

NEW GEOPHYSICAL DATA ABOUT THE INNER STRUCTURE OF DRAKE PASSAGE CRUST

S. Levashov¹, I. Korchagin², Yu. Kozlenko², V. Solovyov²

¹*Institute of applied problems of Ecology, Geophysics and Geochemistry, Kyiv.*

²*Institute of Geophysics of National Academy of Science of Ukraine, Kyiv, valera@igph.kiev.ua.*

The Ukrainian Antarctic expeditions 1997-2004 years provided new geophysical data for many West Antarctica bottom structures. Gravity, magnetic- and electromagnetic surveys of Drake Passage made near the Antarctic Peninsula also. New obtained results for the tectonic structures enabled to specify the age of the formation of some blocks, separate local crustal inhomogeneities, specify the schemes of the structural division of the continental margin of Antarctica. A great effect of the tectonic factors on the formation of the inhomogeneous sediments (100m to 2,5km thick) and existence of some intrusion zones and tectonically active fracture zones in Drake Passage has been detected.

Key words: West Antarctic region, Drake Passage, magnetic anomalies, vertical electric-resonance sounding survey, deep crustal structure.

Реферат. Отримано нові дані про розподіл геофізичних полів для тектонічних структур літосфери Західної Антарктики, що дозволило уточнити вік формування окремих блоків, виділити локальні неоднорідності земної кори. Виявлено велику неоднорідність розподілу осадової товщі та існування окремих зон інтрузій і тектонічно активних зон розломів у протоці Дрейка. Проведені дослідження засвідчили високу ефективність методу електрорезонансного зондування та можливість його практичного застосування при дослідженнях глибинної будови структур літосфери.

Реферат. Новые данные о распределении геофизических полей для тектонических структур литосферы Западной Антарктики позволили уточнить возраст формирования отдельных блоков, выделить локальные неоднородности земной коры, выявить распределения осадочной толщи, закартировать отдельные зоны интрузий и тектонически активные зоны разломов в проливе Дрейка. Исследования подтвердили высокую эффективность применения метода электрорезонансного зондирования при исследованиях глубинного строения структур литосферы.

1. Introduction

The Ukrainian Antarctic expeditions provided new geophysical (gravity, magnetic- and electromagnetic) data for many West Antarctica bottom structures of Drake Passage, Scotia Sea and continental margins of the Antarctic Peninsula.

The clearest structural elements belonging to large plates were cut by survey tacks, which enabled specifying of the features of their deep structure, evolution and geodynamics.

Drake Passage segment adjacent to the Antarctic Peninsula and lying between the Anvers Fracture Zone in the South and the Shackleton Fracture Zone in the North – West is most interesting for a review since this region was notably covered by geophysical observations during the Antarctic expeditions made by the Institute of Geophysics of National Academy of Science of Ukraine in 1997-2004 and provided a great volume of new information for estimating the features of the distribution of the potential field anomalies (fig.1).

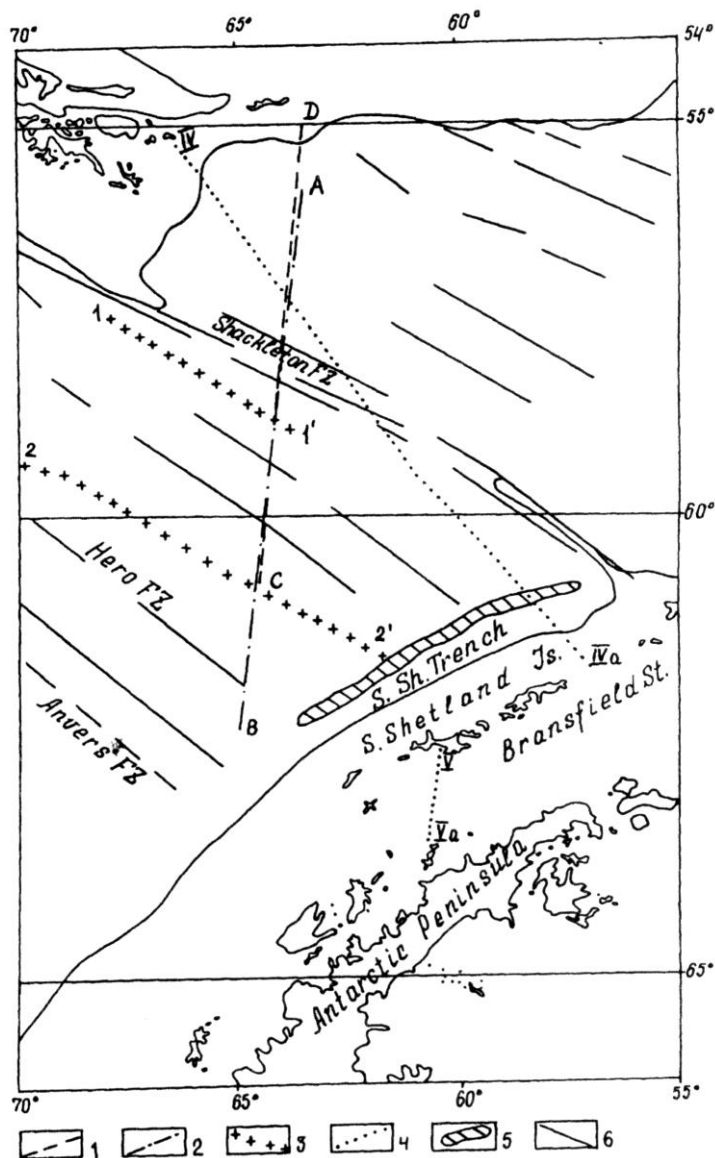


Fig. 1. Geophysical profiles position in the central part of the Drake Passage. Legend: ship's tracks of JGF NASU survey: 1 – magnetic (A-C); 2 – gravity (B-D); 3 – location of magnetic and modeling profiles; 4 – location of the electromagnetic sounding profiles; 5 – the South Shetland Trench; 6 – fracture zones.

2. Results

The history of studying the geologic setting and evolution of the structures of Drake Passage and Scotia Sea counts several decades. The deep seismic soundings made in Drake Passage and Scotia Sea region provided data on the regional and local features of the distribution of the main crustal horizons changing rather largely. E.g., the M-discontinuity depth varies, according to the data of polish researchers, from 10km in Drake Passage to 40km for the continental crust) beneath the Antarctic Peninsula [5, 8].

The heterogeneity of the earth crust and its fracture zones find the clear reflection in geoelectrical anomalies. In this connection, the geoelectrical investigations with using the methods of formation of short-impulse electromagnetic field (FSPEF) and vertical electric-resonance sounding (VERS) were enclosed to investigation program of the seasonal functioning of the 9-th Ukrainian Antarctic expedition [2,3].

The typical sediment thickness in Drake Passage is not more than 300-900m. Its size is influenced by the low sediment accumulation rate, the large-scale –Antarctic-Circumpolar Current as well as the clear-cut areas of the disturbed relief at the spreading centers where new oceanic crust forms actively.

Figure 2 illustrates an important feature of Drake Passage crust structure, namely that no thick sediments exist at the base of South America continental slope and only few present types of sediment were carried out from the shelf region. In the central part of Drake Passage the existence of some intrusion zones and the presence tectonically active fracture zones was detected. The sedimentary cover thins with approaching to segments of the Drake Ridge and the Western Ridge of Scotia in the central part of Passage.

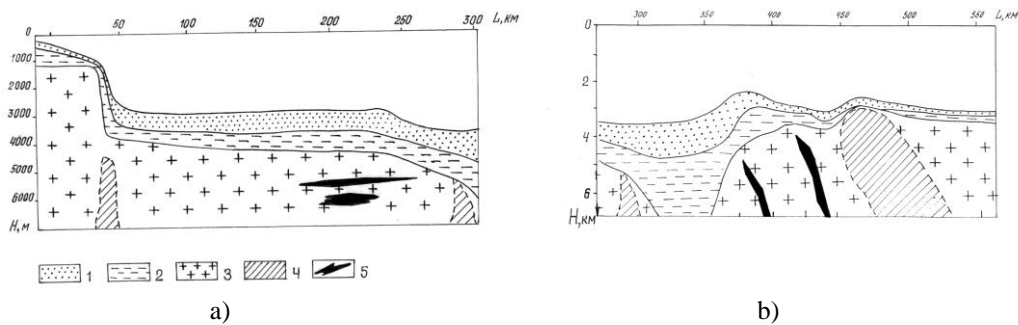


Fig. 2. The upper part of Drake Passage oceanic crust section at the base of South America continental slope (a) and the central part of Drake Passage by electromagnetic sounding data. Legend: 1 – sediments; 2 – rocks of the second oceanic layer; 4 – zones of heating and crushed rocks, 5 – dikes.

The crestral zones of ridges are often clear of sediments though in some places this conformity is not a rule, at the western side of the ridge especially. Such sediment pockets may be of more ancient age than the nearest bottom places.

The distribution of gravity free air anomalies in Drake Passage (fig.3) showed the complicated character of geological structure and geodynamics of this region. The amplitude of positive anomalies in the central part of Passage and bottom depth point out that typical oceanic crust of a mature age may be absent here. Shackleton and Hero fracture zones have gravity anomalies of high amplitude.

In Drake Passage, the anomalous magnetic field of the oceanic type characteristic was first separated and interpreted in 1970 [4,6,7,11]. It consists of systems of different size anomalies that are symmetric relative to the ridge axis and have passed over the transformed fault zones.

The depth of the occurrence the obtained bodies of simple form and their thickness as a rule corresponded with the position of the second (basaltic) oceanic horizon. Approximation of a magnetic layer by separate blocks was made in several stages since the formal solution did not enable a satisfactory recovering of the value throughout the profile (fig.4).

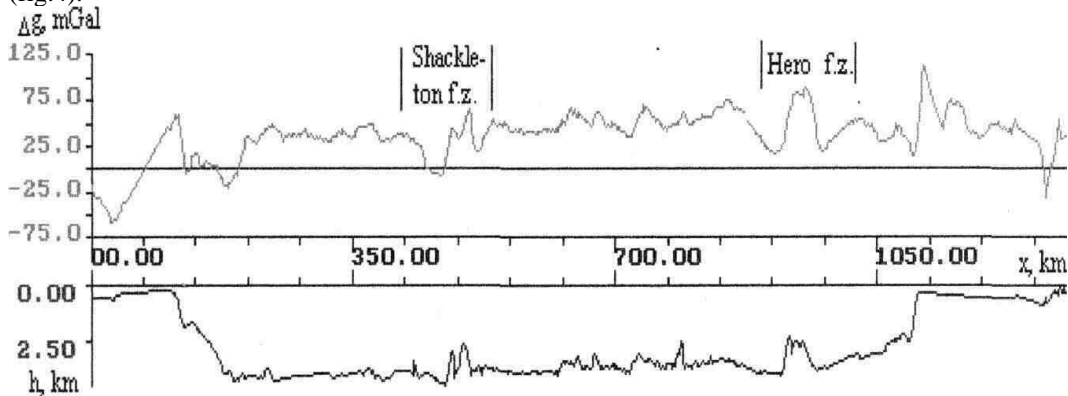


Fig. 3. The gravity anomaly field and bottom relief for profile through Drake Passage.

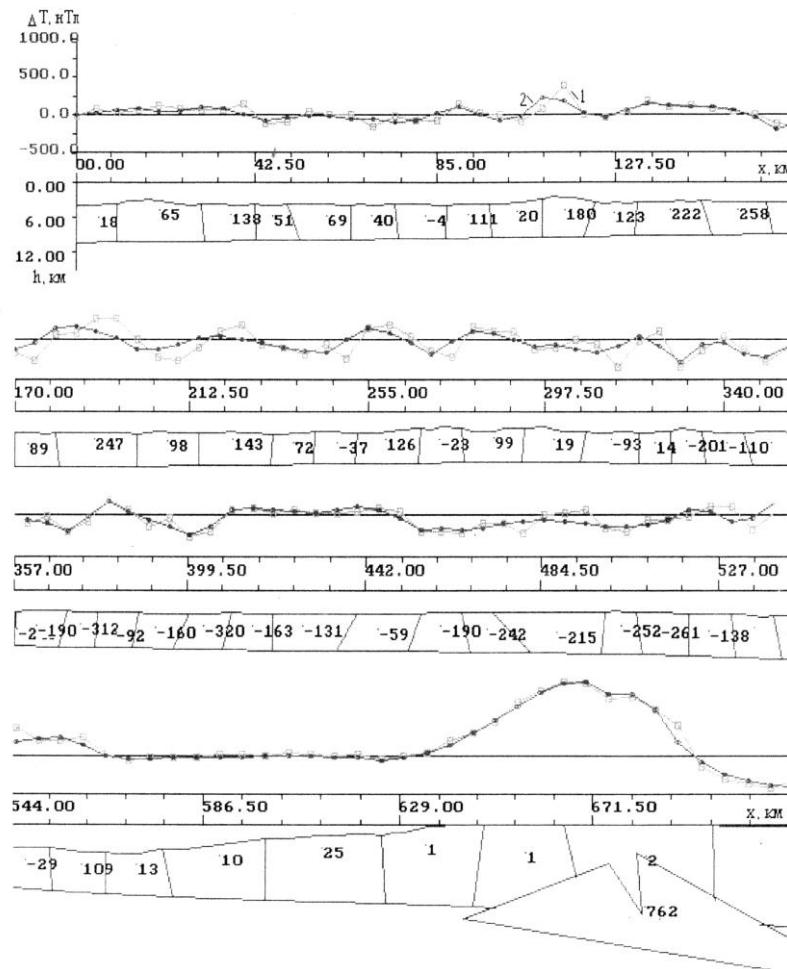


Fig. 4. An example of modeling anomalies along the profile through Drake Passage by automated fitting method: 1 – observed anomaly curve; 2 – fitted anomaly curve. Numbers – the magnetization values. The profile location is shown on fig.1.

Within the continental slope and the shelf of Antarctica an anomaly with two maximums of 400 nT intensity was distinguished on the side of Drake Passage. The source of this anomaly is a magnetoactive body with magnetization of $+2,7 \text{ A}\cdot\text{m}^{-1}$, which corresponds with the mean value of the positively magnetized blocks of the oceanic area of Passage. However, unlike them, this body is deep (6km) from the bottom surface, has a complicated configuration of the upper surface and is to 12km thick [1,9].

The formal interpretation by the fitting method shows the correspondence of the obtained magnetic parameters with the mean values of the magnetic characteristics obtained from the results of petrophysical studies of an Antarctic Peninsula rock collection with predominant samples that were magnetized by the present magnetic field.

The results of geophysical studies made of Drake Passage for the last 10-15 years were used to perform a correlation and identification of separate magnetic anomalies far from each other and subdivided by numerous faults of different order that violate the ordered succession of the anomalies.

The analysis of the magnetic anomaly patterns in Drake Passage has allowed the reconstruction of the geological events since Late Oligocene [11]. The existent negative and positive magnetic anomaly distribution associated with different time of the oceanic floor areas formation corresponds with the dated linear anomalies of the Lamont paleomagnetic scale whose age is 7.07-8.28m.y.

Some areas are still difficult to place in the tectonic history of this region.

The complicated tectonic interaction of several large and small plates (North American, Antarctic, Scotia, Aluc (Phoenix), Shetland) was at some evolution stages discontinuous and was alternatively dominated by phases of regional and local influence. It was accompanied by processes of accretion, spreading and subduction expressed in dated linear magnetic anomalies and fixing of the dynamics of the behavior of the spreading rates for the last 35my (fig. 5).

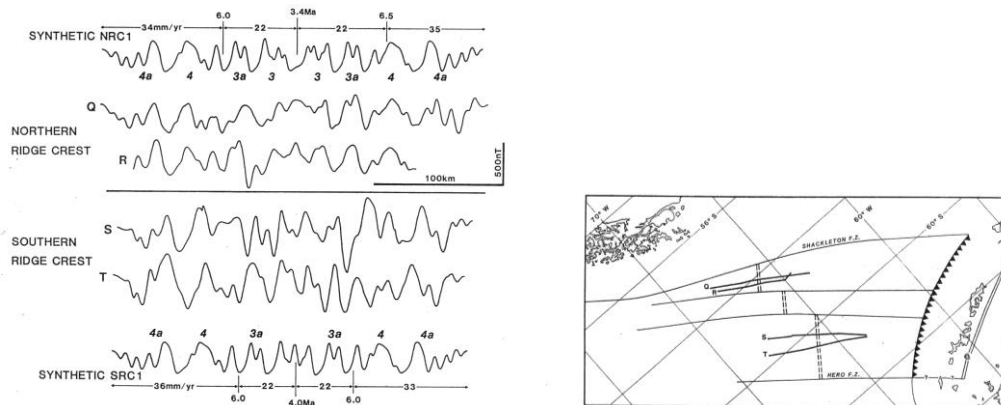


Fig. 5. Correlation of linear magnetic anomalies and profiles location in Drake Passage [11].

The obtained spreading rate values correlate with the direction of the local effect of tectonic stress on the margins of separate plates.

An analysis of the magnetic anomaly distribution in this region shows that the age of the oceanic floor increases NW- and N-wards from the three remnant segments of the ridge Aluc (Phoenix). The minimal age of the oceanic crust is not more than 4my. The isochrones distribution data for the whole area gives an idea of the time and the succession of the oceanic crust formation in the conditions of the complicate paleodynamics of this region.

In general, the age of the subducted oceanic crust of the Pacific coast of Antarctica between the Hero and Shackleton fault zones is more than 20my. In the areas of the young collision zones southwest of the Northern zone of the Anvers faults, the magnetic anomalies overstep the limits of the present continental slope, which is also seen for the fault zones situated south of the Anvers fault zone. Therefore it may be assumed that at some areas near the Antarctic Peninsula the magnetic distribution sources of the anomalies are buried in the younger sea-floor sediments.

The terrigenous sediments accumulation rate was practically high along the whole Peninsula but the changes in the sediment accumulation regime due to the glaciers formation processes on the adjacent Antarctic Peninsula land favored a clear differentiation of the sediment thickness distribution. Near the Shackleton Fracture Zone the sediment thickness changes notably since the sediment deposits filling the South Shetland Trench and the oceanic basement relief reflect the total effect of numerous geologic and geodynamic factors (fig.6).

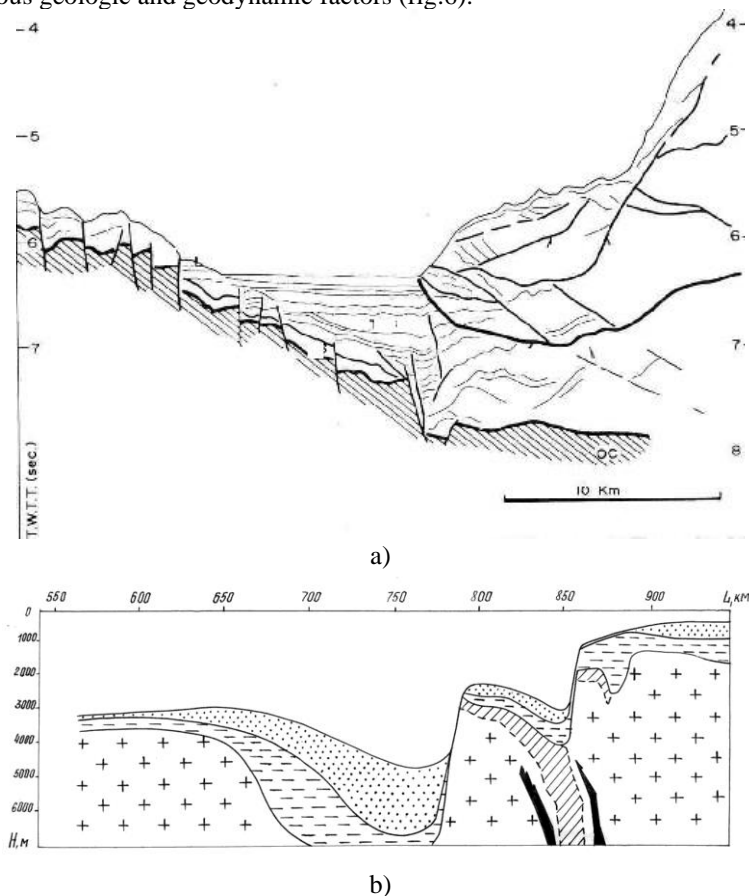


Fig. 6. The South Shetland Trench structure by seismic (a) and electro-magnetic sounding data (b). Legend: 1 – sediments; 2 – rocks of the second oceanic layer; 4 – zones of heating and crushed rocks, 5 – dikes. TWTT is two-way travel time [10].

There is also an interpretation version of the electromagnetic data investigations that made along the profile cutting Drake Passage and the South Shetland Trench. The sedimentary cover thins with approaching segments of the Drake Ridge and the Western Ridge of Scotia in the central part of Passage. There is no sign of active subduction at depths to 6km. The shown distribution of the geophysical inhomogeneities of the upper part of the lithosphere near the Antarctic Peninsula may be local [9,10] and notably differ from those at other Drake Passage areas, i.e. the active continental margin area in the region of the South Shetland trench may be less extensive.

3. Conclusions

New data on the geophysical field distribution for the tectonic structures of the West Antarctica lithosphere enabled to specify the age of the formation of some blocks, separate local Earth's crust inhomogeneities, specify the schemes of the structural division of the continental margin of Antarctica. A great effect of the tectonic factors on the formation of the inhomogeneous sediments (100m to 2,5km thick) and the existence of some intrusion zones and the presence tectonically active fracture zones (the West Scotia Ridge, the Shackleton FZ) in Drake Passage has been detected.

These results may suggest the necessity of specify in the existent ideas of the sediments distribution and the spatial inhomogeneities of the upper lithosphere. The presence of some dikes and sills at depths of not more than 6 km enables to specify the results of a numerical interpretation of magnetic anomalies and their influence on the local and regional correlation of the dated anomalies in this region.

New results have been obtained for the South Shetland Trench where large areas of possible heating, series of intrusions near the Antarctic Peninsula coast were tasted; data on the character of the depth distribution of sediments have been specified. It is important for estimating the subduction processes in the region.

References

1. **Бахмутов В.Г.**, Козленко Ю.В., Корчагин И.Н., Орлова М.И., Соловьев В.Д., Шепель С.И., Якимчук Н.А., Якимчук Ю.Н. Геофизические исследования в украинских морских антарктических экспедициях (по материалам 60 и 61-го рейсов НИС «Эрнст Крендель») // Ин-т геофизики НАН Украины. – Киев, 2001. – 323 с. – Деп. в ГНТБ Украины 9.04.2001. – № 70-Ук2001.
2. **Левашов С.П.**, Якимчук М.А., Корчагин И.М., Пищаний Ю.М. Метод электрорезонансного зондирования та його можливості при проведенні комплексних геолого-геофізичних досліджень. Геоінформатика. – 2003.– №1. – С. 15–20.
3. **Левашов С.П.**, Пищаний Ю.М. Картографические материалы результатов геоэлектрических работ в районе Антарктического полуострова. Материалы IX Украинской Антарктической экспедиции. Киев-2004.
4. **Старостенко В.И.**, Гросс С.С., Коболев В.П., Корчагин И.Н., Михайлюк С.Ф., Соловьев В.Д., Русаков О.М., Якимчук Ю.Н. Новые технологии при проведении гидромагнитных исследований в морских акваториях: методика измерений, алгоритмы обработки, практические результаты // Геофізичний журнал. – 2003. – 25, № 2. – С. 70–89.
5. **Ashcroft W.A.** 1972. Crustal structure of the South Shetland Islands and the Bransfield Passage. – British Antarctic Survey Scientific Reports. 66: P.1–43.
6. **Barker P.F.** The Cainozoic subduction history of the Pacific margin of the Antarctic Peninsula: ridge crest-trench interactions // J. Geol., Soc. London. – 139. – 1982. – P. 787–801.
7. **Barker P.F.** and Lawver L.A. 1988. South American-Antarctic plate motion over the past 50 Myr, and the evolution of the South American-Antarctic Ridge. — Geophysical Journal, 94: P. 377–386.
8. **Grad M.**, Gutterch A., Janik T. Seismic structure of the lithosphere across the zone of subducted Drake Plate under the Antarctic Plate, West Antarctica // Geophys. J. Int., 1993. – Vol. 115. – P. 568–600.
9. **Kozlenko Ju.V.**, Korchagin I.N., Solovjov V.D., Yakymchuk M. A. New results of geophysical investigations in the western Antarctic region // Ukrainian Antarctic Centre Bulletin. Issue 4. – Kyiv, 2002. – P. 157–160.
10. **Maldonado A.**, Larter R.D., Aldaya F. Forearc tectonic evolution of the South Shetland Margin, Antarctic Peninsula. Tectonics, 1994, v.13, 6. P.1345–1370.
11. **Robert D.** Larter and Peter F. Barker. 1991.Effects of Ridge Crest-Trench Interaction on Antarctic-Phoenix Spreading: Forces on a Young Subducting Plate-Journal of Geophysical Research, vol. 96, NO. B12, P. 19,583–19,607.