Reports

Airborne Geophysical Study in the Pensacola Mountains of Antarctica

Abstract. *A seismic reflection, gravity, and aeromagnetic reconnaissance was made in the Pensacola Mountains, Antarctica, during the 1965–66 austral summer. Prominent ice streams located between the Neptune and Patuxent Ranges and east of the Forrestal Range overlie channels in the rock surface 2000 meters below sea level which are probably of glacial origin. Seismic reflections show that the Filchner Ice Shelf is 1270 meters thick near its southern margin. Along the boundary between West and East Antarctica, Bouguer anomalies decrease from +60 milligals in West Antarctica to −80 milligals in East Antarctica. An abrupt change in crustal structure across this boundary is required to explain the 2 milligals per kilometer gradient. This may indicate a fault extending through the crust into the mantle. Aeromagnetic profiles delineate anomalies up to 1800 γ associated with the basic stratiform intrusion which comprises the Dufek and Forrestal ranges. A probable minimum area of 9500 square kilometers is calculated for the intrusive body on the basis of the magnetic anomalies, making it one of the largest bodies of its type. The extension of this magnetic anomaly across a fault forming the north border of the Pensacola Mountains probably precludes transcurrent movement.*

A reconnaissance geophysical survey was made in the Pensacola Mountains of Antarctica (Fig. 1) during the 1965–66 austral summer. The survey included seismic reflection measurement of ice thickness, gravity measurements at 396 locations on snow or rock, and 6000 km of aeromagentic traverse. Turbine helicopters were used in making the seismic and gravity survey, which was coordinated with simultaneous geologic (*1, 2*) and topographic work by the U.S. Geological Survey. A ski-equipped Dakota (C47) aircraft was used in making the aeromagnetic survey.

Elevations (∼ ± 20 m) were determined by barometric altimetry. Horizontal control was determined in the mountains, in conjunction with the topographic mapping party, by triangulation and intersection; in the glacierized areas it was determined by starshots. The gravity survey was tied to a base at McMurdo Station (*3*). Seismic reflections were obtained throughout the area, in spite of the persistent noise associated with cold firn (*4*), and occasional thin ice. Reflections were positively identified at the 15 stations shown on the maps.

An Elsec-Wisconsin proton precession magnetometer (*5*) was used for the aeromagnetic survey, which was flown at a constant barometric elevation of 2100 m. Positions were determined by maps at scales of 1:45,000 to 1:500,000 and, in the mountains, by use of air photos. Diurnal control was obtained from a base line connecting the profiles. No flights were made during magnetic storms.

The glaciology is illustrated by the snow surface elevation map of the area (Fig. 1A). The thickness of the Filchner Ice Shelf, determined by the reflections from the ice-water interface, is 1270 m, making it the thickest known ice shelf. It is about twice as thick as the Ross Ice Shelf (*4*). The southern boundary of the Filchner Ice Shelf is controlled by a deep channel probably carved out by an ice stream which flows between Neptune and Patuxent Ranges. Another prominent ice stream flows into the ice shelf east of the Forrestal Range.

Bedrock elevation (Fig. 1B) was determined from recordings at seismic reflection stations and from gravity measurements tied to seismic reflection stations or rock outcrops (*4, 6*). The deep channels between the Neptune and Patuxent Ranges and east of the Forrestal Range trend into the broader trough area, beneath the Filchner Ice Shelf, which was discovered during the International Geophysical Year (*6*). Two interesting features are the closed depressions, below sea level, between the Thiel Mountains and the Patuxent Range, and the channel between the Patuxent and Neptune Ranges. These must be of either structural or glacial origin, as fluvial erosion does not appear to be a possible mechanism of formation. The 3500 m of relief between the Dufek Massif and the trough is probably the result of a fault zone, parts of which were mapped by Ford and Boyd (*2*). The area lower than −1000 m closes to the west (*7*) and continues east and north for about 800 km into the Weddell Sea (*6*). The bedrock topography east of the area mapped is not known, but the traverses in East Antarctica (*4*) indicate that it probably is near or above sea level.

Simple Bouguer anomalies (Fig. 1C) were computed for all stations on bedrock and at seismic reflection stations, with a correction made for the ice or water below sea level, as was done for the Filchner Ice Shelf traverse (*6*) to the north. Values range from +60 mgal over the trough to −80 mgal in the south. A steep linear gradient of about 2 mgal/km trends northeast to southwest across the area following the general trend of the Transantarctic Mountains, of which the Pensacola Mountains are a part. Robinson (*8*) observed similar gravity gradients in the McMurdo Sound area and interpreted their extension along the Transantarctic Mountains for 2300 km from Cape Adare to 90°W.

Average mantle depths of 40 and 30 km have been reported (*4, 9*) for East and West Antarctica. These findings were based on gravity anomalies and dispersion data for earthquake surface waves. The Pensacola Mountains lie at this boundary between East and West Antarctica and the change in gravity is therefore interpreted as a change in the thickness of the crust. A two-dimensional, line integral gravity model (Fig. 2), based on an assumed thickness of the crust of 30 km for West Antarctica, was computed along section *A–A′* of Fig. 1C. The striking feature of the model is the vertical step in the interface of the crust mantle. A similar abrupt increase in the thickness of the crust in the McMurdo area was required

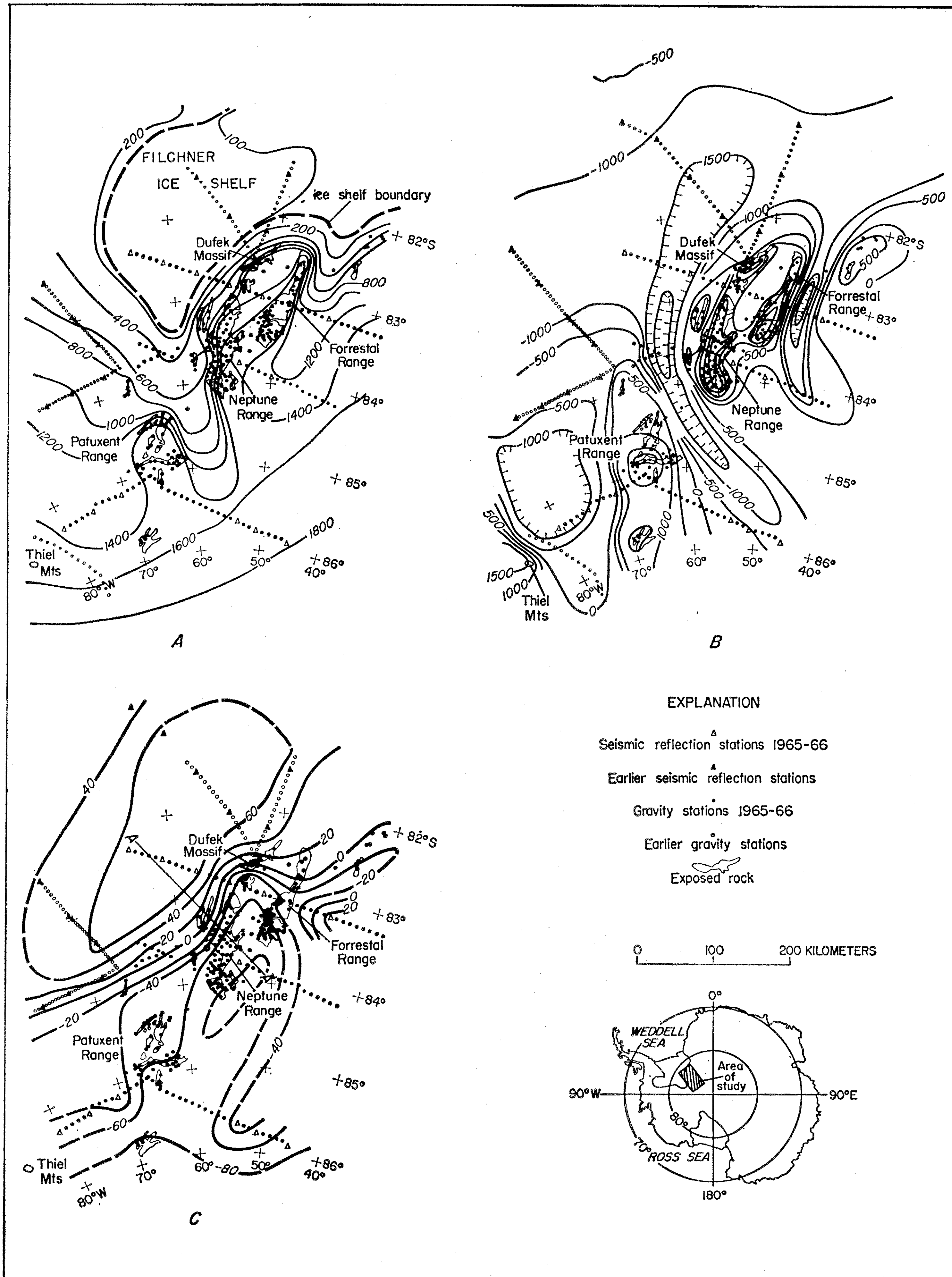

Fig. 1. Snow surface (A) and rock surface (B) elevation and Bouguer anomaly (C) maps of Pensacola Mountains area. Insert shows location of the project area. Contour intervals are 200 and 500 m and 20 mgal, respectively. Contours at edges are based on earlier results (*4*, *6*).

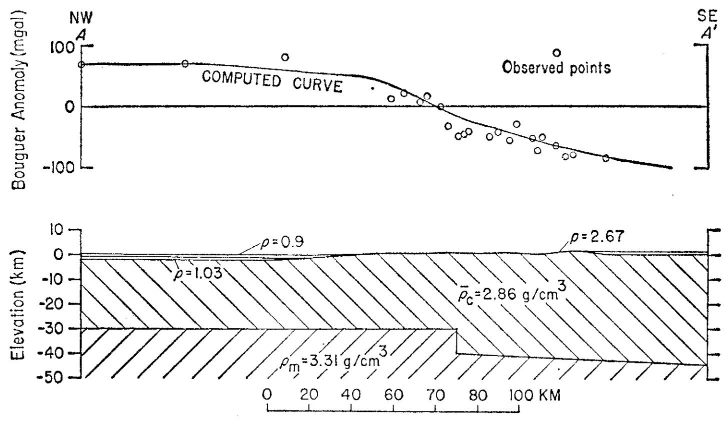

Fig. 2 (above). Two-dimensional, line integral model compared with observation data. Standard deviation of observed points is ± 14 mgal. An additional 4 km thickening of the crust was used to far left of area shown to obtain illustrated curve.

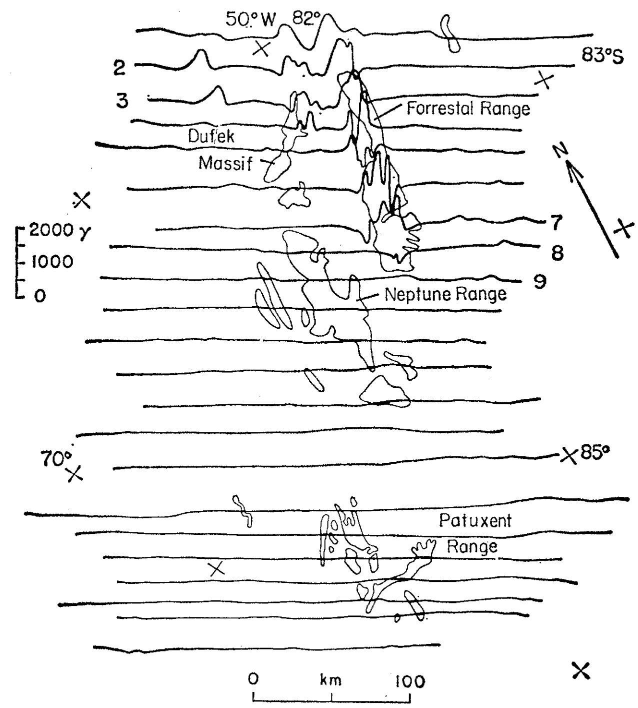

Fig. 3 (right). Total magnetic intensity profiles relative to arbitrary datum.

by Robinson (*8*) to account for the gravity data there; he interpreted this increase in thickness as a fault extending through to the mantle. Considering the length of the fault, he suggested the possibility of transcurrent motion. This would explain the thinner crust on the downside of the fault. The step or fault, if it extends through the crust, projects to the surface just west of the Dufek Massif and the western outcrops of the Neptune Range. At this point the rock surface drops to a depth of −1500 m. It is near this line that small faults were observed in the surface geology (*2*). Other models with density variations within the crust or upper mantle could be computed to fit the observed data, but all would require an abrupt change at this critical boundary area between East and West Antarctica.

The aeromagnetic profiles (Fig. 3) show high amplitude anomalies of up to 1800 γ associated with the Forrestal Range and Dufek Massif, as well as a 600 γ anomaly northwest of the Dufek Massif. These northernmost ranges of the Pensacola Mountains are composed of one or more basic stratiform intrusions (*2*) consisting of at least 2000 m of interlayered gabbro and anorthosite which contain widespread magnetite layers and lenses. The high amplitude anomalies occur over the entire mass of the Forrestal Range, but they occur only over the northeastern part of the Dufek Massif. This is in agreement with the locations of the rocks containing magnetite which were examined in the field (*2*). The similarity of the two groups of anomalies suggests a common origin but we cannot be certain of this.

The anomalies are probably caused by truncation at the east and west edges of layered magnetic rocks within the intrusive bodies. Bath (see *10*) showed anomalies and computed models of this type in the Lake Superior area. The analysis of oriented samples which were collected by Ford and Boyd (*2*) will greatly aid in the interpretation. These anomalies could not be due to topography because there is essentially no decrease in amplitude of the Dufek anomaly beneath the Filchner Ice Shelf, where the source must be at least 2500 m deeper than over the range (compare Fig. 1B).

The southern extent of the Forrestal anomaly occurs at the southern end of that range. The contact between the intrusive body and older Permian (*1*) sedimentary rocks to the south lies between profiles 7 and 8 (Fig. 3). This indicates that the contact is not vertical but slopes to the south. An estimate of the depth to the source of the anomaly, based on the horizontal extent of the maximum gradient on profile 8, indicates an elevation of 0.7 km, or about 0.7 km below the rock surface at the southern end of the Forrestal Range. Depth estimates for profiles across the Forrestal Range north of profile 8 give elevations of the source approximately at the rock surface. Profile 9 immediately south of the Forrestal Range shows a 200 γ anomaly, which suggests that the intrusive body extends beneath the ice and sedimentary rock in this area.

The area covered by the anomalies comprises one of the largest known stratiform intrusive bodies. If the intrusive body underlies the area between the Dufek Massif and Forrestal Range, as the aeromagnetic data suggests, the minimum size of the intrusive body would be 9500 km^2 compared with 14,000, 400, and 60 km^2 for the Bushveld, Stillwater, and Skaergaard intrusives, respectively (*2, 11*).

The anomaly northwest of the Dufek Massif may or may not be a separate body, possibly of similar origin as the Dufek-Forrestal anomalies. The character of this anomaly on profiles 2 and 3 has the appearance of a mirror image to the Dufek anomaly and the slight positive anomaly between the two suggests a relationship. Estimates of the depth of the source place it at or close to the bedrock surface at the bottom of the trough (Fig. 1B). Other anomalies of lower amplitude (100 to 300 γ) are found throughout the area.

If the trend of the escarpment at the north front of the Dufek Massif (Fig. 1B) is the result of fault displacement, as seems likely, the Dufek anomaly crosses the fault. Since the intrusive body is Permian or later in age, the fault must also be Permian or later, and is probably Cenozoic (*12*). Any transcurrent movement along a fault which extends through the crust would have offset the observed magnetic anomalies, which cut across the steep gravity gradients, if the movement occurred after the emplacement of the intrusive body. Therefore transcurrent movement appears unlikely as an explanation of the abrupt increase in the thickness of the crust.

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13. We thank M. Hochstein for unpublished data on the west edge of the Pensacola Mountains area, W. Rambo and R. Wanous, of the U.S. Geological Survey, for assistance in the gravity and magnetic surveys, and the members of the U.S. Geological Survey geologic and topographic control parties for assistance in the geophysical program. Logistical requirements were filled by a U.S. Army helicopter detachment and by U.S. Navy Air Development Squadron 6. Research supported by the National Science Foundation. Geophysical equipment supplied by the University of Wisconsin Geophysical and Polar Research Center. Publication authorized by the Director, U.S. Geological Survey.

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Fossil Mammals from Baja California: New Evidence on Early Tertiary Migrations

Abstract. *Ungulates belonging to the family Barylambdidae were found in the same geologic unit with, but stratigraphically above, a specimen assigned to the Tillodontia and above several molars of the perissodactyl cf.* Hyracotherium *sp. This arrangement is unusual, as in the well-documented faunas from the Rocky Mountain Region Barylambdidae are known only from the Paleocene, Tillodontia from the Paleocene and Eocene, while* Hyracotherium *is known only from the Eocene. The expected stratigraphic order would be, from lowest to highest, Barylambdidae, Tillodontia, and* Hyracotherium. *It is suggested that the Baja California assemblage is late Paleocene on the basis of the generalized molars of cf.* Hyracotherium *sp. and the characters of cf.* Esthonyx *sp.*

Paleocene terrestrial mammals are extremely rare in North America west of the Rocky Mountains. A few specimens have been found in the Goler Formation of southeastern California (*1*) but, while some represent new taxa, all greatly resemble Rocky Mountain faunal elements and, at least in the light of present knowledge, there is nothing unusual from a biochronological aspect about the Goler assemblage.

During the summer of 1965 early Tertiary mammals were discovered on the Pacific side of Baja California, approximately 400 kilometers south of Ensenada near the small village of Punta Prieta (29°N, 114°W) (Fig. 1). The first specimen was collected by S. Applegate and H. Garbani of the Los Angeles County Museum of Natural History; later, I collected additional material (*2*). So far the Punta Prieta locality has yielded only four identifiable specimens. Fortunately, however, the taxa represented are of considerable significance from a paleoecological and taxonomic aspect.

Paleontologic studies provide a very practical and necessary geochronology based upon geographic as well as stratigraphic distribution of fossil faunas and floras. A valid geochronology based upon assemblages of fossil organisms presupposes that the assemblages will occur in a readily defined sequence and that each one within the sequence serves to mark a time interval or horizon. These requirements are rather easily met within a small geographic area and when a large time interval is involved, but when the assemblage is correlated regionally the problem of similarity of faunal sequences and synchroneity of faunas is compounded. Extinction, migration, and environmental change can cause any one faunal assemblage to change gradually, both geographically and temporally. The fossil assemblages of widely separated geologic sections would show these changes.

Increased stratigraphic precision demands a time framework consisting of smaller and smaller intervals. The smaller the interval the more probable it is that the assemblage lacks time synchroneity. The amount of time necessary for migration throughout its lateral extent will cause elements of the assemblage to transgress time when the interval measured is short, and in widely separated areas the same taxon is not necessarily synchronous.

Discovery of new localities for critical biochronological guide fossils extends the geographic areas in which these fossils may be used for correlation. Extending the temporal range of critical guide fossils into areas beyond localities where they were previously recognized permits evaluation of the amount of temporal transgression.

The four specimens reported here are significant in adding to knowledge of geographical extent and temporal significance of standard Paleocene terrestrial faunas of the Rocky Mountain area. Provincial ages based upon faunal assemblages and guide fossils pertinent to this discussion are shown in Table 1.

A brief taxonomic and descriptive summary of the specimens from Punta Prieta is as follows.

Order: Pantodonta
Family: Barylambdidae
1) Scapula
2) Partial skeleton including skull
Order: Tillodontia
Genus: cf. *Esthonyx* sp.
3) Several poorly preserved upper and lower molars, premolars, and associated incisors
Order: Perissodactyla
Genus: cf. *Hyracotherium* sp.
4) Several upper molars

Hyracotherium is perhaps the most well-known taxon from Punta Prieta. Prior to the discovery of the Baja material, this genus was restricted to the Wasatchian of North America and the Sparnacian of Europe (*3*). The genus *Esthonyx* ranges from the Clarkforkian through the Wasatchian in North America (*4*); in addition one form, *E. munieri*, has been reported from the Sparnacian or Cuisian of France (*5*). The Baja California specimen resembles most closely the Clarkforkian forms from the Rocky Mountain area (*6*).