D21-46
59 98
9202

N86-28556

W9901063

SOME EXAMPLES OF DEEP STRUCTURE OF THE ARCHEAN FROM GEOPHYSICS;

S.B. Smithson, R.A. Johnson and W.R. Pierson, Department of Geology and Geophysics, Program for Crustal Studies, University of Wyoming, Laramie, Wyoming 82071

The development of Archean crust remains as one of the significant problems in earth science, and a major unknown concerning Archean terrains is the nature of the deep crust. The character of crust beneath granulite terrains is especially fascinating because granulites are generally interpreted to represent a deep crustal section.

Some of the oldest Archean crust in North America is found in the Precambrian of Minnesota, which has dates of 3.6-3.8 b.y. (1). Here the ancient Minnesota Valley gneiss terrain is bounded on the north by the Great Lakes tectonic zone (2) and a series of late Archean greenstone belts. The Great Lakes tectonic zone was presumed to be a steeply dipping Archean border but COCORP crustal reflection data (3,4) shows a gently dipping reflection beneath the zone. Because some of the best crustal reflectors may be fault zones along which mylonites have formed within the ductile regime (5,6), the reflection could be caused by a mylonitic thrust fault. It could equally well be interpreted as a mylonitic listric normal fault, especially since younger rocks lie on older across the fault. However, the indication of a major recumbent fold above the fault reflection (4) suggests that this event is coming from a thrust fault; mylonitization along the fault zone is the postulated cause of the strong, multicyclic-reflection (6). Magnetic data from this area can be best modeled with a magnetized wedge of older Archean rocks (granulitic gneisses) underlying the younger Archean greenstone terrain ~~(Fig. 1)~~. The dip of the boundary based on magnetic modeling is the same as the dip of the postulated thrust-fault reflection. Thus several lines of evidence indicate that the younger Archean greenstone belt terrain is thrust above the ancient Minnesota Valley gneiss terrain, presumably as the greenstone belt was accreted to the gneiss terrain, so that the dipping reflection represents a suture zone. This dipping reflection, however, with a thickness of about 1-2 km, seems remarkably simple to represent an Archean suture. Its apparent simplicity may just be a function of resolution in the seismic survey and the postulated suture may be more geologically extensive and broader.

Other dipping events beneath the greenstone terrain may also be reflections from thrusts. Thus by at least late Archean time, a horizontal tectonic regime was dominant. This may reflect the operation of plate-tectonics mechanisms, and if greenstone belts are formed around island arcs, then their presence is more evidence for early plate tectonics.

Seismic data from underneath the granulite-facies Minnesota gneiss terrain shows abundant reflections between 3 and 6 s, or about 9 to 20 km. These are arcuate or dipping multicyclic events indicative of layering. Flat events continue to 10 s or more than 30 km. The gneisses consist of granodioritic to tonalitic gneisses with mafic layers or schlieren and garnets (7). Foliation in the gneiss generally dips moderately. Although the layered sequences underlying the gneiss could be mylonites their arcuate geometry and general geologic setting suggest that these events are caused by layered gneisses that could represent a supracrustal sequence (although with transposed layering). This indicates that no mafic residuum from anatexis closely underlies the gneiss unless it is highly heterogeneous. The significance of layering may rather be to indicate a large-scale migmatite terrain. This reflection data furnishes important information concerning what underlies a granulite terrain. The rocks appear to be a heterogeneous, layered, deformed sequence of rocks with moderately dipping foliation.

Seismic data is available from two areas within the Archean Wyoming province, the Wind River Mountains which are comprised of some of the oldest rocks of the Wyoming province, and the Laramie Range. The COCORP Wind River lines that imaged the Laramide Wind River thrust fault crossed the flank of a greenstone belt at South Pass (8). Except for one strong event at 2.5 s, the seismic section does not show many reflections from the upper crust. This is somewhat surprising because of the different velocity contrasts expected from within the greenstone belt rocks; however, the explanation for this might be the steep dips that are present near the surface.

The crust beneath the Wind River Mountains produces discontinuous but strong reflections all through the crust and complex arcuate events at 8 s on line 1A (10). Interpretation of these events on the basis of fold structures exposed up-plunge in the hanging-wall block of the Wind River uplift suggests that the deep crust is not significantly different from the folded high grade metamorphic rocks intruded by granites exposed in the core of the range. Furthermore, Smithson et al. (1980) suggest that a crustal thickness of 35-40 km was attained by 3 b.y. based on the interpretation of complex fold structure. Constraints on deep crustal development may best be determined from the reflection data.

A Proterozoic suture zone in southeastern Wyoming marks the border between the Archean Wyoming province (which includes the basement rocks of the Wind River Mountains) and 1.7 b.y. crust to the south (10). The suture zone consists of a steeply dipping mylonite zone from 1 to 7 km wide (10). This area has been the site of extensive geophysical studies including acquisition of seismic reflection and gravity data by the University of Wyoming (11,12) and COCORP seismic lines (13). These data have provided constraints on the interpretation of surficial geological features as well as deep crustal structure. Most of the seismc data comes from the Proterozoic terrain south of the suture zone. Gravity interpretation indicated that charnockitic syenite associated with the Laramie anorthosite complex was underlain at several kilometers depth by mafic rock (14), and later seismic work showed refractions coming from a high-velocity (mafic) zone. Both seismic reflection interpretation (11,13) and gravity interpretation suggest that the Laramie anorthosite itself is about 6 km thick. Reflections from depths of 4 to 18 km are found beneath the vast 1.4 b.y. Sherman granite and indicate the presence of heterogeneities that could represent features such as xenoliths or the base (or far below the base) of the batholith (11).

Many ambiguities still exist in the interpretation of deep crustal reflections. Complexities are illustrated by a zone of reflections resembling an unconformity on COCORP line 5. When this data is migrated to move dipping events into proper geometric position, the reflections then form the shape of a dipping saucer. This could come from a layered mafic intrusion (15), and modeling, which is generally the only check on a deep crustal reflection interpretation, indicates that this is a plausible conclusion (16, Fig. 4, p. 96).

The shear zone marking the Proterozoic suture may have been detected by ~~the COCORP~~ reflection survey which suggests that it dips about 50° southeast (13). Although Moho depths were picked from the COCORP data, the seismic data are highly ambiguous and unreliable on this question. Gravity data, however, indicates a change in crustal structure across the Archean-Proterozoic suture (12). The gravity field decreases to the southeast at the suture zone (Fig. 2) and the interpretation of this observation is that the crust thickens to the south and/or crustal density decreases to the south (12). Because of Laramide effects, some long-wavelength thickening of the crust occurs to the south, but an abrupt change in crustal thickness or change in crustal density or both occurs at the boundary and has apparently persisted since middle Proterozoic time (12). The southern Proterozoic province is believed to consist of deeply eroded roots of a migrating chain of island arcs and a continental margin that evolved from an Early Proterozoic Atlantic-type passive margin to a convergent margin in the Middle Proterozoic with the accretion of island arc terrains (10). This is somewhat similar to the early Paleozoic history of the Appalachians.

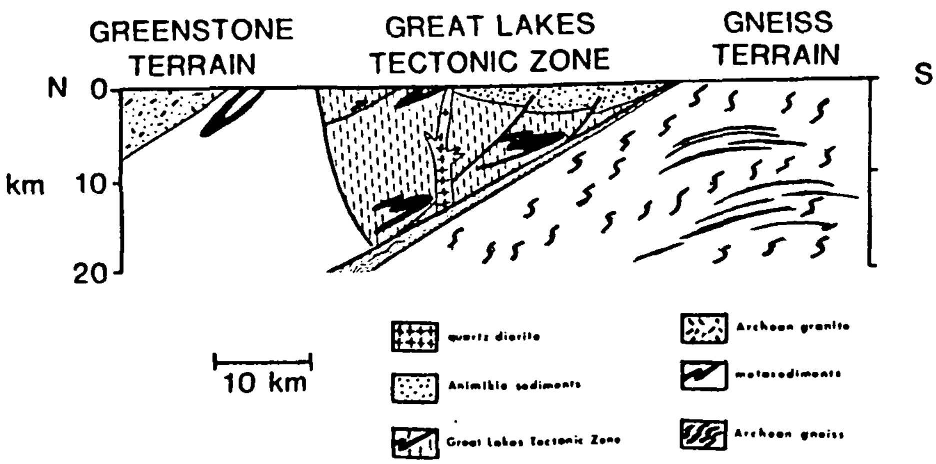

Figure 1. Interpretation of seismic sections showing structural relationships between different terrains in Minnesota Archean separated by a mylonitic thrust zone.

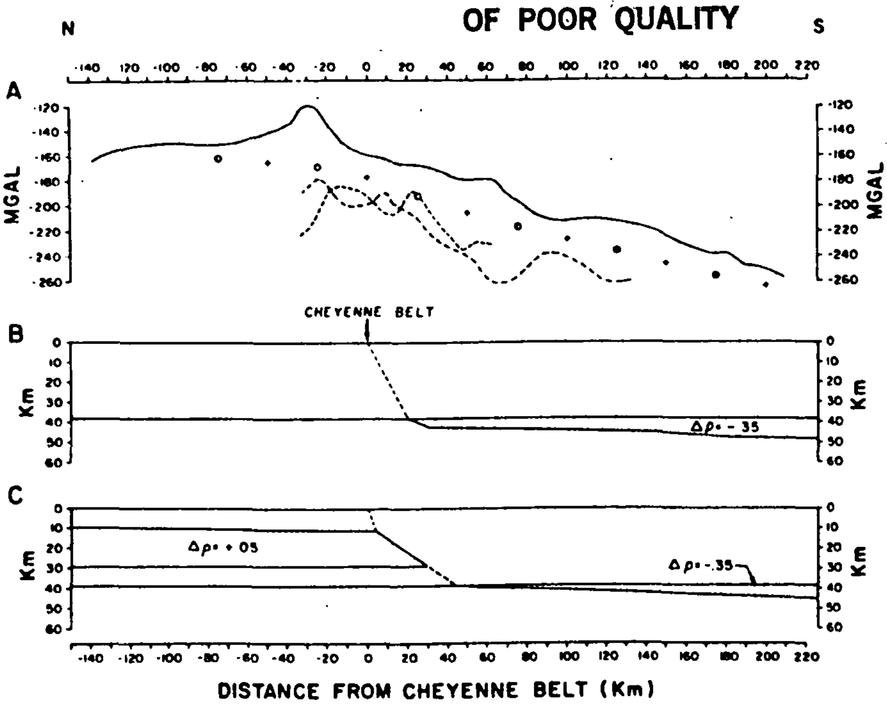

Figure 2. Gravity profiles (A) over Proterozoic suture (Cheyenne belt) in southeastern Wyoming. Profiles are from three different areas and show a general decrease in gravity across the Cheyenne belt. Gravity model B explains the decrease in gravity solely on the basis of a change in crustal thickness and gravity model C combines a change in crustal density with a small change in crustal thickness as an alternative interpretation (After Johnson et al., 1984).

References

1. Goldich, S.S. & Hedge, C.E. 1974. '3,800 myr granitic gneiss in south western Minnesota'. Nature, 252, p. 467-468.
2. Sims, P.K., Card, K.D., Morry, G.B., & Peterman, Z.E. 1980. 'The Great Lakes tectonic zone - A major crustal feature in North America'. Geol. Soc. Amer. Bull. 91, p. 690-698.
3. Gibb, A.K., Payne, B., Setzer, T., Brown, L.D., Oliver, J.E. & Kaufman, S. 1984. 'Seismic-reflection study of the Precambrian crust of central Minnesota'. Geol. Soc. Am. Bull. 95, p. 280-294.
4. Pierson, W.R. 1984. A geophysical study of the contact between the greenstone-granite terrain and the gneiss terrain in central Minnesota. Unpubl. M.S. Thesis, University of Wyoming, Laramie, 84 p.
5. Smithson, S.B., Brewer, J.A., Kaufman, S., Oliver, J., & Hurich, C. 1979. 'Structure of the Laramide Wind River uplift, Wyoming, from COCORP deep reflection data and from gravity data'. J. Geophys. Res. 84, p. 5955-5972.
6. Fountain, D.M., Hurich, C.A & Smithson, S.B. 1984. 'Seismic reflectivity of mylonite zones in the crust'. Geology, 12, p. 195-198.

7. Grant, J.A. 1972. 'Minnesota River Valley, southwestern Minnesota'. in Sims, P.K. and Morey G.B., eds. Geology of Minnesota-A centenial volume. Minnesota Geological Survey, p. 177-198.
8. Condie, K.C. 1972. 'A plate tectonics evolutionary model of the South Pass Archean greenstone belt, southwestern Wyoming'. 24th Int'l. Geol. Congr. Sect. 1, p. 104-112.
9. Smithson, S.B., Brewer, J.A., Kaufman, S., Oliver, J.E. & Zawislak, R.L. 1980. 'Complex Archean lower crustal structure revealed by COCORP crustal reflection profiling in the Wind River Range, Wyoming'. Earth Planet. Sci. Lett. 46, p. 295-305.
10. Karlstrom, K.E. & Houston, R.S. 1984. 'The Cheyenne belt: Analysis of a Proterozoic suture in southern Wyoming'. Precambrian Research, 25, p. 415-446.
11. Smithson, S.B., Shive, P.N., & Brown, S.K. 1977. 'Seismic reflections from Precambrian crust'. Earth Planet. Sci. Lett. 35, p. 134-144.
12. Johnson, R.A., Karlstrom, K.E., Smithson, S.B., & Houston, R.S. 1984. 'Gravity profiles across the Cheyenne Belt, a Precambrian crustal suture in southeastern Wyoming'. J. Geodynamics, 1, in press.
13. Allmendinger, R.W., Brewer, J.A., Brown, L.D., Kaufman, S., Oliver, J.E., & Houston, R.S. 1982. 'COCORP profiling across the Rocky Mountain Front in southern Wyoming, part 2: Precambrian basement structure and its influence on Laramide deformation'. Geol. Soc. Am. Bull. 93, p. 1253-1263.
14. Hodge, D.S., Owen, L.B. & Smithson, S.B. 1973. 'Gravity interpretation of Laramie anorthosite complex, Wyoming'. Geol. Soc. Amer. Bull. 84, p. 1451-1464.
15. Johnson, R.A., Pierson, W. & Smithson, S.B. 'Reprocessing of crustal reflection data'. Int'l Symp. on Deep Structure of the Continental Crust, submitted to American Geophysical Union, Geodynamics Series.
16. Wong, Y.K., Smithson, S.B. & Zawislak, R.L. 1982. 'The role of seismic modeling in deep crustal reflection interpretation, Part I'. University of Wyoming Contributions to Geology, 20, p. 91-109.