triassic-Permian boundary. Thirteen sites were collected from the Changxing Formation, which spans the Permo-Triassic boundary in the Zhejiang Province. Thermal demagnetization was carried out on all specimens. No fold test was reported. The pole position from this study (50.7°N, 204.8°E) also has a 95% confidence circle, which overlaps those of the previous studies. We therefore conclude that the paleopole position for the Triassic of the Yangtze platform is well determined, with the results coming from four different formations from three provinces that span the Triassic. The sampling sites on the Yangtze platform are widely spaced, yet yield coincident pole positions; this demonstrates that the Yangtze block has acted as a ridged plate since the Triassic.

Recently, two different hypotheses have been proposed for the tectonic history of China. The first, by Klimetz (1983), suggests that the North China block and Yantze block were not sutured together until the Late Triassic or Early Jurassic and they together did not suture to Asia until the Late Jurassic. The second hypothesis, championed by Zhang et al. (1984) and Mattauer et al. (1985), suggests that the North and South China cratons had sutured together by the Silurian or Devonian and together were sutured to Siberia at the end of the Paleozoic.

Triassic paleomagnetic results are available from the Siberian platform, Europe, Yangtze platform, North China block, and Thailand, which can be used to test these hypotheses. The pole positions from these various paleoplates are shown in Figure 11. It is immediately obvious that the pole positions from the Yangtze platform are significantly different from the pole positions from all other continental blocks, including those from North China and Thailand. Therefore it is clear that these microcontinents (Siberia, Europe, Yangtze platform, North China block, and Thailand) were not in their present configuration during the Triassic.

It is now well known that rotations of continental fragments take place, and it is instructive to compare paleolatitudes to see what the data imply. Unfortunately, the Triassic data from the North China block are not compelling and have a 95 of 17°. No fold test is reported, and no other evidence for stability is presented (Lin et al., 1985). The data must be regarded as very preliminary and imply low paleolatitudes for the North China block. The data, although tentative, indicate that the North China block and the Yangtze block were both in low latitudes and rotated relative to each other approximately 90°. Their longitudinal relationship to each other is obscure, but they well may have been adjacent to one another.

The relationship of these two blocks to the Siberian plate is interesting, since the paleomagnetic pole for Europe and Siberia falls near Sakhalin and Kamchatka Peninsula, respectively. If the North China block and the

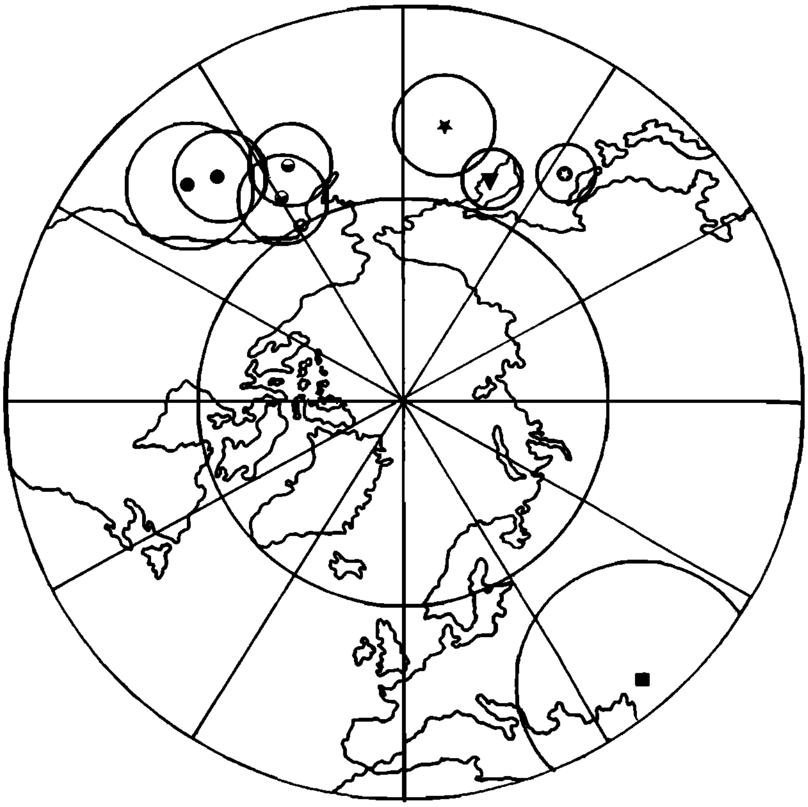

Fig. 11. Pole positions with 95% circles of confidence for the South China platform (solid circles) are this study. Half-solid circles are other recent studies for the Yangtze platform, (Chan et al., 1984; Lin et al., 1985) compared with the North China block (square) (Lin et al., 1985), Europe (solid triangle) (Khramov et al., 1981), and Siberia (open star) and Thailand (solid star) (J. Achache and V. Cortillot, 1985).

Yantze block were sutured to Siberia at this time, steep inclinations could be expected from China. The data, however, indicate that 30° of latitude separated the Chinese plates from Siberia. This difference in positions of these plates was eliminated during the middle Mesozoic, since the upper Cretaceous paleopoles for these different regions are in agreement. This closure must have been affected by the closure of an ocean basin or transform motion along the northern margin of the paleotethys, or both.

The position of Thailand is also enigmatic since the paleolatitudes derived by J. Achache and V. Courtillot (1985) would place it at a higher paleolatitude in the Triassic than the Yangtze block.

It is nevertheless clear that the suturing of the North China block and the Yangtze block into their relative positions and their final suturing to Siberia must have been post-Triassic in age. The Mesozoic formation of Eurasia is therefore highly favored. It seems most probable, as was earlier postulated by McElhinny et al. (1981), that Pangea never included the continental blocks that now comprise China, since Africa and North America were already separating by the time Chinese blocks were suturing to Siberia. The possibility that the North China block and the Yangtze block might have been separated geographically in the Triassic is supported by recent paleobotanical evidence from China, which indicates a great dissimilarity in the vegetation of the two areas in the Late Permian and Lower Triassic time (Ziqiang, 1985).

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