POPULAR SUMMARY.

Magnetic Signature for the Pole-of-Opening of the Canada Basin.

Patrick T. Taylor, Geodynamics Branch, NASA/Goddard Space Flight Center, Greenbelt, MD 20771. and G. Leonard Johnson, University of Alaska Fairbanks, Fairbanks, AK 99775

A scissors-like tectonic-plate motion opening of the Canada Basin was first proposed by Carey (1955) and developed by Tailleur (1973) according to their model, after initial rifting, a sliver of the Canadian shelf would have been rotated, in an anti-clockwise rotation, of some 70 degrees; eventually docking against northern Alaska and easternmost Chukota. Several researchers have calculated the pole of opening or rotation to be in the MacKenzie River Delta region Based on low-level aeromagnetic profiles, Taylor et al.1981, suggested that the time of opening of the Canada began in Late Jurassic (155 mybp) and continuing until Early Cretaceous (125 mybp). There is a large amplitude, long-wavelength satellite-altitude magnetic anomaly (Magsat) at the fulcrum for this opening. We wanted to study and interpret this Magsat anomaly by using ground-based geological and other geophysical information. Our study area borders the southern Canada Basin in the vicinity of the Mackenzie River Delta. The presence of earthquake and the stress data compilation indicate that stress is still present in the region of the discontinuity. One may speculate if this long term geologically activity can be correlated with the region having acted as the pole of rotation for the opening of the Canada Basin. Since the opening hinge or fulcrum region would be a locus of exothermic activity and this could produce the source of these large magnetic anomalies. Thus the Magsat data revealed information on crustal motion in the region of the opening of the Canada Basin.

Magnetic Signature for the Pole-of-Opening of the Canada Basin.

Patrick T. Taylor, Geodynamics Branch, NASA/Goddard Space Flight Center, Greenbelt, MD 20771 U.S.A.

G. Leonard Johnson, University of Alaska Fairbanks, Fairbanks, AK 99775 U.S.A.

Abstract.

Long-wavelength, relative high amplitude-magnetic anomalies obtained at satellite altitudes have provided an understanding of the nature of the deeper crust of the Earth. We have studied one such long-wavelength (19 nT positive, -6 nT negative) feature on the Canada Basin continental margin in the Northwest and Yukon Territories, Canada. This area is also the focus of significant stress and earthquake activity. We interpret this anomaly and associated tectonic activity with this region's position at or near the fulcrum of the scissors-like opening of the Canada Basin in the mid-Mesozoic Era.

Introduction.

Even in the 21st Century the Arctic remains a largely inaccessible and poorly understood region of the Earth. Information on a regional scale in this large area is most easily obtained by remote means, such as aircraft and satellite observations. Therefore recognizing that the magnetic anomaly field is key to an understanding the structure and evolution of the Arctic and given the logistical difficulty of working there, airborne surveys were initiated in 1946 by the agencies of the former Soviet Union. Extensive magnetic surveys have been made since this time (see, for example, Coles and Taylor,1990). Scientists from the United States and Canada soon joined the effort conducting airborne surveys of this region. Arkady Karasik in particular was a pioneer in using aeromagnetic methods in the 1970's for determining the structure and development of the Arctic Basin (Karasik, 1980).

A new perspective was added with the advent of satellite data, initially from the Polar Orbiting Geophysical Observatory (POGO) satellites and subsequently from the Magnetic

Satellite (Magsat) (Coles and Taylor, 1990 and Langel and Hinze, 1998). At satellite altitudes a complete coverage, over both land and water, of the Polar region could be obtained on a more regional scale with admittedly a lower resolution than aeromagnetics. For the most recent example of a Magsat compilation from the Arctic see Alsdorf et al. (1998). Satellite altitude magnetic anomaly surveys reveal the long wavelength (>500 km) structures that are most indicative of deeper crustal features. Our study area is the northern sectors of the Yukon and Northwest Territories, Canada. This region borders the southern Canada Basin in the vicinity of the Mackenzie River Delta. It extends from 90° West longitude to 180° and from 60° to 80° North latitude. We will use geological and other geophysical information to interpret one of these long-wavelength Magsat anomalies from this Northwestern part of Canada (Figures 1 and 2).

Background.

Based on low-level aeromagnetic profiles, Taylor et al.1981, suggested that the Canada Basin was formed by a rotational spreading event beginning in Late Jurassic (M-25) and continuing until Early Cretaceous (M-12). This scissors-like opening of the Canada Basin was first proposed by Carey (1955) and developed by Tailleur (1973) according to this model, after initial rifting, a sliver of the Canadian shelf would have been rotated, in an anti-clockwise rotation, of some 70 degrees; eventually docking against northern Alaska and easternmost Chukota. Several researchers have calculated the pole of rotation to be in the MacKenzie River Delta region. Extending the aeromagnetic anomalies of Taylor et al. (1981) back to their convergence point would place the axis of rotation at approximately 69.25° North, 142.50° West. Grantz et al. (1979), based on matching the 1000m isobath, suggested a pole of 69.1° North, 130.5° West in the eastern MacKenzie Delta. In a subsequent study, Grantz et al, (1990) matched the tectonic hinge lines in the eastern and western Beaufort Shelves that placed the paleo-pole near 68.5° North, 135° West. Norris (1983), however, studied the regional geology in the lower Mackenzie River valley and sited the paleo-pole at the southern apex of the Rapid Depression (Figure 3) near 68° North, 138° West. The location of these postulated poles of rotation are shown in Figure 3 with the tectonic diagram.

Jones (1980), however, proposed that this area was a locus of the complex interaction of several transcurrent faults (see Jones, 1980, his figure 1).

Data Processing and Analysis.

Polar regions present special problems for magnetic studies because of the extensive external fields most dramatically displayed by the auroral phenomena. External fields combine with the internal field and make it difficult to separate these static and dynamic components. All methods designed to isolate the crustal field from the total field observation begin with a rigorous selection of data based visual correlations of adjacent orbits and the Kp and/or Ae indices. The orbital profiles used to produce the Magsat anomaly map of our study region are shown in Figure 2. Thirty-six orbits (28 ascending-dusk and 8 descending-dawn) were utilized in the orbit-crossing analysis technique described in detail by Taylor and Frawley (1987). Briefly this method employs data from a restricted altitude range (350 km +/- 10 km) and the errors at the orbit crossing points are reduced to a minimum by the fitting of a bias and low-order polynomial surface. In this manner all crossover point errors are treated at once, whether they are from external fields, secular variation or instrument noise. Other methods have been employed. A more recent method of noise removal that involves computing spectral analysis of each orbit and subsequently correlating adjacent orbits is discussed by Alsdorf et al. (1998).

Magnetic Anomalies:

Figure 1 illustrates the large northeast-southwest striking Magsat anomaly present between 110° and 140° West and 69° -72° North. At its maximum it has a 19 and 16 nT positive peaks. On regional scale compilations such as magnetic anomaly map of North America (Geological Society of America, 1990) this anomaly shows as a large positive feature. Coles et al (1976) high-level airborne data also confirms this Magsat anomaly. They describe it as a wide belt of intense anomalies and may be evidence for a Precambrian orogenic zone. Coles et al. (1976) further suggest that the crystalline continental basement (Figure 3, Interior Platform) extends far to the west beyond the exposed and known buried shield. Three dimensional seismic reflection profiling also favors the idea that the structural basement is composed of Proterozoic strata (Cook and Coflin, 1990) The magnetic anomalies support these conclusions and imply that there are major contrasts between the basement beneath the MacKenzie Foldbelt and that of the craton. Taylor and Frawley (1986) suggested that the source for this large positive (peak to trough) anomaly (25 nT at 350 km altitude) might be a Precambrian rift.

A three-dimensional magnetic model (Plouff, 1976) of these anomalies was made (Figure 4). This model duplicates both the 25 nT and 13 nT (positive peak-to-surrounding negative trough) highs of the Magsat map. We used a fifteen km thick body (depth extent 5 to 20 km) for the larger anomaly and a thirteen km thick body (depth extent 5 to 18 km) for the smaller anomaly. Both were given a vertical polarization and magnetization of 5 A/m. These models provide an estimate of the geometry and depth extent of the geologic units producing these magnetic anomalies and indicate that an intra-crustal source is likely.

Other Geophysical Data.

Seismicity

The region of poles of rotation is one of enhanced seismicity (Figures 1 and 3). Earthquake epicenters are from USGS data 1986. In Figure 1 it is evident that a N-S trending group of earthquakes form the western boundary of the Magsat anomaly and may be related to a fundamental crustal discontinuity. Stress measurements from bore holes reveal high levels; however no directionality could be determined (Zobeck, 1992). The seismicity may denote an offset in the Aklavik Arch (Figure 3) as it strikes southwest toward Alaska.

Heat Flow

Low heat flow values (< 40 mWm^{-2}) occur in the Beaufort-MacKenzie Basin and Rapid depression (Figure 3). Both of these areas are characterized by thick successions of Upper Devonian, Cretaceous and Tertiary clastic sedimentary strata. High heat flow values (>60 mWm^{-2}) are found on the northeastern part of the Aklavik Arch Complex (Jones et al, 1988).

Gravity

Sobczak et al, (1990) map of Arctic gravity anomalies shows slightly positive gravity anomaly relative to the regional negative field in the region of the Magsat high amplitude anomaly. This relative positive trend coincides with the NE-SW striking line of Magsat positive anomalies. Both potential field anomalies terminate at about 135° W 66° N on the Richardson Anticlinorium. The gravity field then shows a weak east-west anomaly striking west toward Alaska. Clearly there is a major discontinuity present as indicated by these geopotential data.

Summary:

Satellite derived magnetic fields are valuable for determining regional geologic variations and tectonic deformation (Alsdorf et al., 1998). The Magsat anomaly illustrated in this paper and other geophysical data represent a major discontinuity in the crustal structure and most likely is the westward continuation and termination, at 135° West, of the Proterozoic Canadian shield. The Aklavik Arch may indicate the front of an orogenic belt during the Devonian Ellesmerian orogeny (Cook and Coflin,1990). The geologic map of Canada (GSC Map 1860A, 1996) shows the region of the prominent Magsat positive anomaly to be upper Devonian sediment on Precambrian basement. The presence of earthquake and the stress data compilation indicate that stress is still present in the region of the discontinuity. One may speculate if this long term geologically activity can be correlated with the region having acted as the pole of rotation for the opening of the Canada Basin. Since the opening hinge or fulcrum region would be a locus of exothermic activity and this could produce the source of these large magnetic anomalies.

Figure Captions.

Figure 1. Magsat Anomaly map of Alaska-Canada margin with seismicity.

Figure 2. Arctic Magsat profiles used in construction of anomaly map.

Figure 3. Tectonic elements of the region with postulated poles of rotation.

Modified from Jones et al.. (1988); a. Taylor et al.,1981; b. Grantz et al., 1979; c. Grantz et al.,1991; d. Norris, 1983. Dashed line is strike of Magsat anomaly.

Figure 4. Magnetic model study of magnetic anomalies.

References:

Alsdorf, D., Taylor, P., von Frese, R., Langel, R., and Frawley, J., 1998, Arctic and Asia lithospheric satellite magnetic anomalies, Physics of the Earth and Planet. Interiors., 108, 81-99.

S. W. Carey, 1955, The Orocline Concept in Geotectonics, Papers and Proceedings of the Royal Society of Tasmania, 89, 255-288.

Coles,R.L., Haines, G.V., and Hannaford, W., 1976, Large Scale magnetic anomalies over western Canada and the Arctic: a discussion, Canadian Journal of Earth Science, 3, 790-802.

Coles, R.L. and Taylor, P..T. 1990, Magnetic anomalies, In Grantz, A., Johnson, G.L., and Sweeney, J.F., eds., The Arctic Ocean region: Boulder, Colorado, Geological Society of America, The geology of North America, v. L, 119-120.

Cook, F.A. and Coflin, K., 1990, Experimental three-dimensional imaging of crustal structure in the northwestern Canadian Arctic, Tectonophysics, 173, 43-52.

Geological Society of America, 1987. A Gravity Anomaly Map of North America, B. Magnetic Anomaly Map of North America in The geology of North America-An overview, Boulder, Colorado, Geological Soc. of Amer, The Geology of North America, vol. A, Plate 1.

Grantz, A., Eittrim, S. and Dinter, D., 1979, Geology and tectonic development of the continental margin north of Alaska, Tectonophysics, 59, 263-291.

Grantz, A., May, S.D., Taylor, P.T. and Lawver, L.A., 1990, Canada Basin, in Grantz.A., Johnson, L. and Sweeney, J.F.,eds., The Arctic Ocean region: Boulder, Colorado, Geological Soc. of America, The Geology of North America, vol. L, 379-402.

Jones, F.W., Majorowicz, J.A., and Dietrich, J., 1988, The Geothermal Regime of the Northern Yukon and Mackenzie Delta regions of Northwest Canada-Studies of Two regional Profiles, Pageophysics, 127, No4, 642-658.

Jones, P.B., 1980, Evidence from Canada and Alaska on plate tectonic evolution of the Arctic Ocean Basin, 285, Nature, 215-217.

Karasik, A.M., 1980, Basic specifics of the history of development and the structure of the Arctic Basin bottom according to aeromagnetic data: Marine Geology, Sedimentology, Sedimentary petrography, and Geology of the Ocean, Academy of Sciences of the U.S.S.R, Ministry of geology of the U.S.S.R, National committee of Geologists of the Soviet Union, Leningrad, 178-193. (Translated 1981: NASA GSFC-07).

Langel, R.A. and Hinze, W.J., 1998, The Magnetic Field of the Earth's Lithosphere, Cambridge University Press, 429 p.

Norris, D.K., 1983, The structural link among the Columbia, Innuition, and Alaska Orogens, Geol Assoc Canada- Mineral Assoc Canada Geophysical Union Program with Abstracts, 8, A51.

Plouff, D., 1976, Gravity and magnetic fileds of polygonal prisms and application to magnetic terrain corrections. Geophysics, 41, 727-741.

Sobczak, L. W., Hearty, D.B., Forsberg, R., Kristoffersen, Y., Eldholm, O., and May, S.D., 1990, Gravity from 64 N to the North Pole, in Grantz, A., Johnson, L., and Sweeney, J.F., editors, The Arctic Ocean region: Boulder, Colorado, Geological Society of America, The Geology of North America, v.L, 101-118.

Tailleur, I.L., 1973, Probable Rift Origin of Canada Basin, Arctic Ocean, 526-535, American Association of Petroleum Geologists, Tulsa, Oklahoma.

Taylor, P.T. and Frawley, J.J., 1986, MAGSAT anomaly map of the Alaska-Canada Arctic continental margin. EOS Trans, American Geophysical Union, 67, 920.

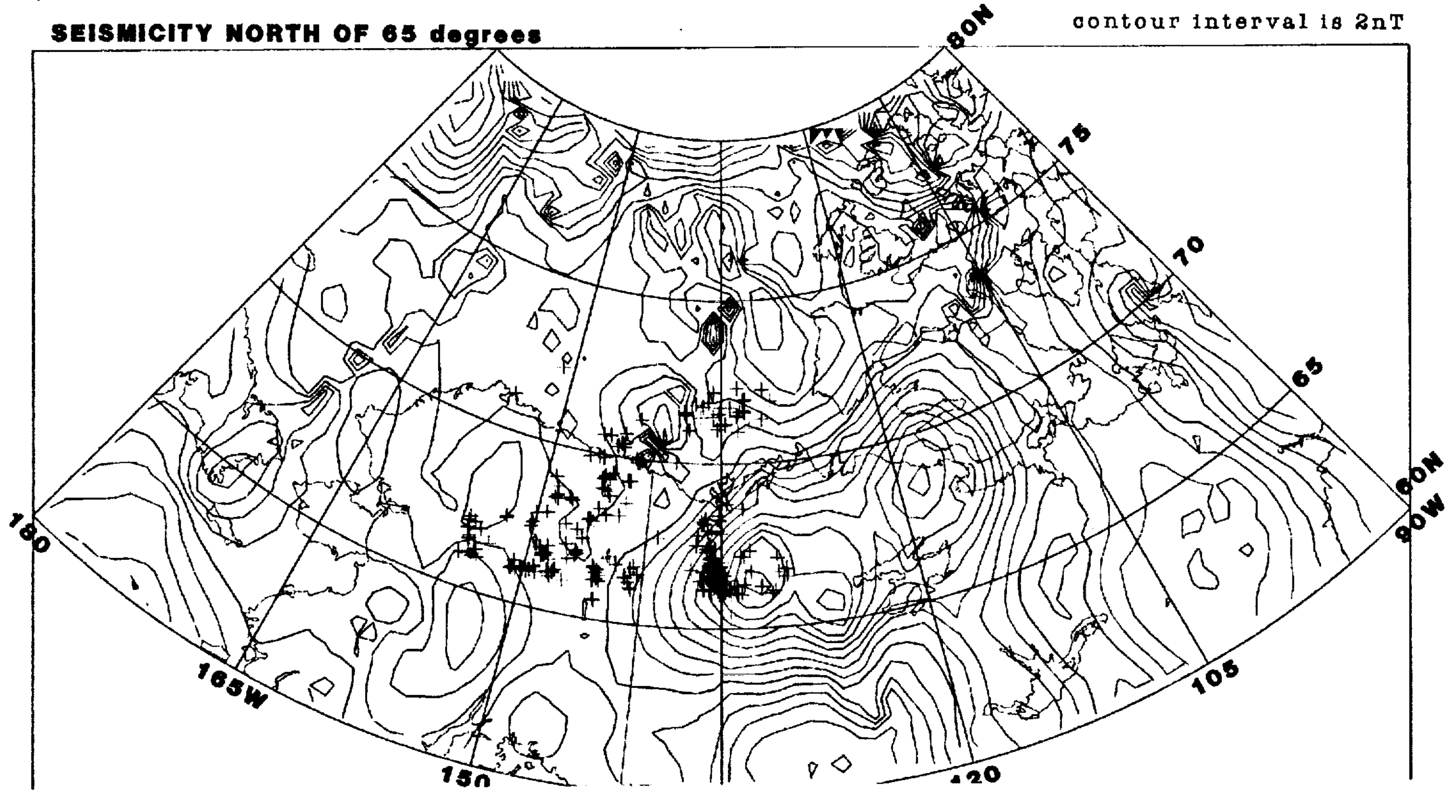
Taylor, P.T. and Frawley, J.J., 1987, Magsat anomaly data over the Kursk region, U.S.S.R., Physics of the Earth and Planetary Interiors, 45, 255-265.

Taylor, P. T., L.C. Kovacs, P.R. Vogt, and G.L. Johnson, 1981, Detailed aeromagnetic investigations of the Arctic basin, 2, Journal of Geophysical Research,86, 6323-6333.

Zoback, M.L., 1992, First- and Second-Order Patterns of Stress in the Lithosphere: The World Stress Map Project, Journal of Geophysical Research, 97, 11,703-11,728.

SEISMICITY NORTH OF 65 degrees

contour interval is 2nT



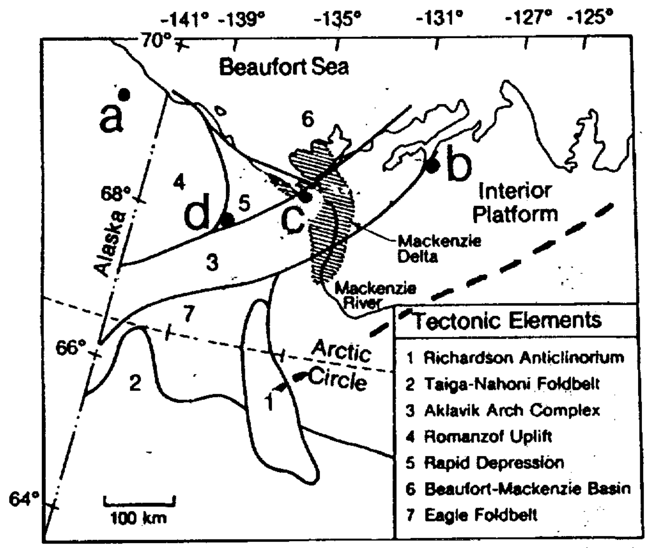
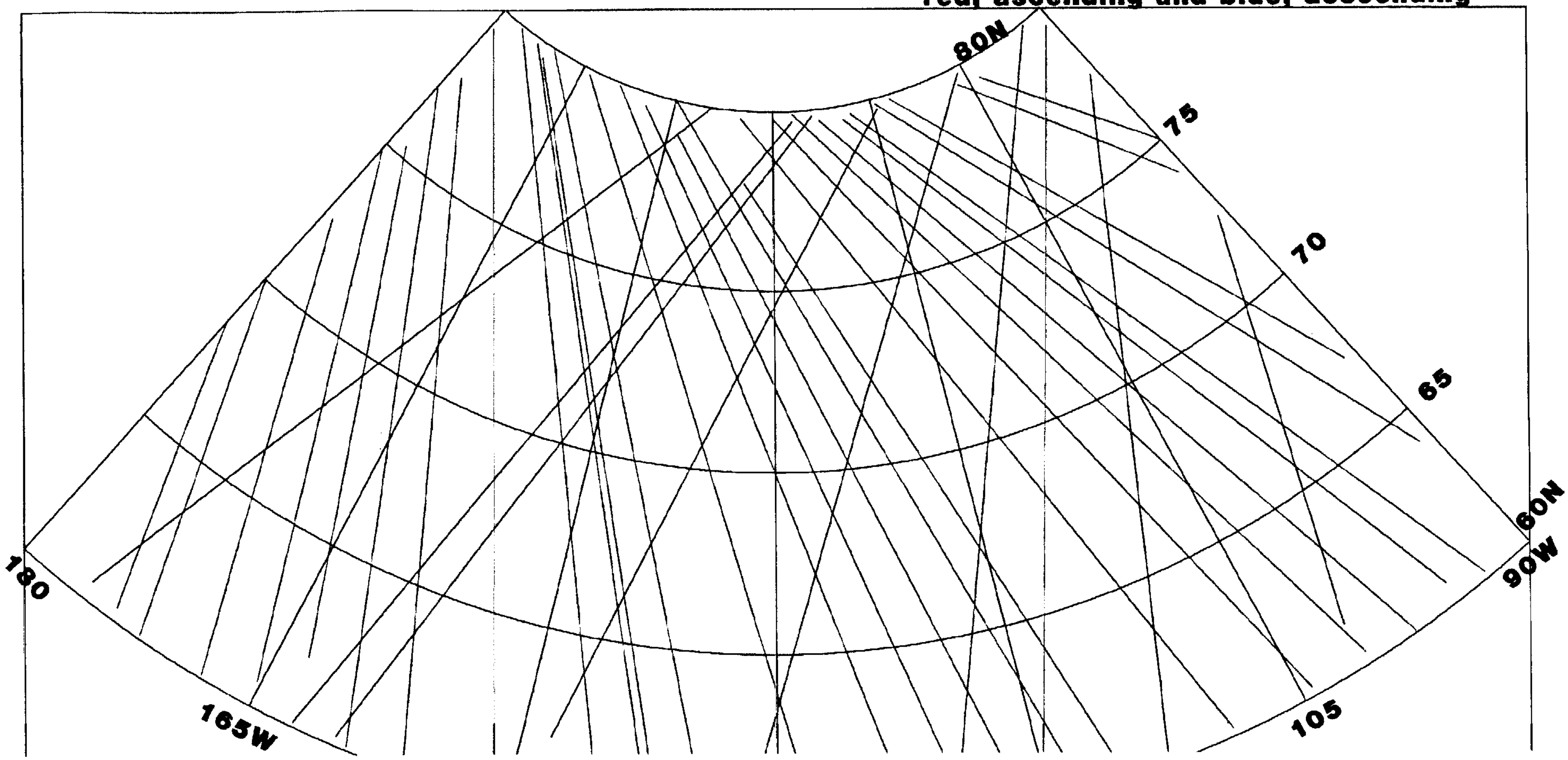


Figure ~~2~~ 3

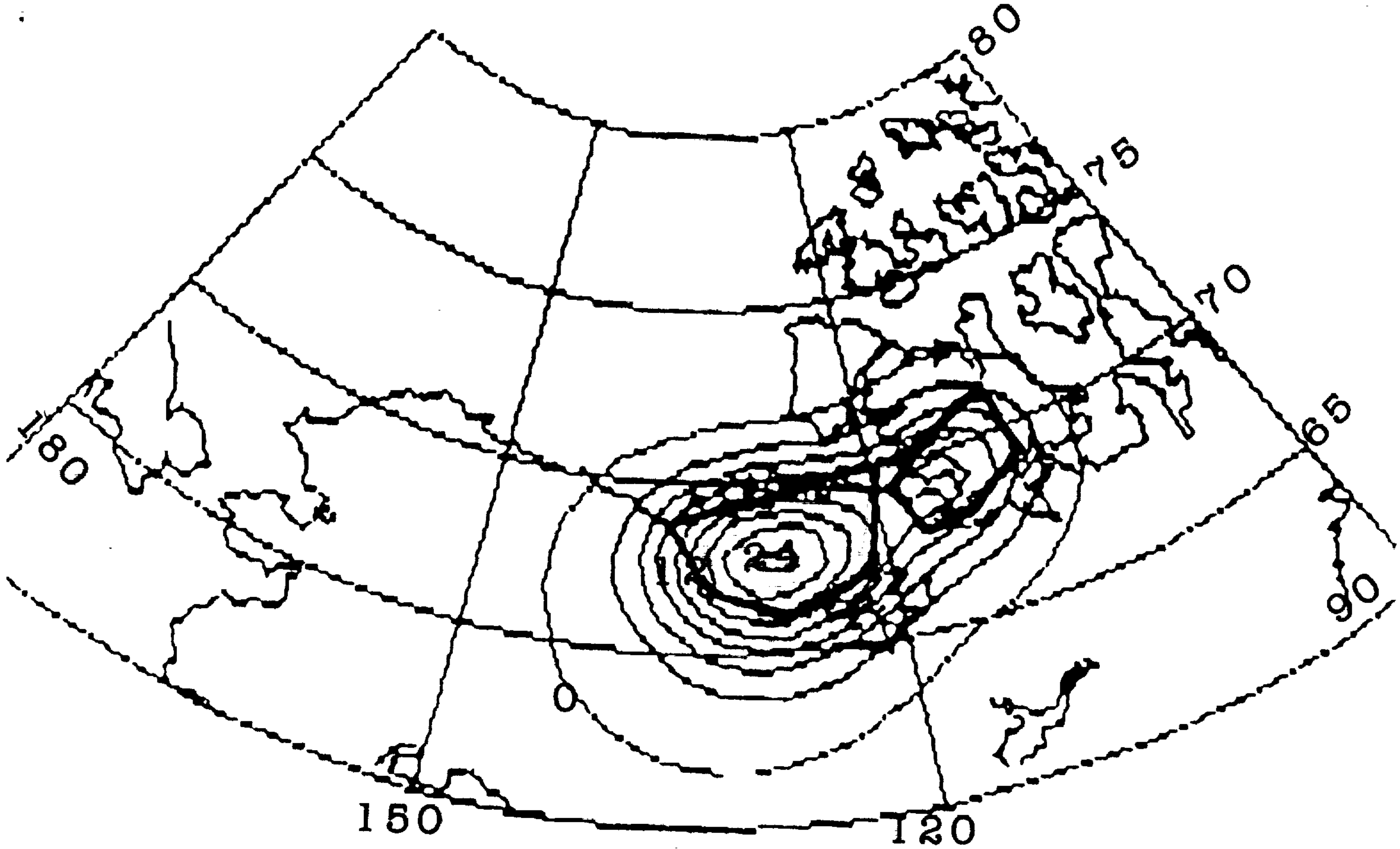
Locations of the heat flow profiles AA′ and CC′ on the tectonic element map of the eastern Cordilleran foldbelt of northern Canada (after NORRIS, 1985).

MAGSAT ORBITS

red, ascending and blue, descending



thickness 15 km k equals 0.008 cgs



contour interval 3 nT

Model Study