pling has focused on effects of doping [for example, O content in $YBa_2Cu_3O_{7-\delta}$ (*7*, *41*)]. Our present data suggest similar activity as a function of temperature in the superconducting onset regime. Second, the large fluctuation regime and variations of effective ion potential that we have suggested around $T_c$ should be reflected in ion and electron dynamics, as in conventional perovskite transitions. Thus, elastic constants, inelastic neutron scattering, nuclear magnetic resonance, and electron paramagnetic resonance, both in the plane and in the *c* direction, can be expected to become increasingly important probes to discriminate time scales (*39*). For instance, central peak scattering from domain motion and *c*-direction sound speed anomalies can be anticipated. Third, complete analysis of EXAFS data in the strong anharmonic situations envisaged demands extensions of harmonic Debye-Waller factor theory (*17*). Ab initio analysis of our EXAFS data is in progress (*29*).

*Note added in proof*: Results from (*29*) indicate that the effective potential for the Cu1–O4 relative motion is a deep double well that is present at all studied temperatures, and the motion of the O4 atom is best described in a quantum mechanical regime. In the fluctuation region the minima of the potential move closer to each other, decreasing the separation in distance and the height of the potential barrier between the two minima of the potential.

REFERENCES AND NOTES


1. J. G. Bednorz and K. A. Müller, *Z. Phys. B* **64**, 189 (1986); M. K. Wu *et al.*, *Phys. Rev. Lett.* **58**, 908 (1987); H. Maeda, Y. Tanaka, M. Fukutomi, T. Asano, *Jpn. J. Appl. Phys.* **27**, L209 (1988); Z. Z. Sheng and A. M. Hermann, *Nature* **332**, 55 (1988); Y. Tokura *et al.*, *ibid.* **337**, 345 (1989).
2. See, for example, T. M. Rice, *Z. Phys. B* **67**, 141 (1987); W. A. Little, *Science* **242**, 1390 (1988); K. A. Müller, *Proceedings of the Workshop on High Temperature Superconductors* (Oberlech, Austria, August 1988) (IBM Research Journal, Zurich, 1989).
3. W. L. McMillan, *Phys. Rev.* **167**, 331 (1968).
4. R. J. Cava *et al.*, *Nature* **332**, 814 (1988).
5. J. F. Zasadzinski *et al.*, *Physica C* **158**, 519 (1989); C.-K. Loong *et al.*, *Phys. Rev. Lett.* **62**, 2628 (1989); P. B. Allen, *Nature* **339**, 428 (1989).
6. A. R. Bishop *et al.*, *Z. Phys. B* **76**, 17 (1989).
7. R. J. Cava *et al.*, *Physica B* **153–155**, 560 (1988).
8. M. Mali *et al.*, *Phys. Lett. A* **124**, 112 (1987); N. Nücker *et al.*, *Phys. Rev. B* **37**, 5158 (1988); A. Bianconi *et al.*, *ibid.* **38**, 7196 (1988); C. Taliani *et al.*, *Solid State Commun.* **66**, 487 (1988).
9. S. D. Conradson and I. D. Raistrick, *Science* **243**, 1340 (1989); H. Maruyama *et al.*, *Physica C* **160**, 524 (1989).
10. F. Seidler *et al.*, *Physica C* **157**, 375 (1989).
11. L. Genzel *et al.*, *Phys. Rev. B* **40**, 2170 (1989).
12. I. Batistic *et al.*, *ibid.*, p. 6896.
13. R. Zamboni, G. Ruani, A. J. Pal, C. Taliani, *Solid State Commun.* **70**, 813 (1989).
14. R. S. Markiewicz and B. C. Giessen, *Mod. Phys. Lett. B* **3**, 723 (1989); L. Pietronero and S. Strässler, *Phys. Rev. Lett.* **47**, 593 (1981).
15. C. Murayama *et al.*, *Nature* **339**, 293 (1989).
16. J. J. Caponi *et al.*, *Europhys. Lett.* **3**, 1301 (1987); M. A. Beno *et al.*, *Appl. Phys. Lett.* **51**, 57 (1987); W. I. F. David *et al.*, *Nature* **327**, 227 (1987); T. Siegrist *et al.*, *Phys. Rev. B* **35**, 7137 (1987); A. Williams *et al.*, *ibid.* **37**, 7960 (1988).
17. See J. A. Krumhansl, in *Proceedings in Life Sciences: Protein Structure, Molecular and Electronic Reactivity*, R. Austin *et al.*, Eds. (Springer-Verlag, New York, 1987).
18. C. C. Torardi *et al.*, *Science* **240**, 631 (1988).
19. M. A. Subramanian *et al.*, *J. Solid State Chem.* **77**, 192 (1988).
20. P. A. Lee *et al.*, *Rev. Mod. Phys.* **53**, 769 (1981); B.-K. Teo, *EXAFS: Basic Principles and Data Analysis* (Springer-Verlag, New York, 1986).
21. C. Y. Yang *et al.*, *Phys. Rev. B* **38**, 6568 (1988).
22. E. A. Stern and S. M. Heald, in *Handbook on Synchrotron Radiation*, E. E. Koch, Ed. (North-Holland, Amsterdam, 1983), p. 955; S. M. Heald *et al.*, *Phys. Rev. B* **38**, 761 (1988).
23. D. E. Farrell *et al.*, *Phys. Rev. B* **36**, 4025 (1987).
24. I. Ihara *et al.*, *Nature* **334**, 510 (1988); H. Ihara *et al.*, *Phys. Rev. B* **38**, 11952 (1988).
25. B.-K. Teo, *J. Am. Chem. Soc.* **103**, 3990 (1981); J. J. Bolan *et al.*, *J. Chem. Phys.* **77**, 142 (1982).
26. S. P. Cramer, K. O. Hodgson, E. I. Steifel, W. E. Newton, *J. Am. Chem. Soc.* **100**, 2748 (1978).
27. P. Eisenberger and G. S. Brown, *Solid State Commun.* **29**, 481 (1979); E. D. Crozier and A. J. Seary, *Can. J. Phys.* **58**, 1388 (1980); P. Eisenberger and B. Lengeler, *Phys. Rev. B* **22**, 3551 (1980); C. Bouldin and E. A. Stern, *ibid.* **25**, 3462 (1982).
28. S. D. Conradson and I. D. Raistrick, unpublished data.
29. J. Mustre de Leon, S. D. Conradson, I. Batistic, A. R. Bishop, manuscripts in preparation. Curve fits based on a novel approach, calculations of the EXAFS from a particular potential function floating the parameters which determine the potential to optimize the fit, provide direct support for this model of the structure and its temperature dependence beyond the qualitative analysis given here.
30. B. Renker *et al.*, *Z. Phys. B* **67**, 15 (1987).
31. D. Reagor *et al.*, *Phys. Rev. Lett.* **62**, 2048 (1989).
32. H. Monien and A. Zawadowski, *Phys. Rev. B* **41**, 6297 (1990).
33. M. Hervieu *et al.*, *J. Solid State Chem.* **75**, 212 (1988); J. B. Parise *et al.*, *ibid.* **76**, 432 (1988).
34. R. J. Cava *et al.*, *Nature* **336**, 211 (1988).
35. A. Santoro *et al.*, *Mater. Res. Bull.* **22**, 1007 (1987); S. Katano *et al.*, *Jpn. J. Appl. Phys.* **26**, L1049 (1987); R. J. Cava *et al.*, *Phys. Rev. B* **36**, 5719 (1987).
36. D. Shindo *et al.*, *Jpn. J. Appl. Phys.* **26**, L1667 (1987); J. M. Tarascon *et al.*, *Phys. Rev. B* **37**, 7458 (1988); T. J. Kistenmacher, *ibid.* **38**, 8862 (1988).
37. M. E. Lines and A. M. Glass, *Principles and Applications of Ferroelectrics and Related Materials* (Clarendon, Oxford, 1977).
38. S. K. Kurtz *et al.*, *Ferroelectrics* **87**, 29 (1988); A. Bussman-Holder *et al.*, *Phys. Rev. B* **39**, 207 (1989).
39. A. D. Bruce and R. A. Cowley, *Adv. Phys.* **29**, 219 (1980).
40. It is important to realize that the static potential double-well description we have given may only be a convenient parameterization. As in other structurally transforming perovskites (*39*), the true situation may very well be dynamic but with slower reorientation time scales, associated, for instance, with domain motions: such time scales may be strongly renormalized to lower frequencies in the transition region and below. EXAFS is effectively instantaneous ($10^{-15}$ s) and therefore gives information of only "frozen" snapshot profiles. Alternative techniques are needed to discriminate the various possible time scales (*39*).
41. Z. Tesanovic, A. R. Bishop, R. L. Martin, *Solid State Commun.* **68**, 337 (1988).
42. L. R. Testardi, W. G. Moulton, H. Mathias, H. K. Ng, C. M. Rey, *Phys. Rev. B* **37**, 2324 (1988).
43. S. K. Kurtz *et al.*, *Mater. Lett.* **6**, 317 (1989).


44. We thank A. Mayer, T. Rollet, and R. Sherman for sample preparation and x-ray powder diffraction analysis; J. Thompson for performing magnetic susceptibility measurements; J. Beery for the conductivity measurements; M. Aronson, F. Garzon, and the SSRL operations staff for their assistance in acquiring these data; R. Albers, R. Martin, Z. Fisk, D. Smith, J. Smith, K. Müller, and D. Reagor for useful discussions and for reviewing this manuscript; and R. Scott for the XAFPAK data analysis software. Data acquisition and some analysis were done at SSRL, which is funded by the Department of Energy under contract DE-AC03-82ER-13000, Office of Basic Energy Sciences, Division of Chemical Sciences and the National Institute of Health Biotechnology Resource Program, Division of Research Resources. This work was supported by the Department of Energy.

25 July 1989; accepted 27 February 1990


# North-South Contraction of the Mojave Block and Strike-Slip Tectonics in Southern California


J. M. Bartley, A. F. Glazner, E. R. Schermer



**The Mojave block of southern California has undergone significant late Cenozoic north-south contraction. This previously unappreciated deformation may account for part of the discrepancy between neotectonic and plate-tectonic estimates of Pacific–North American plate motion, and for part of the Big Bend in the San Andreas fault. In the eastern Mojave block, contraction is superimposed on early Miocene crustal extension. In the western Mojave block, contractional folds and reverse faults have been mistaken for extensional structures. The three-dimensional complexity of the contractional structures may mean that rigid-block tectonic models of the region based primarily on paleomagnetic data are unreliable.**


Deformation of the Mojave block of southern California (Fig. 1) is linked to such diverse neotectonic phenomena as movement on the San Andreas and Garlock faults, thrust faulting in the Transverse Ranges, rotation of crustal blocks, and development of the Big Bend in the San Andreas fault (*1–4*). The importance of these features to tectonic and seismic-hazard studies makes it vital to determine the kinematics of deformation in the Mojave block.


J. M. Bartley, Department of Geology and Geophysics, University of Utah, Salt Lake City, UT 84112.
A. F. Glazner, Department of Geology, Campus Box 3315, University of North Carolina, Chapel Hill, NC 27599.
E. R. Schermer, Department of Geological Sciences, University of California, Santa Barbara, CA 93106.

Neogene deformation of the Mojave block has been thought to comprise two events: early Miocene northeast-directed crustal extension (*5, 6*), and later strike-slip faulting along northwest-trending dextral faults (*7, 8*). This superposition reflects an overlap of Basin and Range extension with dextral faulting of the San Andreas fault system. Intense early Miocene extension is well documented in the eastern Mojave block and has recently been extrapolated into the western part of the block (*9*). Our field studies and compilation of published mapping indicate that the entire Mojave block may have experienced significant late Cenozoic crustal contraction, and that structures in the western Mojave block are dominantly contractional. These data require reevaluation of the Neogene kinematic evolution of the region.

Macroscopic folds and reverse or thrust faults involving early Miocene and younger rocks have been mapped in most ranges in the Mojave block (Fig. 1) (*10*). The structures generally trend east-west and thus indicate north-south contraction. This pattern is compatible with the kinematics of the bounding San Andreas and Garlock faults and the smaller dextral faults within the Mojave block, as well as with large-scale convergence in the Transverse Ranges and elsewhere along the San Andreas fault (*4, 11*).

Many of the individual structures have long been known, but they have been either neglected in regional syntheses or interpreted individually as local effects at restraining bends or at terminations of dextral faults (*12–14*). However, the distribution of these structures indicates that north-south contraction is a regional, rather than a local, phenomenon (Fig. 1). For example, contractional structures occur adjacent to the Calico fault along its entire length and indicate significant contraction as well as right-slip displacement. North-south contraction also may be responsible for some, and perhaps most, of the many east-trending range boundaries in the Mojave block. East-striking faults in the northeastern Mojave block, which previously have been interpreted as sinistral strike-slip faults (*1, 2*), may be reverse or sinistral-oblique reverse faults; limited mapping in this region indicates that these faults typically dip steeply and show evidence for significant dip slip (*15*).

Although some late Neogene basins, such as the Lavic and Bristol Lake basins, may have formed by local transtension (*14, 16*), there appear to be an insufficient number of transtensional basins to balance the contractional structures and maintain constant area during slip along the dextral faults. Net contraction of the Mojave block therefore seems to be required. Because even the largest dextral faults in the Mojave block appear to have displacements of 10 km or less (*17*), the contractional strain, although not readily quantified with available data, must represent a significant component of the total Neogene crustal strain.

Geologic relations in several areas of the eastern Mojave block indicate that this contraction was superimposed on early Miocene extension. The lower Miocene volcanic and sedimentary sequence exposed in the Rodman and Newberry mountains (Fig. 2) accumulated in an early Miocene extensional basin (*5, 18*), as were correlative strata in the nearby Waterman Hills (*19*). These rocks form southwest-dipping homoclines in the Rodman, Newberry, and Cady mountains that are interpreted to represent tilting during extension along northwest-striking normal faults (*5, 20*). However, the homocline in the Rodman Mountains actually is the north limb of a large east-trending syncline, which, as it converges westward with the Calico fault, changes from open and upright to tight and overturned (*18*) (Fig. 2A). Adjacent to the fold, the Calico fault is locally a reverse fault [(*21*) (Fig. 2A)]. Even where the fold is relatively open, its chevron style and associated thrust and reverse faults indicate that folding was due to layer-parallel contraction.

A similar contraction also affected correlative Tertiary rocks in the Newberry Mountains, which were directly west of the northeastern Rodman Mountains before 10 km of dextral slip on the Calico fault (*1*). Along the north side of Kane Wash (*5*) (Fig. 2B), Tertiary rocks are folded into an east-trending asymmetric anticline with a vertical southern limb. This structure previously was interpreted as a rollover anticline above a north-dipping, listric, oblique-normal fault that bounded the rift basin (*5*). However,

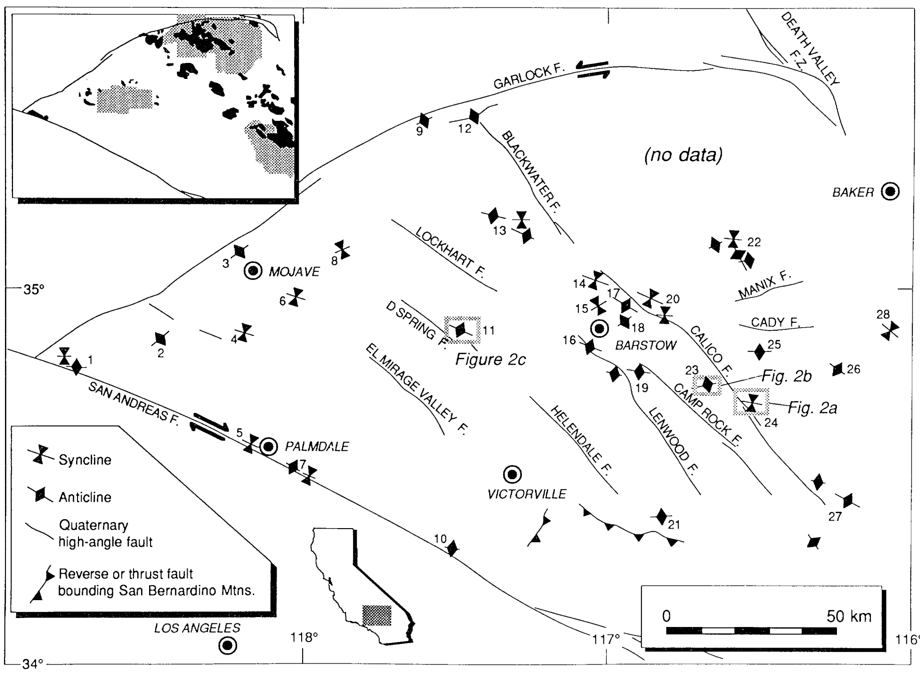


**Fig. 1.** Map of the Mojave block, which is bounded by the San Andreas fault, the Garlock fault, and the southward projection of the Death Valley fault zone, showing locations and orientations of Neogene contractional structures identified from published mapping and this study. Only the dominant structure in a given area is shown. Selected Quaternary faults are shown to illustrate the regional pattern. Northwest-striking faults show predominantly dextral shear; east-striking faults (for example, Manix and Cady) have been assumed to be sinistral but may be reverse or reverse-oblique. The inset map gives the general distribution of Tertiary rocks (black) and the locations of military bases (gray), where the geology is only known in reconnaissance. The numbers indicate the following structures and sources: 1, western Antelope Valley folds (*8*); 2, Sand Hills anticline and reverse fault (*8*); 3, Horned Toad Hills folds (*8*); 4, Rosamond Hills folds (*8*); 5, folds near Palmdale (*8*); 6, Bissell Hills syncline (*8*); 7, syncline near Little Rock (*8*); 8, Castle Butte folds (*8*); 9, Summit Diggings anticline (*8*); 10, Cajon Pass folds (*8*); 11, Kramer Hills folds (*8, 23*); 12, Lava Mountains anticline (*37*); 13, Gravel Hills folds (*12*); 14, Barstow syncline (*12*); 15, Waterman Hills syncline (*19*); 16, Lenwood anticline (*8*); 17, folded alluvium between Mitchel Range and Calico Mountains and (*28*); 18, folds at Lead Mountain (*28*); 19, folds in alluvium, Tertiary rocks, and Su Casa basement arch at restraining bend in Camp Rock fault (*5, 28*); 20, folds in Calico Mountains (*28, 38*); 21, folds and faults in alluvium in Lucerne Valley (*39*); 22, Alvord Mountain anticlines (*29*); 23, Kane Wash folds and reverse fault (*23*); 24, overturned syncline in northeastern Rodman Mountains (*18, 23*); 25, anticline in southwestern Cady Mountains (*40*); 26, anticline in southeastern Cady Mountains (*32*); 27, folds and reverse faults in alluvium between Bullion Mountains and Hidalgo Mountain (*41*); and 28, Broadwell Mesa syncline (*42*).

the anticline is locally overturned, and pre-Tertiary basement in its core is thrust over Tertiary sandstone along a reverse fault that dips 45° north. The Tertiary sandstone in the footwall is folded into a south-vergent overturned syncline. These relations indicate that the vertical dips along Kane Wash record contractional deformation of the earlier extensional basin.

In the western part of the Mojave block, blocks of tilted Tertiary strata have been interpreted to record normal faulting above a low-angle detachment (*9*). Field relations, however, indicate that steep stratal tilts in this area record contraction rather than extension. For example, the Kramer Hills (Fig. 2C) comprise pre-Tertiary granitoid and metamorphic rocks that are overlain by tilted strata of the lower Miocene Tropico Group (*8*). The outcrop pattern defines a west-plunging, close to tight, basement-cored anticline with a faulted hinge (Fig. 2C). Along both flanks of the anticline, Tropico Group limestones and tuffs contain mesoscopic to macroscopic, east-trending, upright, tight to isoclinal folds (Figs. 2C and 3). Locally, early isoclinal folds are coaxially refolded by open folds, suggesting intense shear strain. Concordant orientations indicate that the mesoscopic folds are related to the macroscopic Kramer Hills anticline. The structural style contrasts strongly with that of extensional terranes, in which upper-crustal strata are moderately to intensely extended along small-scale normal faults (*22*). Regional mapping (*8, 23*) shows that most ranges with Tertiary rocks in the western Mojave block exhibit folding like that in the Kramer Hills (Fig. 1).

Regional Miocene stratigraphy indicates that significant extension probably was limited to the eastern Mojave block. Lower Miocene rift-related strata of the eastern Mojave block are dominantly coarse syntectonic clastic deposits and voluminous intermediate volcanic rocks, like synextensional deposits elsewhere in the Basin and Range province (*24*). By contrast, Miocene deposits of the western Mojave block are mainly fine-grained lacustrine rocks, rhyolite plugs, and thin basaltic lava flows (*8*) and suggest comparative tectonic stability. In the Turkana basin of northern Kenya, a similar sequence of Miocene lacustrine sediments and basalt flows (Koobi Fora Formation) appears to have been deposited on what, during the Miocene, was the unfaulted outer flank of the East African rift system (*25*). Structural and stratigraphic data therefore suggest that the western Mojave block lay outside of the belt of early Miocene extension.

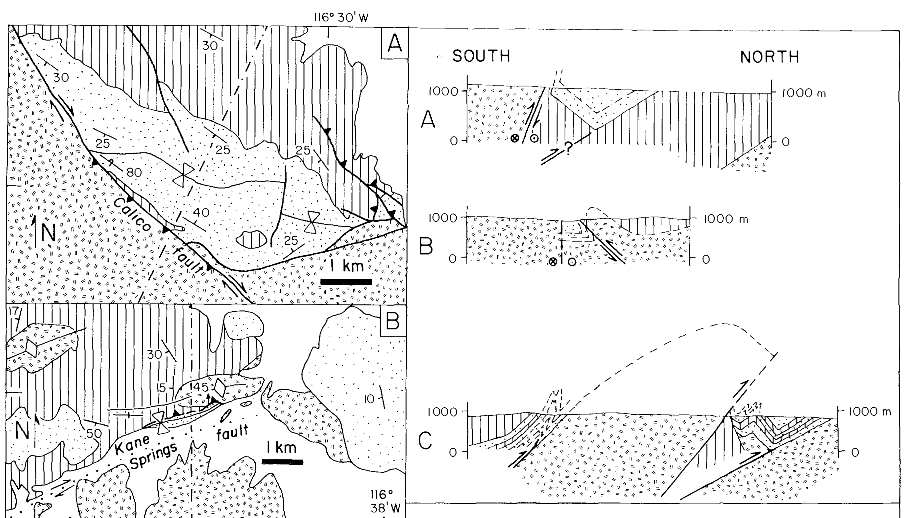


**Fig. 2.** Simplified geologic maps and cross sections of (**A**) northeastern Rodman Mountains (*18, 23*), (**B**) Kane Wash area and Newberry Mountains (*5, 23*), and (**C**) Kramer Hills (*8, 23*). Orientation of reverse fault in Kane Wash area is from measurements of an exposure of the fault plane, whereas the orientation of the reverse fault in the Kramer Hills was calculated from deflection of the mapped fault trace crossing surface topography. Interpretation of the major folds as fault-propagation folds at blind thrust tips is consistent with, but not required by, our data.

Data previously cited by Dokka (*9*) in support of Miocene extension of the western Mojave block include (i) an apparent normal fault imaged in a shallow seismic-reflection profile across Antelope Valley (southwestern Mojave block), (ii) subhorizontal deep-crustal reflectors imaged by a COCORP seismic-reflection experiment, and (iii) a proposed exposure of an extensional detachment fault near Harper Lake (northwest of Barstow, California). The normal fault interpretation of the Antelope Valley seismic profile is plausible, but no data were presented to document the ages or lithology of rocks imaged at depth. The nearest pre-Quaternary outcrops are 12 km from the profile, and no subsurface (drillhole) data were presented. The profile therefore permits, but does not require, Tertiary extension in the area. The deep reflectors imaged by COCORP could be extensional detachments, but are equally consistent with other interpretations such as thrust faults or sills. Li and Henyey (*26*) reprocessed the COCORP data to enhance imaging of upper-crustal structures, and found apparent reverse faults and contractional basins in Antelope Valley. Reexamination of outcrops in the Harper Lake area indicates that the inferred detachment is a locally faulted Mesozoic intrusive contact (*19*), as Dibblee (*12*) reported.

The western and eastern parts of the Mojave block have thus undergone different Neogene tectonic histories. The resulting structural geometries in both areas are complex. Polyphase deformation of Miocene strata in the eastern Mojave block resulted in complex three-dimensional fold and fault geometries (Fig. 2) (*19*). Even in the absence of superposed deformations, the Kramer Hills of the western Mojave block are characterized by cover detached from the basement along a complexly folded horizon of lacustrine strata (Figs. 2C and 3), forming noncylindrical plunging folds. In such complex structures, the conventional structural correction of paleomagnetic vectors (rotation about the strike line) will yield declination anomalies that are not a result of vertical-axis block rotation (*27*). Regional-tectonic models for this area based on rotation of rigid blocks defined by paleomagnetic data (*2, 14*) are therefore unlikely to be accurate.

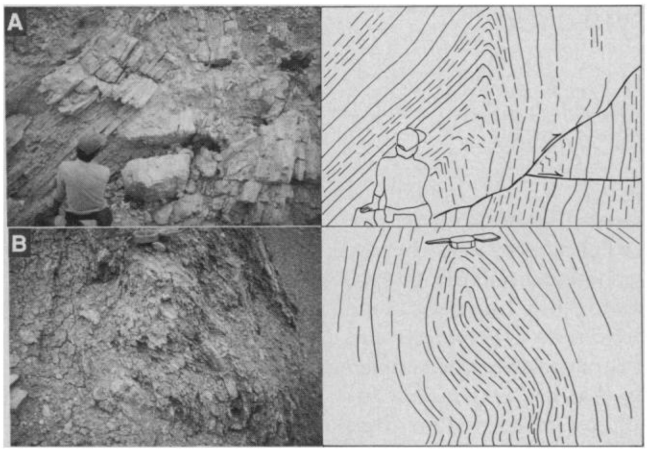


**Fig. 3.** Field photos and line drawings of folded Tertiary lacustrine strata in the Kramer Hills. See Fig. 2C for locations. (**A**) Overturned antiform, north limb of Kramer Hills anticline; view is to the west. (**B**) Refolded isoclinal fold on south limb of Kramer Hills anticline; view is to the east. Compass at top is 22 cm long.

The age of extension in the Mojave is well constrained in the early Miocene (*19*), but age constraints on contraction and dextral faulting of the Mojave block are few, suggesting protracted and diachronous deformation. Locally, unconsolidated alluvial deposits (inferred Quaternary age) are folded (*7, 28, 29*) (Fig. 2C), and thus contraction could continue at the present time. The Barstow syncline (*12*) (Fig. 1, location 14) formed after deposition of the Barstow Formation, the youngest part of which is about 13 million years old (*30*). However, the 18.5-million-year-old Peach Springs Tuff (*31*) overlaps folded 23- to 20-million-year-old synextensional volcanic rocks in the Cady and Newberry mountains (*5, 32*). This relation indicates that north-south contraction (and, by inference, dextral faulting) locally may have begun as early as 19 million years ago, a million years or less after extension ceased. Humphries and Weldon (*33*) argue that slip on dextral precursors of the San Andreas fault system also began in the early Miocene.

North-south contraction of the Mojave block via folding and thrust faulting would contribute to formation of the Big Bend, a 25° counterclockwise deflection of the San Andreas fault trace. Garfunkel (*1*) proposed that the Big Bend is a consequence of north-south contraction of the Mojave block accommodated by dextral faulting and resulting counterclockwise rotation of rigid crustal blocks and their bounding faults. With current estimates of the total slip (27 to 38 km) (*17*) across major dextral faults in the Mojave block, Garfunkel's geometric model yields a bulk shear strain of 0.24 to 0.33 and predicts a 15° to 20° counterclockwise rotation of the San Andreas fault. This estimate leaves 5° to 10° of rotation that may be accounted for by internal contraction of the blocks along folds and thrust faults. Paleomagnetic results from relatively undeformed Neogene strata in the central Mojave block are contradictory, with some results supporting this rotation estimate and others indicating little or no rotation (*30, 34*). Whether Garfunkel's model is valid or not, some of the rotation to form the Big Bend probably was achieved by folding and thrusting within the Mojave block.

North-south contraction of the Mojave block may also account for part of the discrepancy between plate-tectonic and neotectonic estimates of Pacific–North American relative plate motion. Studies indicate that present-day displacements across active strike-slip faults in southern California fail to account for a significant portion of the relative plate motion (*4, 35*). The vector of missing neotectonic displacement trends approximately north and represents a displacement rate of about 10 mm per year (*35*). Seismic and geodetic studies in the area (*36*) suggest that modern deformation in the Mojave block is dominated by dextral slip and the present contraction rate may be insufficient to account for all of the missing displacement. More data are needed to determine the total amount and present rate of north-south contraction of the Mojave block and thus to evaluate how much of the relative slip between the North American and Pacific plates may be absorbed in this way.

### REFERENCES AND NOTES


1. Z. Garfunkel, *Bull. Geol. Soc. Am.* **85**, 1931 (1974).
2. B. P. Luyendyk, M. J. Kamerling, R. Terres, *ibid.* **91** (part I), 211 (1980).
3. P. Bird and R. W. Rosenstock, *ibid.* **95**, 946 (1984).
4. R. J. Weldon and E. Humphreys, *Tectonics* **5**, 33 (1987).
5. R. K. Dokka, *Geol. Soc. Am. Spec. Pap.* **208**, 75 (1986).
6. A. F. Glazner, J. M. Bartley, J. D. Walker, *Geology* **17**, 50 (1989).
7. T. W. Dibblee, Jr., *U.S. Geol. Surv. Prof. Pap.* **424-B**, 197 (1961).
8. ______, *ibid.*, p. 522.
9. R. K. Dokka, *Tectonics* **8**, 363 (1989).
10. The regional distribution of structures in Fig. 1 is strongly influenced by exposure and detail of extant mapping. Related structures may well occur unrecognized within blank areas on Fig. 1 in the western, northeastern, and southern Mojave block.
11. M. L. Hill and T. W. Dibblee, Jr., *Bull. Geol. Soc. Am.* **64**, 443 (1953); M. L. Hill, *Geology* **18**, 23 (1990); T. P. Harding, *Bull. Am. Assoc. Pet. Geol.* **60**, 356 (1976); J. Namson and T. Davis, *Geology* **16**, 675 (1988).
12. T. W. Dibblee, Jr., *Calif. Div. Mines Geol. Bull.* **188** (1968).
13. R. K. Dokka, *Geol. Soc. Am. Abstr. Program* **19**, 645 (1987).
14. R. K. Dokka and C. J. Travis, in *The West-Central Mojave Desert: Quaternary Studies Between Kramer and Afton Canyon*, R. E. Reynolds, Ed. (San Bernardino County Museum, Redlands, CA, 1989), pp. 65–68.
15. T. W. Dibblee, Jr., and A. M. Bassett, *U.S. Geol. Surv. Misc. Geol. Inv. Map I-467* (1966); J. R. Keaton and R. T. Keaton, *Calif. Geol.* **30**, 177 (1977).
16. A. F. Glazner, thesis, University of California at Los Angeles, Los Angeles, CA (1981).
17. R. K. Dokka, *Geology* **11**, 305 (1983).
18. W. K. Sanner, thesis, University of North Carolina, Chapel Hill, NC (1985).
19. J. D. Walker, J. M. Bartley, A. F. Glazner, *J. Geophys. Res.* **95**, 557 (1990).
20. T. W. Dibblee, Jr., *U.S. Geol. Surv. Misc. Geol. Inv. Map. I-430* (1964).
21. D. L. Gardner, *Calif. J. Mines Geol.* **36**, 257 (1940).
22. G. A. Davis, J. L. Anderson, E. G. Frost, T. J. Shackelford, *Mem. Geol. Soc. Am.* **153**, 79 (1980).
23. J. M. Bartley, A. F. Glazner, E. R. Schermer, unpublished mapping.
24. P. B. Gans, G. Mahood, E. R. Schermer, *Geol. Soc. Am. Spec. Pap. 233* (1989).
25. C. Feibel, personal communication.
26. Y. G. Li and T. L. Henyey, *Eos* **70**, 1214 (1989).
27. L. S. Chan, *J. Geophys. Res.* **93**, 12151 (1988).
28. T. W. Dibblee, Jr., *U.S. Geol. Surv. Misc. Geol. Inv. Map I-592* (1970).
29. F. M. Byers, Jr., *U.S. Geol. Surv. Bull. 1089-A* (1960).
30. D. B. Burke, J. W. Hillhouse, E. H. McKee, S. T. Miller, J. L. Morton, *U. S. Geol. Surv. Bull. 1529-E* (1982); B. J. MacFadden, M. O. Woodburne, N. D. Opdyke, *Geol. Soc. Am. Abstr. Program* **20**, 176 (1988).
31. J. E. Nielson, D. R. Lux, G. B. Dalrymple, A. F. Glazner, *J. Geophys. Res.* **95**, 571 (1990).
32. A. F. Glazner, *Bull. Geol. Soc. Am.* **100**, 424 (1988).
33. E. D. Humphries and R. J. Weldon, *Am. Assoc. Pet. Geol. Mem.*, in press.
34. R. E. Wells and J. W. Hillhouse, *Geol. Soc. Am. Bull.* **101**, 846 (1989).
35. C. DeMets, R. G. Gordon, S. Stein, D. F. Argus, *Geophys. Res. Lett.* **14**, 911 (1987).
36. N. E. King, *J. Geophys. Res.* **90**, 4491 (1985); S. N. Ward, *ibid.* **93**, 7716 (1988).
37. G. I. Smith, *U. S. Geol. Surv. Prof. Pap. 457* (1964).
38. D. W. Tarman and D. M. Thompson, in *Geologic Excursions in the Mojave Desert*, L. Gaskin, Compiler (Guidebook for Spring Conference of Far Western Section, National Association of Geology Teachers, Barstow College, Barstow, CA, 1988), p. 31.
39. T. W. Dibblee, Jr., *U.S. Geol. Surv. Misc. Geol. Inv. Map I-426* (1964).
40. ______, *ibid. I-461* (1966).
41. ______, *ibid. I-488* (1967); *ibid. I-490* (1967).
42. ______, *ibid. I-478* (1967).


43. This work was supported by National Science Foundation grants EAR-8816944 to J.M.B. and EAR-8817071 and EAR-8219032 to A.F.G. and by a University of California President's Fellowship to E.R.S. Discussions with J. D. Walker and B. F. Cox contributed significantly to the ideas presented here and critical review of the manuscript by K. A. Howard led to clarification.

19 December 1990; accepted 14 March 1990