studies. Together these data will be used to develop a model of the structural architecture and motion history associated with the Transantarctic Mountains in southern Victoria Land.

We thank Jane Ferrigno for cooperation and advice on image selection; John Snowden, David Cunningham, and Tracy Douglass at the Ohio State University Center for Mapping for help with computer processing; and Carolyn Merry, Gary Murdock, and Ralph von Frese for helpful discussions concerning image analysis. This research was supported by National Science Foundation grant OPP 90-18055 and by the Byrd Polar Research Center of Ohio State University.

References

Isachsen, Y.W. 1974. Fracture analysis of New York State using multistage remote sensor data and ground study: Possible application to plate tectonic modeling. In R.A. Hodgson, S.P. Gay, Jr., and J.Y. Benjamins (Eds.), *Proceedings of the First International Conference on the New Basement Tectonics* (Publication number 5). Utah Geological Association.

Lucchita, B.K., J. Bowell, K.L. Edwards, E.M. Eliason, and H.M. Ferguson. 1987. *Multispectral Landsat images of Antarctica* (U.S. Geological Survey bulletin 1696). Washington, D.C.: U.S. Government Printing Office.

Wilson, T.J. 1992. Mesozoic and Cenozoic kinematic evolution of the Transantarctic Mountains. In Y. Yoshida, K. Kaminuma, and K. Shiraishi (Eds.), *Recent progress in antarctic earth science*. Tokyo: Terra Scientific.

Wilson, T.J. 1993. Jurassic faulting and magmatism in the Transantarctic Mountains: Implication for Gondwana breakup. In R.H. Findlay, M.R. Banks, R. Unrug, and J. Veevers (Eds.), *Gondwana 8—Assembly, evolution, and dispersal*. Rotterdam: A.A. Balkema.

Wilson, T.J., P. Braddock, R.J. Janosy, and R.J. Elliot. 1993. Fault kinematic studies in the Transantarctic Mountains, southern Victoria Land. *Antarctic Journal of the U.S.*, 28(5).

Fault kinematic studies in the Transantarctic Mountains, southern Victoria Land

TERRY J. WILSON, PETER BRADDOCK, *and* ROBERT J. JANOSY, *Byrd Polar Research Center* and *Department of Geological Sciences, Ohio State University, Columbus, Ohio 43210*
R. JAMES ELLIOT, *Department of Geological Sciences, University of California, Santa Barbara, California 93106*

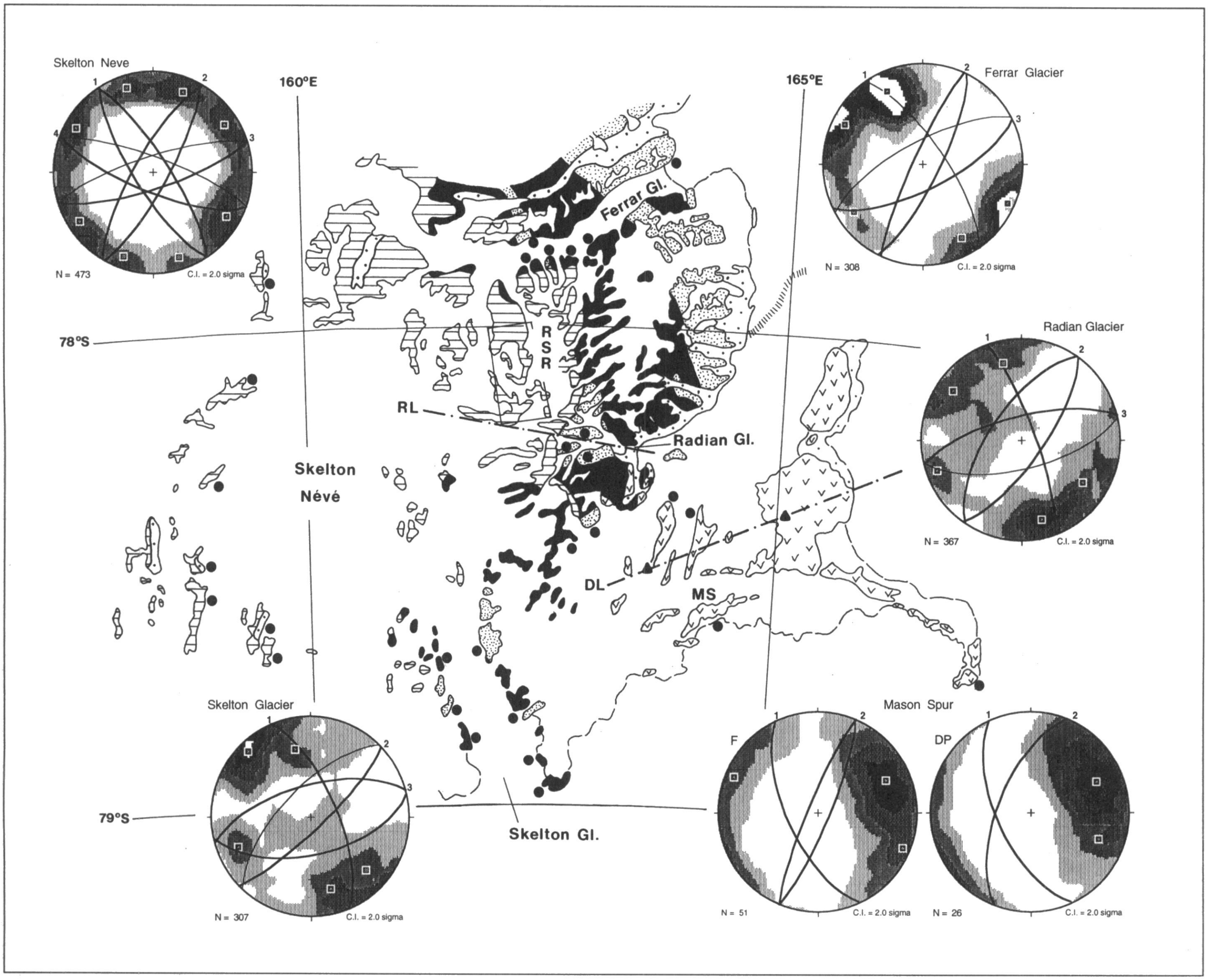
Continental rift systems are segmented along their length into discrete structural basins that are linked by transverse structures known as *transfer faults* or *accommodation zones* (Gibbs 1984; Rosendahl 1987). The transverse structures not only permit changes in the orientation and sense of asymmetry of the normal-slip border-fault systems that define the rift margins but they also accommodate variations in the direction and magnitude of crustal extension across the rift. The orientations of such transverse fault zones and the displacement patterns along them are, thus, keys to evaluating the plate motions associated with rifting. Knowing the timing of development of transverse structures relative to adjacent rift basins is also critical to understanding how rift faults propagate and link to form a continuous rift system as continental crust is stretched prior to breakup (see, for example, Bosworth 1985).

The Mesozoic–Cenozoic west antarctic rift system is of comparable scale to other major continental rifts and should have an analogous structural segmentation. Regional kinks and offsets in the coastline of the Transantarctic Mountains and offshore rift basins of the Ross embayment are believed to mark transverse structures that subdivide the rift system (Cooper, Davey, and Hinz 1991; Tessensohn and Wörner 1991); they have been modeled as transfer faults, but the structural character of these zones has not previously been investigated. One of the most prominent transverse offsets occurs along the southern end of the Royal Society Range, where the Transantarctic Mountain chain steps westward toward the Byrd Glacier. This transverse zone was the site of voluminous magmatism in the Jurassic, pointing to development during the early, prebreakup phase of rifting. Cenozoic activity within the transverse zone is indicated by the localization of the Erebus volcanic province along it, and it has been proposed that Mount Morning, Mount Discovery, and satellite volcanic centers are aligned along a transfer fault within the zone (figure; Wright-Grassham 1987; Kyle 1990). The large extent and complex morphotectonics of the region between the Royal Society Range and Byrd Glacier indicate that it is a diffuse structural corridor more reminiscent of east African accommodation zones than of simple transfer faults. The transverse step as a whole is, therefore, designated here as the *Discovery accommodation zone.*

Determining the structural development of the Discovery accommodation zone is the principal focus of the ongoing research described here. Structural kinematic analysis of brittle fault and dike arrays is being used to map the displacement patterns along and across the zone. During the 1992–1993 field season, brittle fault studies were undertaken at Ferrar Glacier, Radian Glacier, Skelton Glacier, Skelton Névé, the Royal Society Range, and in the Mount Discovery area (figure). Specific scientific objectives and a preliminary summary of results are described below for each of the regions covered during the season.

Ferrar Glacier

The Ferrar Glacier occupies a major morphologic trough transverse to the Transantarctic Mountains, and some researchers have suggested that it is controlled by a structure called the Ferrar Fault (Gunn and Warren 1962; Findlay, Skinner, and Craw 1984; Fitzgerald 1987, 1992). To document the kinematics associated with this proposed structure, fault patterns were investigated in exposures along the glacier margins. The most intense faulting occurs along the Cathedral Rocks, where the dominant fault set trends east-northeast (figure, set 3), parallel to the glacial trough, and has dominantly normal- and left-slip motion. This supports the suggestion that a component of extension occurred across the Ferrar trough. The presence of volcanic vents of probable Pliocene age along the glacier margins suggests activity along this trend in the late Cenozoic, probably as a reactivation of an older structural trend. A northeast-trending fault set (figure, set 2) with mainly normal displacement is best developed in exposures near the Ross Sea margin of the mountains.



Map and new structural data from the study area. Geologic sketch map modified from Warren (1969) and Findlay, Skinner, and Craw (1984). [Dense stipple pattern denotes metasedimentary rocks of the Skelton and Koettlitz Groups; black denotes igneous rocks of the Granite Harbor Intrusive Complex and undifferentiated basement rocks; horizontal line pattern denotes Beacon and Ferrar Supergroup rocks; bold stipple pattern denotes surficial deposits; heavy dash-dot lines mark the Radian lineament (RL) and the transfer fault proposed by Wright-Grassham (1987) and Kyle (1990) through Mount Morning and Mount Discovery (DL); MS denotes Mason Spur; RSR denotes the Royal Society Range; black circles mark data localities; box shows area of exposures examined to the west of the Royal Society Range; black triangles mark Mount Morning and Mount Discovery.] Lower hemisphere, equal area projections show graphical compilations of new fault plane data from each major subregion of the study area. Note that fault sets 1 and 2 occur at all localities and fault set 3 occurs everywhere except in Cenozoic volcanic outcrops at Mason Spur. [Shading indicates concentrations of poles to (that is, lines perpendicular to) fault planes contoured by the Kamb method; average fault poles shown by squares and corresponding average fault plane orientations shown by great circle curves; at Mason Spur, F denotes fault plane data and DP denotes dike plane data; numbers 1–4 designate fault sets].

Radian Glacier

Satellite imagery of the area has revealed a prominent linear feature transecting the southern end of the Royal Society Range, termed here the Radian lineament (RL, figure; Lucchita et al. 1987; see also Wilson and Bradford, *Antarctic Journal*, in this issue). Exposures of basement rocks at Rucker Ridge, Radian Ridge, and Dismal Ridge were examined to determine the geometry and kinematics of this structure. Considerable scatter in the orientation of fault planes at these localities reflects reactivation of preexisting banding and foliation surfaces within metasedimentary rocks in response to rift-related stresses. Discrete fault sets are present, however, with the most prominent trending east-northeast (figure, set 3). Because this set becomes dominant in exposures closest to the Radian Glacier trough, it must be related to the lineament structure, but the fault set makes an acute angle to the overall west-northwest trend of the lineament as a whole. The presence of Ferrar dikes and associated fault planes of this east-northeast orientation in the Bishop Peak area, just north of the western extension of the Radian lineament (box in the figure), suggests a Jurassic age for this set of structures. Superposed striae on faults of the set, however, indicate subsequent motion, probably contemporaneous with emplacement of widespread late Cenozoic volcanic rocks in this sector of the Royal Society Range.

Skelton Glacier

The relatively continuous outcrops along the margins of Skelton Glacier were systematically searched for transverse faults associated with the westward step in the Transantarctic Mountains across the Discovery accommodation zone. Exposures between Fishtail Point in the south and the Baronick Glacier in the north were reached by Ski-doo traverses from a centrally located base camp near Ant Hill (figure). Fieldwork was hampered by periods of very high winds and, later, by a heavy snowfall; thus, although most of the large exposures were visited, none of the smaller outcrops were examined due to time constraints. Reactivation of banding and foliation surfaces as small-scale brittle faults occurred commonly in the metasedimentary units, accounting for some of the scatter in fault-plane orientation (figure). Granitoids in the area are either nonfoliated or contain a weak alignment of crystals and mafic inclusions that may represent a magmatic flow foliation; thus, brittle fault sets at these localities are clearly unrelated to older structural fabrics. The two dominant fault sets at Skelton Glacier trend northeast and east-northeast transverse to the Transantarctic Mountains trend (figure, set 2 and set 3); a third, northwest-trending set (figure, set 1) parallels the glacier and may have controlled its development.

Skelton Névé

Intrusive rocks of the Jurassic Ferrar Group are particularly abundant around Skelton Névé, suggesting that magmatic activity was localized in this part of the Transantarctic Mountains in the Jurassic. The orientation patterns of Ferrar dolerite dikes and associated faults in nunataks exposing Beacon Supergroup sedimentary rocks around Skelton Névé were mapped to establish the orientation of structures formed during Jurassic rifting. Exposures at Tate Peak, Escalade Peak, Spot Height 1890 (78°32'S 158°49'E) and Alligator Peak (both in the Boomerang Range), Mount Metschel, Portal Mountain, and Mount Crean were visited by Ski-doo traverse from three base camps (figure). Faults were discovered to be preferentially developed within the Beacon Heights Orthoquartzite of the Devonian Taylor Group. This massive, indurated unit apparently acted as the dominant stress-bearing structural lithic unit within the Beacon sequence. Field relations show that faulting preceded and accompanied intrusion of the Ferrar dolerites. The most prominent fault sets trend northwest and northeast (figure, set 1 and set 2); fault sets with east-northeast and west-northwest trends (figure, set 3 and set 4) are also well developed at some localities. Ferrar dikes most commonly strike northwest and dip at moderate angles to the southwest. Dike sets trending northeast and east-northeast are also locally developed. These Ferrar dike orientations are comparable to those further north in southern Victoria Land (Wilson 1990), but at Skelton Névé there is more scatter in orientation and dikes dip less steeply.

West of the Royal Society Range

Scattered, high-elevation exposures of Beacon Supergroup rocks around Bishop Peak and in the Emmanuel Glacier area were visited using helicopter close support. The trends of Ferrar dolerite dikes and associated faults were mapped with the objective of establishing whether the transverse Radian lineament first formed during Jurassic rifting. Parallelism between dikes and faults around Bishop Peak and the dominant east-northeast fault set at Radian Glacier supports a Jurassic age. Further north in the Emmanuel Glacier area, both dike and fault planes trend northwest and northeast, with substantial scatter in orientation.

Mount Discovery area

Reconnaissance investigations of the relations between fault sets and Cenozoic volcanic flows and dikes of the McMurdo Volcanic Group were carried out at Lake Morning, "Gandalf Ridge" (78°21'S 164°08'E), Mason Spur, and the southeast cape of Minna Bluff, where these structures had been discovered in previous studies (Wright-Grassham 1987; Kyle and Muncy 1989). This work was undertaken to determine which fault sets were active during the Cenozoic morphologic uplift of the mountains. The most complete data set was collected at Mason Spur, where fault and dike sets show both northwest and northeast trends (figure, set 1 and set 2). This structural pattern is remarkably similar to that in northern Victoria Land within both the Melbourne volcanic province (Lanzafame and Villari 1991) and the Hallett volcanic province (Jordan 1981). It indicates that extension occurred both perpendicular and oblique to the Transantarctic Mountains trend since approximately 12 million years ago.

In summary, during the 1992–1993 field season, brittle fault and dike trends were mapped at localities spanning the Transantarctic Mountains between Ferrar Glacier and Skelton Glacier and between the Ross Sea coast and the Skelton Névé on the polar plateau. The summary data plots presented in the figure show there is a regionally consistent orientation of brittle fault sets in this location. It is important to note, however, that there are local variations in fault trend that are averaged in these summary plots but that are significant in the structural development of each subregion. The northeast regional fault trend (set 2 in the figure) may have first formed in the Paleozoic, contemporaneously with emplacement of the Vanda dike swarm (Wilson 1992; Janosy and Wilson 1992), but data gathered this season clearly show that extension perpendicular to this set has also occurred in the Jurassic and in the late Cenozoic. The northwest fault trend (set 1 in the figure) is present in all areas but is best developed at Skelton Névé and Mason Spur. The dominant northwest orientation of Ferrar dikes and associated faults in the Transantarctic Mountains suggests this trend first developed during Jurassic rifting (Wilson 1993); a component of extension perpendicular to this trend is also indicated by the new Cenozoic data. The dominance of the east-northeast fault trend (set 3 in figure) at Ferrar Glacier, Radian Glacier, and Skelton Glacier marks this as the principal transverse fault set associated with the Discovery accommodation zone.

Detailed evaluation of the age and motion patterns of the brittle fault sets is underway. These data will be used to refine the relative displacement history between East and West Antarctica during Gondwana breakup and development of the west antarctic rift system. The regional orientation patterns of the outcrop-scale fault and dike arrays are being compared to large-scale structures identified from satellite imagery and from previous geological mapping. A reconstruction of the regional structural architecture of the major "step" in the Transantarctic Mountains across the Discovery accommodation zone will be made from these data. This will also establish the relation, if any, between brittle fault geometries and structural trends within the crystalline basement rocks to determine whether the preexisting basement structure controlled the architecture of the superimposed rift structures. These results will be used to compare the rift-margin architecture with that of other rift systems and, thus, to refine models of rift development and mountain uplift.

Helicopter-supported fieldwork by Wilson and Braddock began in late October 1992 and continued through January 1993. Elliot and Janosy participated in fieldwork on Skelton Glacier and Skelton Névé during late November and December 1992; this part of the field program was carried out by Skidoo supported by Twin Otter. Excellent logistic support by staff of Antarctic Support Associates in McMurdo, VXE-6 squadron of the U.S. Navy, and Kenn Borek Air was critical in the success of this ambitious field season. This research was supported by National Science Foundation grant OPP 90-18055.

References

Bosworth, W. 1985. Geometry of propagating continental rifts. *Nature*, 316, 625–627.

Cooper, A.K., F.J. Davey, and K. Hinz. 1991. Crustal extension and origin or sedimentary basins beneath the Ross Sea and Ross Ice Shelf, Antarctica. In M.R.A. Thomson, J.A. Crame, and J.W. Thomson (Eds.), *Geological evolution of Antarctica*. Cambridge: Cambridge University Press.

Findlay, R.H., D.N.B. Skinner, and D. Craw. 1984. Lithostratigraphy and structure of the Koettlitz Group, McMurdo Sound, Antarctica. *New Zealand Journal of Geology and Geophysics*, 27, 513–536.

Fitzgerald, P.G. 1987. Uplift history of the Transantarctic Mountains in the Ross Sea sector and a model for their formation. (Doctoral Dissertation, University of Melbourne, Victoria, Australia.)

Fitzgerald, P.G. 1992. The Transantarctic Mountains of southern Victoria Land: The application of apatite fission track analysis to a rift shoulder uplift. *Tectonics*, 11, 634–662.

Gibbs, A.D. 1984. Structural evolution of extensional basin margins. *Geological Society of London, Journal*. 141, 609–620.

Gunn, B.M., and G. Warren. 1962. Geology of Victoria Land between the Mawson and Mullock Glaciers, Antarctica. *New Zealand Geological Survey Bulletin*, 71, 157.

Janosy, R.J., and T.J. Wilson. 1992. Structural investigations of early Paleozoic mafic dike swarms in the Royal Society Range, southern Victoria Land. *Antarctic Journal of the U.S.*, 27(5), 9–10.

Jordan, H. 1981. Tectonic observations in the Hallett volcanic province, Antarctica. *Geologisches Jahrbuch*, B41, 111–125.

Kyle, P.R. 1990. Erebus Volcanic Province: Summary. In W.E. LeMasurier and J.W. Thomson (Eds.), *Volcanoes of the antarctic plate and southern oceans* (Antarctic Research Series, Vol. 48). Washington, D.C.: American Geophysical Union.

Kyle, P.R., and H.L. Muncy. 1989. Geology and geochronology of McMurdo Volcanic Group rocks in the vicinity of Lake Morning, McMurdo Sound, Antarctica. *Antarctic Science*, 1(4), 345–350.

Lanzafame, G., and L. Villari. 1991. Structural evolution and volcanism in northern Victoria Land (Antarctica): Data from Mt Melbourne–Mt Overlord–Malta Plateau region. *Memorie della Società Geologica Italiana*, 46, 371–381.

Lucchita, B.K., J. Bowell, K.L. Edwards, E.M. Eliason, and H.M. Ferguson. 1987. *Multispectral Landsat images of Antarctica* (U.S. Geological Survey bulletin 1696). Washington, D.C.: U.S. Government Printing Office.

Rosendahl, B.R. 1987. Architecture of continental rifts with special reference to East Africa. *Annual Review of Earth and Planetary Sciences*, 15, 445–503.

Tessensohn, F., and G. Wörner. 1991. The Ross Sea rift system, Antarctica: Structure, evolution and analogues. In M.R.A. Thomson, J.A. Crame, and J.W. Thomson (Eds.), *Geological evolution of Antarctica*. Cambridge: Cambridge University Press.

Warren, G. 1969. Geology of the Terra Nova Bay–McMurdo Sound area, Victoria Land. In V.C. Bushnell and C. Craddock (Eds.), *Geologic maps of Antarctica* (Antarctic Map Folio Series, Folio 12, Plate 13). New York: American Geographic Society.

Wilson, T.J. 1990. Mesozoic and Cenozoic structural patterns in the Transantarctic Mountains, southern Victoria Land. *Antarctic Journal of the U.S.*, 25(5), 31–35.

Wilson, T.J. 1992. Brittle fault arrays in the Royal Society Range, southern Victoria Land. *Antarctic Journal of the U.S.*, 27(5), 6–8.

Wilson, T.J. 1993. Jurassic faulting and magmatism in the Transantarctic Mountains: Implications for Gondwana breakup. In R.H. Findlay, M.R. Banks, R. Unrug, and J. Veevers (Eds.), *Gondwana 8—Assembly, evolution, and dispersal*. Rotterdam: A.A. Balkema.

Wilson, T.J., and S.C. Bradford. 1993. Satellite image analysis of the Transantarctic Mountains, southern Victoria Land, *Antarctic Journal of the U.S.*, 28(5).

Wright-Grassham, A.C. 1987. Volcanic geology, mineralogy and petrogenesis of the Discovery volcanic subprovince, southern Victoria Land, Antarctica. (Doctoral dissertation, New Mexico Institute of Mining and Technology, Socorro, New Mexico.)