Geological and geophysical investigations in the northern Ford Ranges, Marie Byrd Land, West Antarctica

BRUCE P. LUYENDYK, STEVE M. RICHARD,
and CHRISTINE H. SMITH

Institute for Crustal Studies
University of California
Santa Barbara, California 93106–1100

DAVID L. KIMBROUGH

Department of Geological Sciences
San Diego State University
San Diego, California 92182

The Phillips, Fosdick, and Chester Mountains are located in the northern Ford Ranges of western Marie Byrd Land. They trend east-west and are separated by about 15–20 kilometers (figure 1). Plutonic rocks crop out in the Phillips and Chester Mountains while the Fosdick Mountains comprise high-grade metamorphic rocks. The Ford granodiorite is a Devonian-Carboniferous granodiorite-tonalite found in the Phillips and Chester Mountains and the Denfield Mountains immediately to the south; the Byrd Coast granite is a Cretaceous epizonal granite which is ubiquitous throughout the Ford Ranges (Wade, Cathey, and Oldham 1977a, 1977b, 1978). The Fosdick metamorphic complex comprises migmatized paragneiss and orthogneiss found in the Fosdick Mountains (Wilbanks 1972). We conducted field studies during the 1989–1990 and 1990–1991 austral summers in these ranges. The field studies included mapping, structural measurements, and sampling for isotopic, paleomagnetic, and petrological investigations (Project FORCE; Ford Ranges Crustal Exploration). (See also Kimbrough et al. 1990.) The field team included the authors and mountaineers Alasdair Cain and Steve Tucker for 1989–1990 and John Roberts and Terry Schmidt for 1990–1991.

The Phillips, Fosdick, and Chester Mountains form one or more south-dipping tilted blocks. The north face of the Fosdick Mountains is defined by spectacular cliffs up to 500 meters high. A subhorizontal geomorphic surface seen in the Phillips (Mount Paige) and the eastern Fosdick Mountains, may be the Late Cretaceous/Early Tertiary erosion surface described throughout Marie Byrd Land by LeMasurier and Rex (1983). Our field mapping resulted in revisions to the maps of Wade, Cathey, and Oldham (1977a, 1978). In the Phillips Mountains, outcrops at 145°W are Ford granodiorite not Byrd Coast granite, and Herrmann Nunatak is Ford granodiorite not Byrd Coast granite. In the Fosdick Mountains, some outcrops mapped as Fosdick metamorphic rocks in the east are Cenozoic volcanics. A transitional plutonic-metamorphic rock unit (Neptune-Griffiths transitional rocks) has been defined for rocks exposed on Neptune and Griffith Nunataks and on the south side of Mount Richardson. It comprises foliated hornblende-biotite tonalite or granodiorite (Ford granodiorite?) with metamorphic enclaves. It is interpreted to represent the transition between the Fosdick Complex and the Ford granodiorite of the Chester Mountains.

Fosdick metamorphic complex. The Fosdick Mountains provide an opportunity for direct observation of the deeper levels of continental crust in this segment of Marie Byrd Land. The Fosdick metamorphic complex consists primarily of a variety of interlayered migmatitic orthogneisses and paragneiss. The complex is subdivided into three structural-lithologic assemblages:

- predominantly metapelitic gneisses with a steep S_1 and strong crenulation imposed by development of subhorizontal S_2 (Avers assemblage);
- predominantly granitoid orthogneisses, well layered in S_2, with subsidiary layers of paragneiss (Bird Bluff assemblage); and
- transitional metamorphic/plutonic rocks (Neptune-Griffiths transitional rocks).

We interpret that the protolith for the paragneiss component of the Fosdick metamorphic complex was a relatively homogeneous graywacke-argillite, probably correlative with the Cambro-Ordovician Swanson Formation (Bradshaw, Andrews and Field 1983), intruded by granodiorite plutons (Devonian-Carboniferous Ford granodiorite?). The mixed orthogneiss and paragneiss of the northern part of the complex pass southward, structurally upward, into mostly granodioritic orthogneiss. Biotite, sillimanite, garnet, cordierite, quartz and potassium-feldspar are present in pelitic gneisses throughout the range. Petrologic observations indicate a clockwise pressure-temperature path with an episode of near-isothermic decompression at the time of migmatization. Leucogranitic neosome bodies range from homotropic and crosscutting to gneissic and concordant, demonstrating that migmatization and the development of penetrative gneissic foliation were coeval. Peak metamorphic conditions are estimated at 4–5 kilobars and 725–800 °C. Preliminary uranium-lead data indicate that migmatization occurred during Mesozoic time, overprinting older metamorphic events. Argon-40/argon-39 cooling studies show evidence of rapid exhumation of the Fosdick Mountains in Late Cretaceous time.

The Fosdick Mountains constitute a large-scale deformation zone. Older, steeply dipping gneissic foliation is preserved in low-strain, highly crenulated zones in the north-central part of the range. Straight gneisses in much of the rest of complex are interpreted to be transposed from this older foliation. This younger foliation dips predominantly south to southeast. Migmatization was accompanied and followed by intrusion of mafic dikes. Advanced partial melting led to the formation of block gneiss, in which lenses of paleosome and boudinaged dikes were engulfed in a matrix of massive granitic neosome. Block gneiss emplacement was largely post-kinematic. Retrograde pegmatites and extensional veins trend east-southeast, consistent with north-northeast extension during initial cooling of the complex.

The deformation of the metamorphic complex was largely a flattening, as indicated by the lack of a well-defined lineation and the highly variable orientation of syn-metamorphic mafic dikes. One discrete, high-strain zone, about 50 meters wide and dipping to the south is located on the southeast ridge of Mount Richardson; shear indicators show top-to-the-west shear in this zone. Major plastic deformation was synchronous with peak metamorphic conditions. Progressive overprinting by lower temperature deformation features, typical of mid-crustal ductile deformation zones, is not observed.

Plutonic and hypabyssal rocks. Ford granodiorite outcrops south of the Fosdick Mountains in the Chester Mountains consist of granodiorite plutons (approximately 353 million years old,

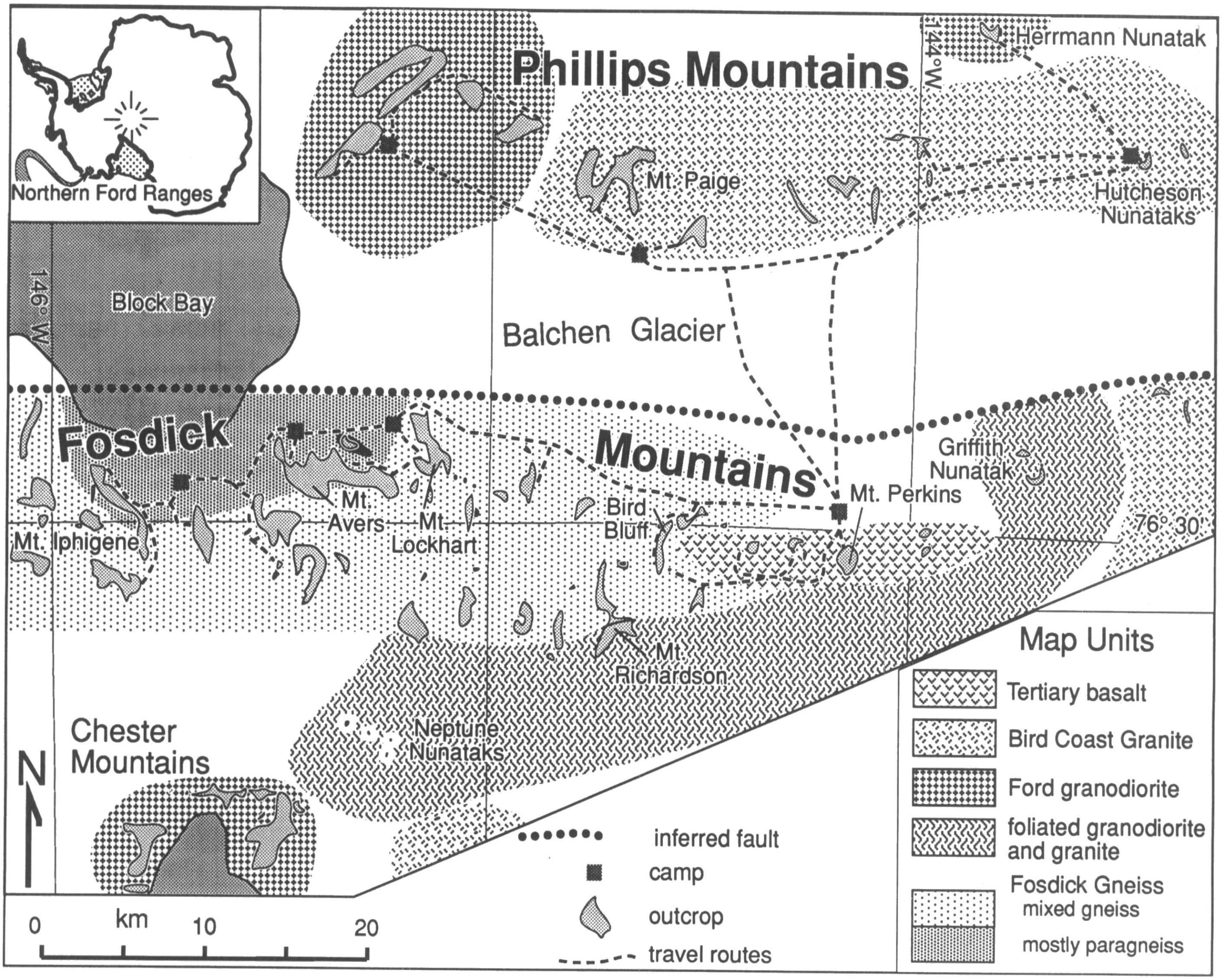

Figure 1. Revised geologic map of the northern Ford Ranges showing routes of the Ford Ranges Crustal Exploration (FORCE) project trail parties during the 1990–1991 austral field season.

based on uranium-lead zircon studies) with pendants of upper greenschist facies metasedimentary rocks. Uranium-lead discordia on zircons show an inherited age of 1,300 million years suggesting Precambrian contributions to source magmas. A similar tonalite to granodiorite plutonic complex crops out in the western Phillips Mountains north of the Fosdick Mountains; these are correlated with Ford granodiorite. Most of the Phillips Mountains, the eastern Fosdick Mountains, and isolated nunataks east of the Chester Mountains comprise epizonal biotite granite (approximately 103 million years old, based on uranium-lead zircon studies) correlated with the Byrd Coast granite. Both Ford granodiorite and Byrd Coast granite are intruded by mafic dikes. Argon-40/argon-39 age spectra on hornblende from a dike in the Chester Mountains are complex but indicate an Early Cretaceous age. Undeformed biotite-muscovite granite intrudes the Fosdick metamorphic complex west of Mount Avers. Two-mica granites also intrude the Ford granodiorite in the Chester Mountains and the Neptune-Griffiths transitional rocks at Neptune Nunataks. Uranium-lead zircon studies from the Neptune granite suggest a Permian age.

Lithologic gradation from mixed migmatite (Fosdick metamorphic complex) to granodioritic orthogneiss (Neptune-Griffiths transitional rocks) to unfoliated granodiorite (Ford granodiorite) between the northern Fosdick and Chester Mountains suggests that the Fosdick complex originated in a sub-batholithic domain related to the Ford granodiorite (figure 2). Uranium-lead isotopic data indicating Mesozoic metamorphism suggests migmatization was coeval with the intrusion of Byrd Coast granites. Chemical data from Byrd Coast granite (Weaver, Bradshaw, and Adams 1991) preclude derivation of these plutons from anatectic melts derived from migmatite complexes like the Fosdick metamorphic complex. Heating associated with the plutonism may have resulted in minor mid-crustal melting without generating discrete magma bodies. Deformation of the complex probably reflects some combination of flattening to accommodate pluton intrusion and large-scale deep-crustal flow related to initial breakup of Gondwanaland.

Volcanic rocks. Cenozoic volcanic centers (with a potassium-argon age of 39 to 3.4 million years (LeMasurier and Rex 1982)) crop out along an east-west trend in the eastern Fosdick Mountains. Fault control of their distribution by unexposed, range-bounding, master normal faults is suspected. The volcanic centers are the only outcrops of young basaltic rocks in the entire Ford Ranges, and they lie along the axis of the Fosdick metamorphic complex. Inclusions of ultramafic rocks in basaltic rocks are common. At several vent complexes inclusions of the Fosdick metamorphic complex are also present. An approximately 200-meter section of basalt pahoehoe flows is exposed at Mount Perkins in the east portion of the Fosdick Mountains. This section is unconformably capped by tephra. The spatial association of young basalts with high-grade rocks uplifted from middle crust depths may correspond with a zone of thin, extended crust. A local bouguer gravity high follows the trend of the Fosdick Mountains and supports this interpretation (Beitzel 1972). All the volcanic rocks are apparently ice-sculpted. At Bird Bluff (figure 1) volcanic rocks drape down the front of the Fosdick range; between Mount Avers and Mount Lockhart, a dissected cinder cone is found on the Balchen valley floor at the base of the cliffs. These observations suggest that volcanism and block faulting were simultaneous. Younger normal faults cutting the volcanic rocks are oriented northwest-southeast (photogeologic interpretation), and may represent a change in strain orientation in Late Tertiary or Quaternary time.

Gondwanaland and Cenozoic rifting. Paleomagnetic studies in progress on all pre-Cenozoic rock types suggest a predominant Cretaceous steep normal (up) direction; the Ford granodiorite was apparently remagnetized at the time of Byrd Coast granite intrusion. At sites in the Chester Mountains, this direction is pointing southward at inclinations of $-50°$ to $-70°$. This is interpreted to be the result of postmagnetization southward tilting. Directions from mafic dikes are both steep and tilted suggesting that tilting was occurring during dike injection. Normal polarity magnetizations indicate that tilting took place during the Cretaceous long normal period. Preliminary determinations of anisotropy of magnetic susceptibility show that the Fosdick metamorphic complex lacks a strong linear fabric, but where it is present, it trends north-northeast parallel to the final strain episode.

The geomorphology is consistent with the idea that the Phillips, Fosdick, and Chester Mountains are fault blocks with steep northern sides. These mountains, along with the rest of the Ford Ranges, evidently have undergone basin-and-range style tectonics. This has been associated with either or both Gondwanaland rifting (Bradshaw 1991; Tulloch and Kimbrough 1989), or Cenozoic extension in the Ross embayment (Cooper, Davey and Behrendt 1987) and uplift of the Transantarctic

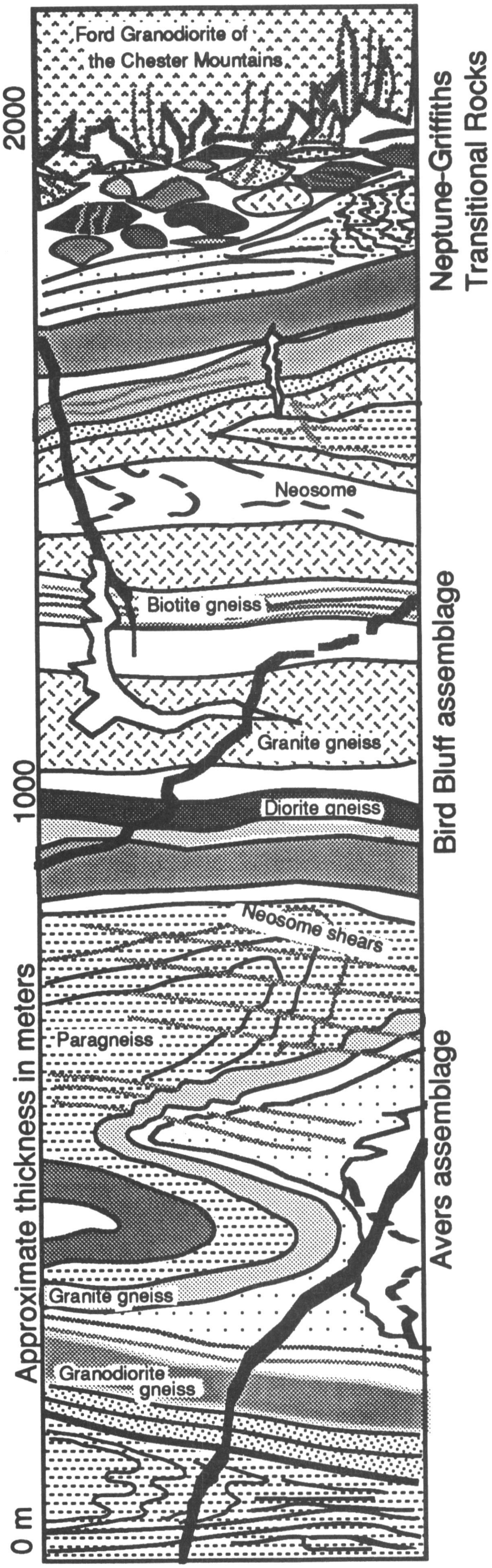

Figure 2. Representative geological column for the Fosdick Mountains and the Chester Mountains showing the transition from mixed migmatitic gneisses of the Fosdick metamorphic complex into the Ford granodiorite. Patterns corresponding to rock types are labeled on the figure. Predominantly metasedimentary crenulated gneisses of the Avers assemblage are shown passing upward into predominantly "straight" orthogneisses of the Bird Bluff assemblage. These in turn pass into very heterogeneous lenticular gneisses containing blocks and lenses of dioritic to monzogranitic composition within leucocratic neosome (Neptune-Griffiths transitional rocks). The actual contacts are not exposed, so this representation of the boundary between the Fosdick complex and overlying Ford granodiorite is highly interpretive. (m denotes meter.)

Mountains (Behrendt and Cooper 1991). The Phillips and Fosdick Mountains trend subparallel to the Transantarctic Mountains (as viewed in polar grid projection), as do other mountains of the Ford Ranges. Furthermore, the individual ranges trend oblique to the passive continental margin here, so their formation may have followed Gondwanaland rifting. A residual bouguer gravity anomaly low of at least −50 milligals (Beitzel 1972) follows the Balchen Glacier which separates the Phillips and Fosdick Mountains, suggesting that the glacier is flowing through a graben between these mountains. Clasts of the Swanson Formation, which crops out to the south, are found in moraines in the Fosdick range. Glacial striae have been found on the range tops showing transport from southeast-to-northwest in the past oblique to present east-to-west transport. Because the west antarctic ice sheet is probably no older than Oligocene (Bartek et al. 1991), this may indicate redirection of glacial flow by Oligocene or later block faulting. Fault-controlled volcanism also indicates significant tectonic events during Cenozoic time. Cretaceous cooling ages, however, point out that major tectonic unroofing preceded Cenozoic faulting. Topography resulting from Gondwanaland rifting in Cretaceous time was largely reduced to a Late Cretaceous/Early Tertiary erosion surface; the present ranges were most likely formed by Oligocene and younger extension tectonics.

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