Geology

Cenozoic vertical-axis rotation of the Altyn Tagh fault system

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Notes

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ABSTRACT

Paleomagnetic declination data were collected from Cenozoic strata of the southern rim of the Tarim basin to address whether the Altyn Tagh fault has undergone significant rotation during the Indian-Asian collision. Results from the eastern and central Altyn Tagh fault zone suggest that it has undergone no significant rotation since the Oligocene. This implies that the boundary between the Tarim and Tibet has remained relatively stationary during most of the Cenozoic. In contrast, declination data from the western Kunlun Shan on the eastern limb of the Pamir orocline, where the Karakax segment of the Altyn Tagh fault system terminates, suggest that the range has undergone clockwise rotations of between 19.3° ± 8.6° and 27.8° ± 5.8°. Such rotation is in mirror image with the documented counterclockwise rotation of 20°–50° in the western Pamir orocline and implies relatively small displacements on the Karakorum fault. Our results also suggest that the Karakax fault may have formed as an accommodation zone between the western Kunlun Shan and the Karakorum Mountains.

INTRODUCTION

In the past two decades, extensive paleomagnetic results have been published concerning central Asia and, in particular, the Tarim and surrounding regions (e.g., Pamir Ranges and the Tien Shan; Li, 1990; Chen et al., 1992, 1993; Bazhenov et al., 1994; Gilder et al., 1996). Despite these studies, the Cenozoic rotational histories of two significant tectonic features, the Altyn Tagh fault and the western Kunlun Shan, remain poorly understood. The late Cenozoic Altyn Tagh fault in central Asia bounds the north edge of the Tibetan plateau and terminates in the Nan Shan and the western Kunlun thrust belts at its eastern and western ends (Tapponnier and Molnar, 1977; Burchfiel et al., 1989; Fig. 1). Documenting the magnitude of vertical-axis rotations of the Altyn Tagh fault and the western Kunlun Shan is important for two reasons. First, Bazhenov et al. (1994) predicted that the western Kunlun Shan should show 20°–50° of clockwise rotations since the Paleogene, a consequence of the nearly 300 km of northward motion of the Pamir Ranges (Burtman and Molnar, 1993). If true, this would minimize the need for large magnitude right-lateral strike-slip faults to accommodate the motion (e.g., the Karakorum fault). Second, by determining if the Altyn Tagh fault has undergone significant magnitude rotations we can better ascertain whether this important tectonic boundary has remained relatively stationary (with respect to Tarim) throughout most of the Cenozoic.

In order to address whether the Altyn Tagh fault and the western Kunlun thrust belt have undergone significant rotation, paleomagnetic samples were collected from Eocene strata at Puska and from Oligocene strata at Aertashi, Jianglisai, and Subei (Fig. 2). The age determinations and lithologies of these stratigraphic sections were described in detail by Rumelhart (1998).

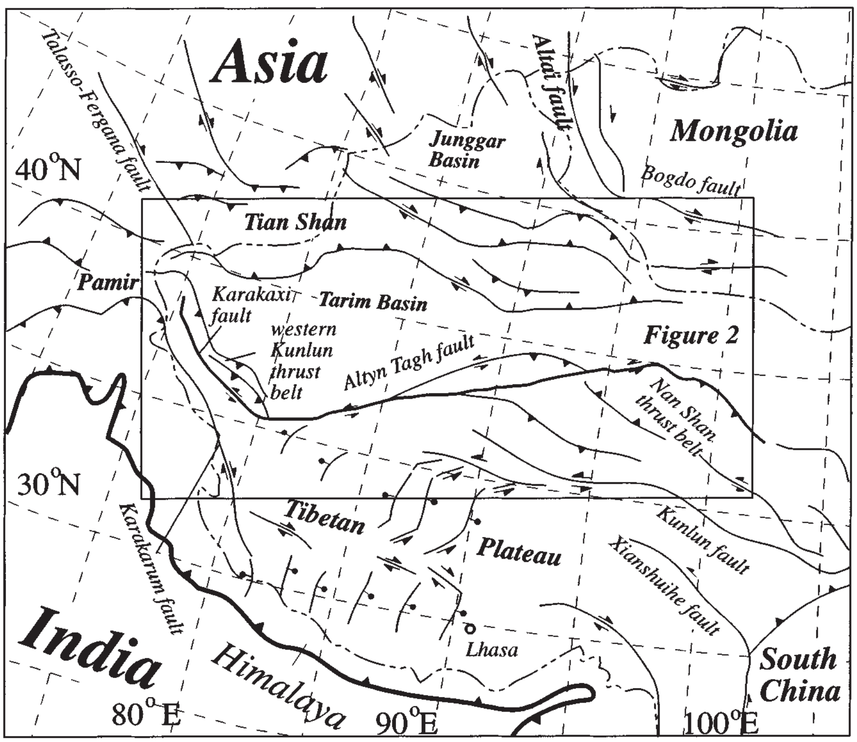

Figure 1. Tectonic map of central Asia showing extent of Altyn Tagh fault system and location of Figure 2.

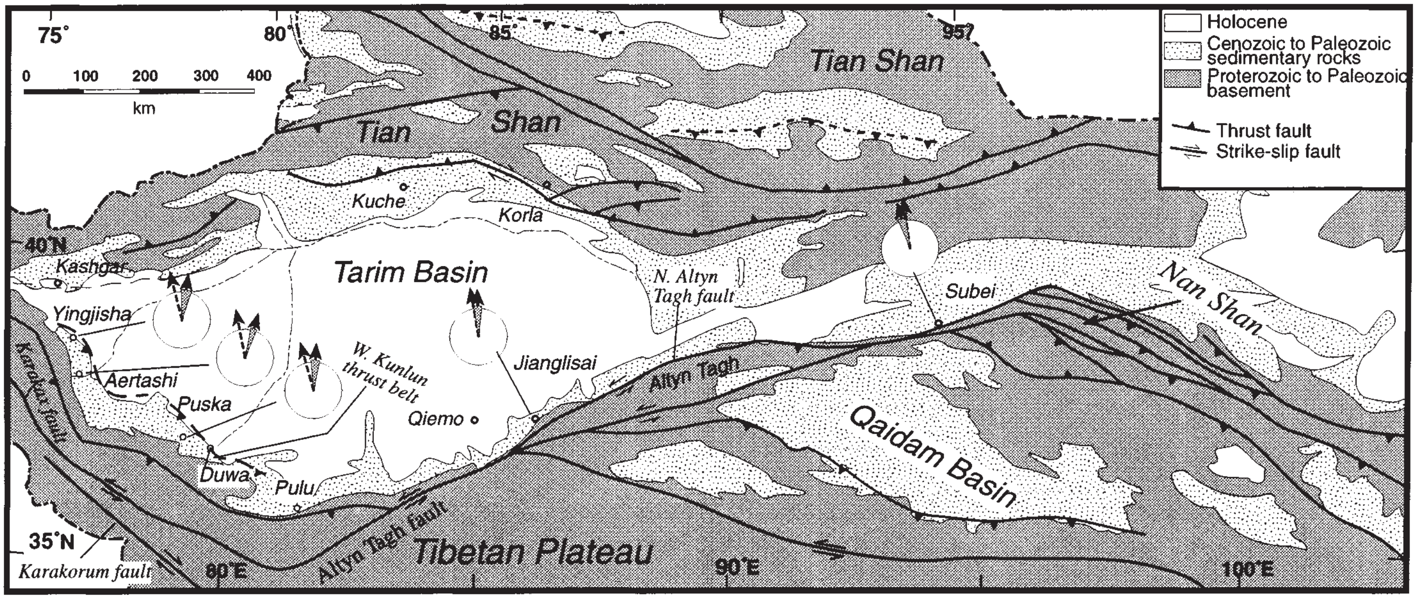

Figure 2. Simplified tectonic map of Altyn Tagh fault system and vertical-axis rotations along southern rim of Tarim basin. Dashed arrows indicate expected declinations; short solid arrows indicate observed mean declinations; shaded wedges indicate confidence limits. Western Kunlun Shan localities show clockwise rotations, whereas southeastern Tarim locations show no significant vertical-axis rotation.

DATA COLLECTION AND EXPERIMENTAL PROCEDURES

At Puska, Aertashi, and Subei, samples were collected from stratigraphic sections that have been incorporated into the western Kunlun and Nan Shan thrust belts (Rumelhart, 1998; Cowgill et al., 1998). Thus, the Cenozoic strata where the samples were collected are allochthonous with respect to the Tarim basement. The Jianglisai site is located in a north-dipping Cenozoic sequence, the deformation of which is associated with the development of the late Cenozoic northern Altyn Tagh fault (Cowgill et al., 1997; Fig. 1).

An original objective of the study was to determine magnetostratigraphy and refine age determinations (Rumelhart, 1998). Thus, most sampling sites were distributed stratigraphically, and three to five samples were collected from each site (= stratigraphic level). However, several sites (i.e., Aertashi and Puska) were collected specifically for rotational analysis, consisting of ~15 samples per site.

The samples were stored, thermally demagnetized, and measured within a magnetically shielded room with average field intensity < 200 nT. Generally, the ChRM (i.e., the direction used in the analyses) was revealed by thermal demagnetization between 650 and 680 °C, suggesting that hematite is the primary remanence carrier. For most usable specimens, the ChRM could be accurately determined by the trajectory of vector end points. Principal-component analysis (Kirschvink, 1980) was used to determine least-square fits to vector end-point trajectories revealed during thermal demagnetization. Site-mean ChRM directions were computed using standard statistical methods (Fisher, 1953) applied to the site-mean directions, inverting the directions from reversed polarity sites. All of the sections pass the regional bedding-tilt test (McFadden, 1990), and all but Subei pass the reversals test at the C level of McFadden and McElhinny (1990). These site-mean paleomagnetic directions are illustrated in Figure 3 and summarized in Table 1. The analyses of vertical-axis rotation ($R \pm \Delta R$) employed the techniques of Beck (1980) and Demarest (1983), and used reference poles of Besse and Courtillot (1991). For a complete discussion of the procedures used see Rumelhart (1998).

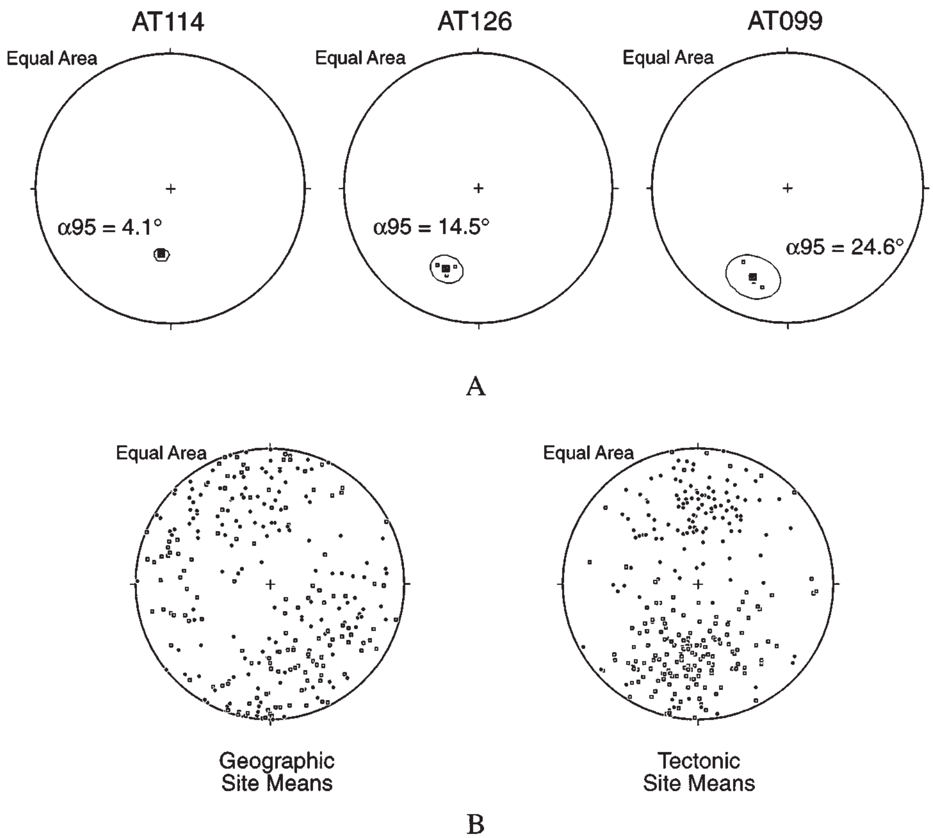

Figure 3. Equal-area projections of paleomagnetic directions used in tectonic analysis for vertical-axis rotations. A: Plots in geographic coordinates without correction for bedding tilt. B: Plots in tectonic coordinates following correction for bedding tilt.

PALEOMAGNETIC RESULTS

Vertical-axis rotations inferred from paleomagnetic declinations are illustrated in Figure 2. The paleomagnetic results from the Altyn Tagh fault zone suggest that the fault has not rotated more than 8° since the Oligocene (i.e., 7.4° ± 7.8° at Jianglisai and –7.3° ± 7.6° at Subei; Table 1; Fig. 2). Given the range of uncertainty for these localities, there is no evidence for significant rotation. This inference is consistent with data from Chen et al. (1993), who concluded that the Tarim basin, which is the northern bounding block of the Altyn Tagh fault, has rotated <7° since the Late Cretaceous. Unpublished paleomagnetic data from Jurassic rocks exposed in the Qaidam basin along the Altyn Tagh fault also show no evidence of rotation (S. Gilder, 1998, personal commun.). Thus, left slip along the Altyn Tagh fault must have resulted from translation of the Tarim block relative to the Tibetan plateau, with little block rotation.

The results from the western Kunlun Shan, however, suggest that this range has rotated clockwise since the late Eocene. The discordance in paleomagnetic declinations from the expected values varies from 19.3° ± 8.6° at Puska to 27.8° ± 5.8° at Aertashi. Although these rotation values are statistically indistinguishable from one another, they suggest that the magnitude of vertical-axis rotation of the western Kunlun Shan increases to the northwest.

Chen et al. (1992) reported paleomagnetic data from Yingjisha, directly north of Aertashi (Fig. 2), which they used in conjunction with other sites to obtain a Cretaceous paleomagnetic pole for the Tarim basin. We reevaluated these data from Yingjisha to obtain vertical-axis rotation information. Our analysis suggests that the Yingjisha location rotated clockwise 21.0° ± 10.4° since the Cretaceous. This value is indistinguishable from our rotation determination at Aertashi. Similarly, the data of Gilder et al. (1996) from early Tertiary strata of Duwa near Puska (Fig. 2) imply ~43° of clockwise rotation. Although different in detail from our results, the observations of Chen et al. (1993) and Gilder et al. (1996) are consistent with clockwise rotation of the western Kunlun Shan.

DISCUSSION AND CONCLUSIONS

Paleomagnetic data from the western Kunlun Shan suggest that it has rotated as much as ~28° clockwise since the late Eocene. In order for the Cenozoic strata to rotate, they must have been detached from the Tarim basement along a thrust fault dipping beneath the Kunlun Shan. These strata were deposited within a foreland basin in front of the evolving western Kunlun Shan thrust system, and were subsequently incorporated into the Kunlun thrust belt, deforming independently of Tarim (Rumelhart, 1998). Our analyses suggest that data from Chen the et al. (1992) Yingjisha location should not be included for determination of a paleomagnetic pole for Tarim, because that area was deformed and incorporated in the foreland thrust belt of the western Kunlun Shan.

Following the proposal by Burtman and Molnar (1993), we suggest that the clockwise vertical-axis rotation of the western Kunlun Shan was caused by northward indentation of the Pamir Ranges into southern Asia during the late Cenozoic (Fig. 4A). This rotation is a mirror image of counterclockwise vertical-axis rotation in the western Pamirs (Bazhenov et al., 1994). This is important because the rotation of the western Kunlun Shan provides a mechanism to accommodate the deformation associated with the indentation and reduces the need for large magnitudes of right slip on the Karakorum fault. This is consistent with recent studies of the fault that suggest between 66 and 150 km of displacement (i.e., Searle, 1996; M. Murphy, 1999, personal commun.). The Karakorum fault has been used as a conjugate to the Altyn Tagh fault to accommodate large magnitudes of continental extrusion (e.g., Peltzer and Tapponnier, 1988); our study suggests that this is unlikely.

The left-slip Karakax fault, south of and subparallel to the western Kunlun thrust belt (Figs. 1 and 4A), has been interpreted to be an extension of the Altyn Tagh fault (e.g., Avouac and Tapponnier, 1993). Alternatively, our study suggests that clockwise rotations in the western Kunlun Shan may explain left-slip motion along the Karakax fault. This fault, separating the western Kunlun Shan to the north from the Karakorum Mountains to the south, may have been an accommodation zone for the clockwise rotation of the two blocks (Fig. 4B). If true, the Karakax fault is not genetically related to the Altyn Tagh fault and probably did not accommodate large magnitudes of eastward extrusion.

Our data indicate that the Altyn Tagh fault has not rotated significantly with respect to the Tarim throughout most of the Cenozoic. This implies that the location of the boundary between the Tarim and Tibet has remained fixed during the Tertiary. This is a crucial understanding in any attempt at paleotectonic reconstructions or geologic modeling of central Asia.

Furthermore, because the Altyn Tagh fault has not undergone significant rotation, the pivot point for rotation of the western Kunlun Shan may have been located at its eastern end, near Pulu (Fig. 2). If this is the case, a simple geometric relationship may be used to estimate the minimum amount of crustal shortening predicted for the western Kunlun, assuming that the Tarim basin has not

TABLE 1. TECTONIC ROTATION ANALYSIS

Section	Age	Site location		Observed direction			Reference pole			p	Expected inc	Expected dec	Rotation	Flattening
	(Ma)	Lat	Long	I_m	D_m	α_{95}	Lat	Long	α_{95}	(°)	I_x ± δI	D_x ± δD	R ± ΔR	F ± ΔF
		(°N)	(°E)	(°)	(°)	(°)	(°N)	(°E)	(°)		(°) (°)	(°) (°)	(°) (°)	(°) (°)
Yingjisha	80	38.1	76.4	37.1	7.6	9.9	76.2	198.9	3.4	60.2	48.9 ± 3.9	–13.4 ± 3.9	21.0 ± 10.4	11.8 ± 8.5
Aertashi	30	38.1	76.4	36.9	17.6	5.0	81.0	132.8	2.7	47.4	61.5 ± 2.3	–10.2 ± 3.7	27.8 ± 5.8	24.6 ± 4.4
Puska	50	37.1	78.4	24.3	4.3	8.4	77.9	149.0	4.3	49.8	59.4 ± 3.8	–15.0 ± 5.6	19.3 ± 8.6	35.1 ± 7.4
Jianglisai	20	38.0	86.5	39.6	358.4	6.7	82.3	147.6	3.3	48.6	60.4 ± 2.9	–9.0 ± 4.4	7.4 ± 7.8	20.8 ± 5.8
Subei	30	39.5	94.8	39.7	344.7	6.6	81.0	132.8	2.7	43.7	64.5 ± 2.1	–8.0 ± 3.9	–7.3 ± 7.6	24.8 ± 5.5

Eurasia Reference Pole*	Age (Ma)	Lat (°N)	Long (°E)	α_{95} (°)
	20	82.3	147.6	3.3
	30	81.0	132.8	2.7
	40	80.2	145.4	3.6
	50	77.9	149.0	4.3
	60	78.5	178.7	3.9
	70	77.2	192.4	4.1
	80	76.2	198.9	3.4

Note: I_m is mean inclination; D_m is mean declination; p is colatitude; I_x is expected inclination; δI is 95% confidence limit on expected inclination; D_x is expected declination; δD is confidence limit on expected declination; R and F are the calculated magnitude of vertical-axis rotation and flattening implied by the difference between the observed and expected directions; ΔR and ΔF are confidence limits on R and F.

*Besse and Courtillot (1991)

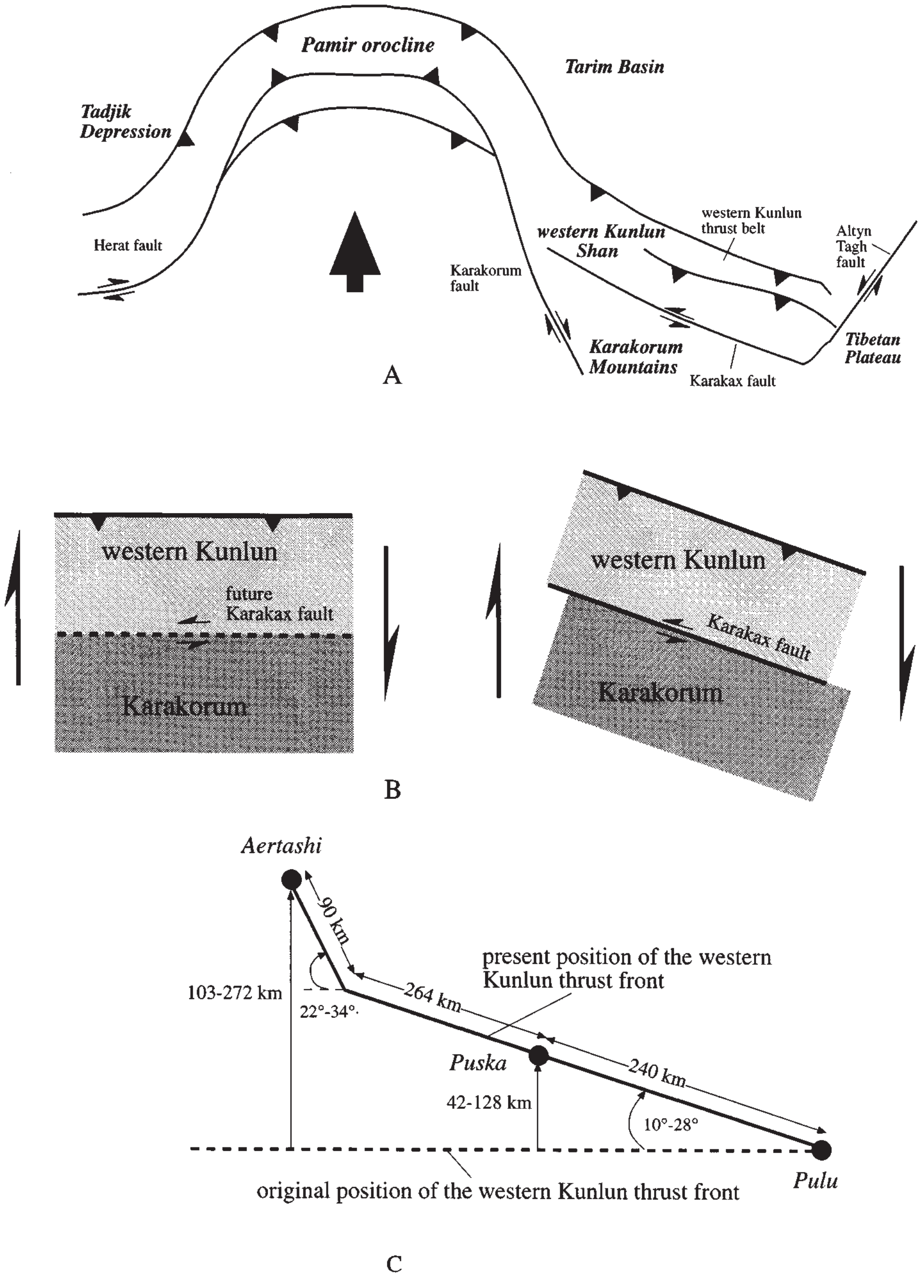

Figure 4. A: Tectonic framework for development of Pamir orocline and its associated structures on its eastern limb: western Kunlun thrust, Karakax fault, Karakorum fault, and Altyn Tagh fault. B: Kinematic model for relation between western Kunlun thrust, Karakax fault, and rotation of western Kunlun Shan and Karakorum Mountains due to northward motion of Pamirs. Western Kunlun thrust belt and Karakax fault have rotated from original east-west orientation to northwest trend. C: Geometric relationship between amount of crustal shortening and rotation of western Kunlun Shan.

rotated (Chen et al., 1992; Fig. 4C). This analysis yields shortening between 42 and 128 km at Puska and between 103 and 272 km at Aertashi since the Oligocene. The amount of shortening near Puska inferred from the rotational model is consistent with the 50–100 km shortening obtained from field mapping and construction of balanced cross sections in this area (Cowgill et al., 1998).

ACKNOWLEDGMENTS

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REFERENCES CITED

Avouac, J. P., and Tapponnier, P., 1993, Kinematic model of active deformation in central Asia: Geophysical Research Letters, v. 20, p. 895–898.

Bazhenov, M. L., Perroud, H., Chauvin, A., Burtman, V. S., and Thomas, J. C., 1994, Paleomagnetism of Cretaceous red beds from Tadzhikistan and Cenozoic deformation due to India-Eurasia collision: Earth and Planetary Science Letters, v. 124, p. 1–18.

Beck, M. E., Jr., 1980, Paleomagnetic record of plate-margin tectonic processes along the western edge of North America: Journal of Geophysical Research, v. 85, p. 7115–7131.

Besse, J., and Courtillot, V., 1991, Revised and synthetic apparent polar wander paths of the African, Eurasian, North American and Indian plates, and true polar wander since 200 Ma: Journal of Geophysical Research, v. 96, p. 4029–4050.

Burchfiel, B. C., Quidong, D., Molnar, P., Royden, L., Yipeng, W., Peizhen, Z., and Weiqi, Z., 1989, Intracrustal detachment zones of continental deformation: Geology, v. 17, p. 448–452.

Burtman, V. S., and Molnar, P., 1993, Geological and geophysical evidence for deep subduction of continental crust beneath the Pamir, *in* Burtman, V. S., and Molnar, P., eds., Geological and Geophysical Evidence for Deep Subduction of Continental Crust Beneath the Pamir: Geological Society of America Special Paper 281, p. 1–76.

Chen, Y., Cogne, J.-P., and Coutillot, V., 1992, New Cretaceous paleomagnetic results from the Tarim basin, northwestern China: Earth and Planetary Science Letters, v. 114, p. 17–38.

Chen, Y., Cogne, J.-P., Courtillot, V., Tapponnier, P., and Zhou, X. Y., 1993, Cretaceous paleomagnetic results from western Tibet and tectonic implications: Journal of Geophysical Research, v. 98, p. 17,981–18,000.

Cowgill, E., Yin, A., Rumelhart, P., Wang Xiao-Feng, and Zhang Qing, 1997, Kinematics of the Central Altyn Tagh fault system, NW China: Eos (Transactions, American Geophysical Union), v. 78, p. 173.

Cowgill, E., Yin, A., Rumelhart, P., Foster, D., Chen, Z., and Wang, X. F., 1998, Magnitude and timing of Cenozoic shortening in the western Kunlun Shan: Eos (Transactions, American Geophysical Union), v. 79, p. F816.

Demarest, H. H., 1983, Error analysis of the determination of tectonic rotation from paleomagnetic data: Journal of Geophysical Research, v. 88, p. 4321–4328.

Fisher, R. A., 1953, Dispersion on a sphere: Royal Society of London Proceedings, ser. A, v. 217, p. 245–248.

Gilder, S., Zhao, X., Coe, R., Meng, Z., Courtillot, V., and Besse, J., 1996, Paleomagnetism and tectonics of the southern Tarim basin, northwestern China: Journal of Geophysical Research, v. 101, p. 22,015–22,031.

Kirschvink, J. L., 1980, The least-squares line and plane and the analysis of palaeomagnetic data: Royal Astronomical Society Geophysical Journal, v. 62, p. 699–718.

Li, Y., 1990, An apparent polar wander path from the Tarim block, China: Tectonophysics, v. 181, p. 31–41.

McFadden, P. L., 1990, A new fold test for palaeomagnetic studies: Geophysical Journal International, v. 103, p. 163–169.

McFadden, P. L., and McElhinny, M. W., 1990, Classification of the reversal test in paleomagnetism: Geophysical Journal International, v. 103, p. 725–729.

Peltzer, G., and Tapponnier, P., 1988, Formation and evolution of strike-slip faults, rifts, and basins during the India-Asia collision: an experimental approach: Journal of Geophysical Research, v. 93, p. 15,085–15,117.

Rumelhart, P. E., 1998, Cenozoic basin evolution of southern Tarim, northwestern China: Implications for the uplift history of the Tibetan Plateau [Ph.D. thesis]: Los Angeles, University of California, 268 p.

Searle, M. P., 1996, Geological evidence against large-scale pre-Holocene offsets along the Karakorum fault: Implications for the limited extrusion of the Tibetan plateau: Tectonics, v. 15, p. 171–186.

Tapponnier, P., and Molnar, P., 1977, Active faulting and tectonics in China: Journal of Geophysical Research, v. 82, p. 2905–2930.

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CORRECTION

A Pleistocene and still-active detachment fault and the origin of the Corinth-Patras rift, Greece

Geology, v. 28, p. 83–86 (January 2000)

Incorrect versions of Figures 1 and 3 were printed with this article. The correct versions appear here.

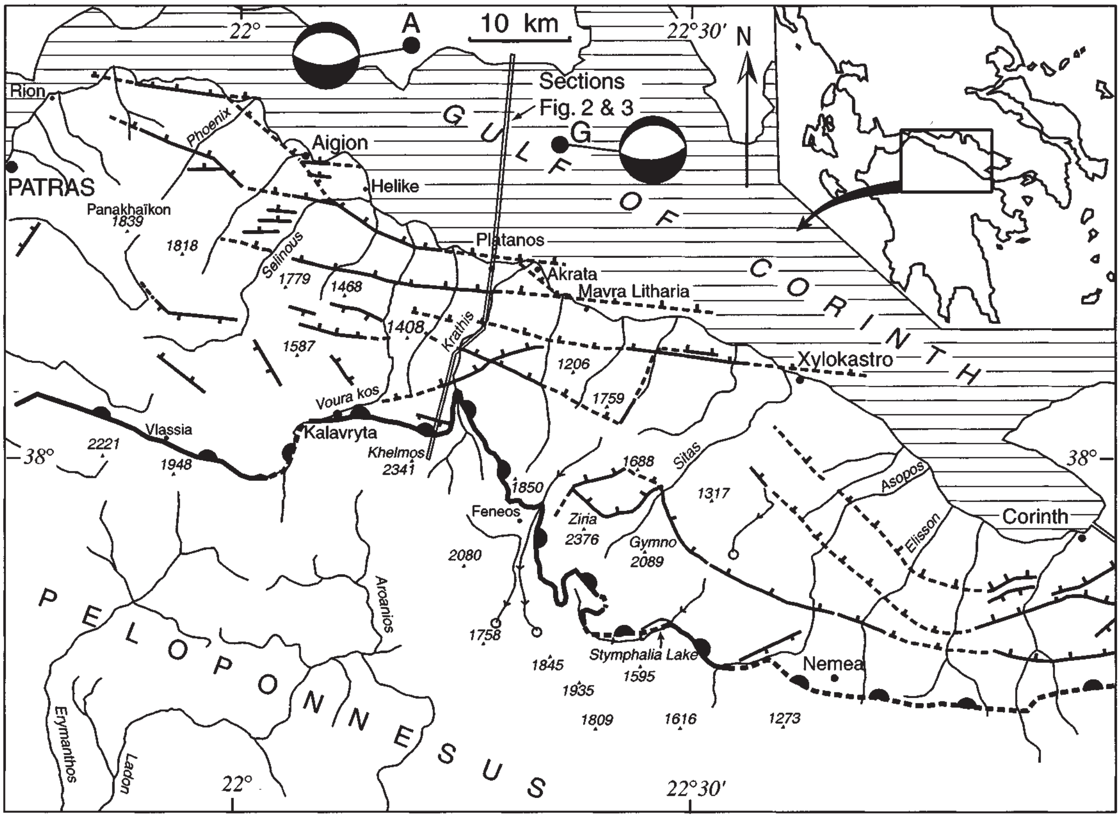

Figure 1: Structural sketch map of the rift-related faults in northern Peloponnesus. Thick line with half dots is Khelmos detachment faut. Ticked lines: normal faults. Thin double line indicates sections of figures 2 and 3. Dots are earthquake epicenters: G, Galaxidi (1992/11/18), M=5.9; A, Aigion (1995/06/15), M=6.2. Focal mechanisms after Bernard et al., 1997.

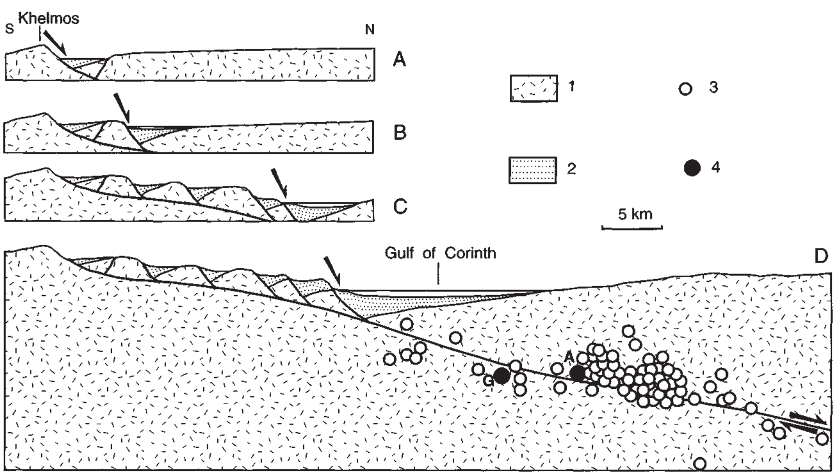

Figure 3: Four step sections in the development of the Corinth-Patras rift (location in Fig. 1). A: Early rift, along active Khelmos fault. B: During activity of the Stolos fault. C: When Akrata fault was active (300–400 ka). D: Present state, showing proposed connection of the Khelmos detachment with the low-angle seismic fault beneath gulf. 1: Alpine basement. 2: Synrift sediments. 3: Microearthquakes, recorded along a north-south section located ~15 km west of our geological section (from Rietbrock et al., 1996, Fig. 1B). 4: Centroid location of Galaxidi (G) and Aigion (A) earthquakes projected on the section.

CORRECTION

Cenozoic vertical-axis rotation of the Altyn Tagh fault system

Geology, v. 27, p. 819–822 (September 1999)

An error was found in the calculation of vertical-axis rotation of the Altyn Tagh fault system. The corrected results are shown in Table 1. Complete details of the implications of the corrected data may be found in the Data Repository.[1]

TABLE 1. TECTONIC ROTATION ANALYSIS

Section	Age	Site location		Observed direction			Reference Pole			p	Expected Inc			Expected Dec			Rotation			Flattening		
	(Ma)	Lat	Long	I_m	D_m	α_{95}	Lat	Long	α_{95}	(°)	I_x	±	δI	D_x	±	δD	R	±	ΔR	F	±	ΔF
		(°N)	(°E)	(°)	(°)	(°)	(°N)	(°E)	(°)		(°)		(°)	(°)		(°)	(°)		(°)	(°)		(°)
Yingjisha	80	38.1	76.4	37.1	7.6	9.9	76.2	198.9	3.4	60.2	48.9	±	3.9	13.4	±	3.9	-5.8	±	10.4	11.8	±	8.5
Aertashi	30	38.1	76.4	36.9	17.6	5.0	81.0	132.8	2.7	47.4	61.5	±	2.3	10.2	±	3.7	7.4	±	5.8	24.6	±	4.4
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Subei	30	39.5	94.8	39.7	344.7	6.6	81.0	132.8	2.7	43.7	64.5	±	2.1	8.0	±	3.9	-23.3	±	7.6	24.8	±	5.5

		Lat	Long	α_{95}
		(°N)	(°E)	(°)
Eurasia Reference Pole	20	82.3	147.6	3.3
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[1]GSA Data Repository item 200053, Correction of Cenozoic vertical-axis rotation of the Altyn Tagh fault system, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140, editing@geosociety.org, or at www.geosociety.org/pubs/drpint.htm.