Reports

Precambrian Rift: Genesis of Strata-Bound Ore Deposits

Abstract. *Study of deep seismic reflections has detected a Precambrian rift valley below flat-lying sediments in southern Alberta. The anomalous magnetic and gravity trends show that the rift is continuous across Alberta and British Columbia (through the Kimberley lead-zinc field) and possibly the Coeur d'Alene mining district of Idaho. There is evidence that these ore bodies were deposited in a Precambrian rift under conditions similar to those prevailing in the hot-brine areas of the modern Red Sea.*

Until recently (*1*), reliable seismic reflections from the lower crust were difficult to obtain; one relied almost entirely on refraction seismology, which produces useful broad-scale regional data but has no great resolving power. Modern instrumentation, improved field techniques, magnetic recording, and digital processing now obtain detailed and reliable information on crustal structure by reflection seismology (*2*).

Several deep reflecting horizons appear to be continuous, except for zones of fracturing, over at least 100 km in southern Alberta. The most prominent event is from the top of an intermediate layer, locally called the Riel discontinuity, at which the velocity increases abruptly from 6.5 to 7.2 km/sec; this may be equivalent to the Conrad discontinuity in Europe. The marker maintains so much character across zones of faulting that the probability of miscorrelation is small. Dips of up to 20 deg, present on many records, necessitated migration of all reflections so that the horizons might be displayed in their true subsurface positions on the migrated section (Fig. 1). The events are plotted in terms of two-way vertical-travel time. The depth scale varies slightly along the section as the average velocity changes. Weak reflection *M* correlates with the Mohorovičić discontinuity from reversed-refraction profiles.

The Moho changes in depth from 47 to 38 km while the Riel discontinuity changes from 37 to 26 km. An in-line reversed-refraction profile along the strike of the deepest part of the graben confirms the great thickness of the crust in this region, while a broadside refraction profile from a shot point 470 km to the west substantiates the structural variation and the faulting perpendicular to the strike. The amount of structural relief is great but not excessive when one remembers that from surface evidence alone Florensov (*3*) found 5 to 7 km of crustal displacement from the deepest part of the rift to the highest nearby mountain at Lake Baikal.

The seismic structure coincides with a notable linear anomaly in the gravitational and magnetic fields; the area (Figs. 2 and 3) has yielded more than 1800 gravity and ground-magnetometer readings, with a reasonable distribution except in the main range of the Rocky Mountains. With a few notable exceptions the rift was apparently filled with low-density, nonmagnetic, Precambrian sediments. Model calculations, based on a relation between seismic velocities and rock densities, have been made (Fig. 4); agreement with the seismic structure is excellent.

The postulated trace of the rift, determined from geophysical evidence, is superimposed in Fig. 2 together with the locations of gravity high and low anomalies, exploratory wells drilled to basement, reflection and refraction lines, and mining developments on the Precambrian Belt Series. The gravity and magnetic trends may be used to trace the remains of the rift along 450 km; it passes at right angles to the strike of

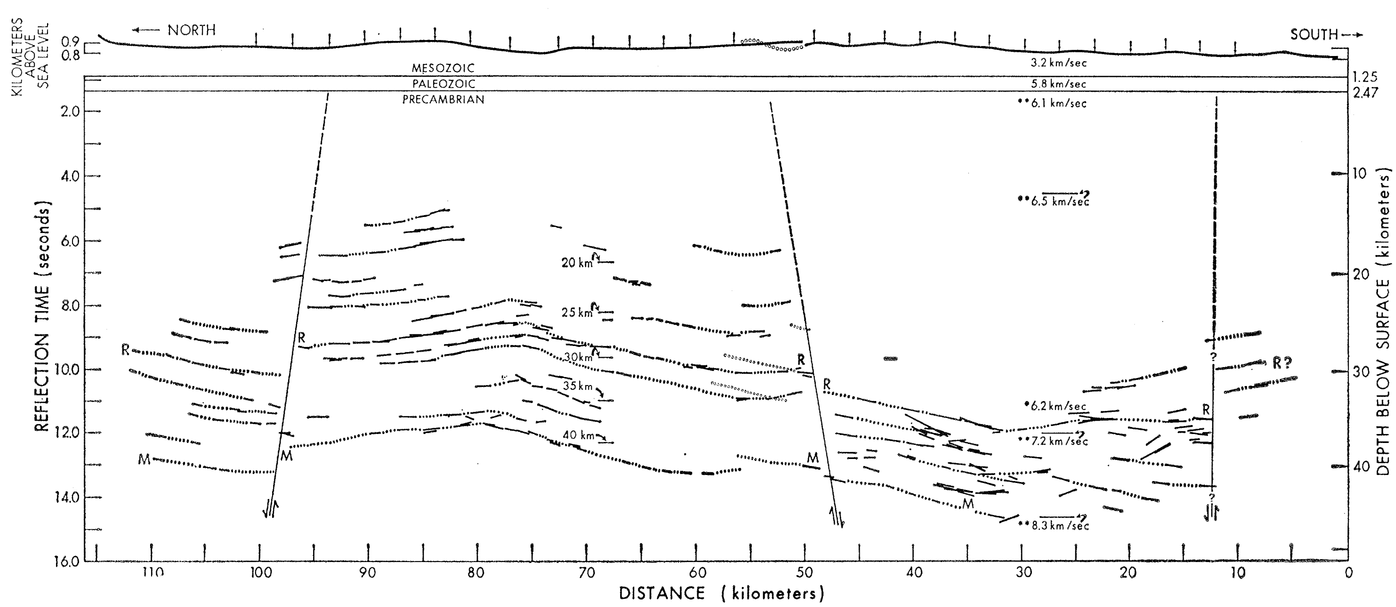

Fig. 1. Seismic-reflection cross section. Depths and velocities of refracting horizons (**) fom an east–west survey are superimposed at the positions of intersection. The *6.2-km/sec velocity is an average vertical velocity between the top of the Paleozoic and the Riel (*R*) discontinuity as obtained from reflection data (*2*). The profile is located in Fig. 2.

the more recent Rocky Mountain system. Ages determined (*4*) from samples from wells into the Precambrian crystalline basement in Alberta make it clear that the rift cuts across Churchill province which is 1.5 to 2.0 $\times$ 10^9 years old. Before deposition of the Cambrian clastics the rift must have been filled with 11 km of sediments in a narrow sea extending from the ancestor of the Pacific Ocean through Idaho, British Columbia, and Alberta into Saskatchewan. Precambrian sediments are exposed over the western section of the proposed rift zone in unusual thicknesses; the Purcell and Belt series vary from a minimum of 11 km near Kimberley to about 15 km in northern Idaho (*5*). A small section of the rift probably remained as a depositional basin near Cranbrook into the Middle Cambrian (*6*). Thrusting during formation of the Rocky Mountains may have moved some of the rocks of the Belt and the Paleozoic eastward from their original positions, but this possibility does not affect my correlation with ore deposition, because any movement must have taken place largely along the strike of the magnetic-anomaly trends in British Columbia.

There are two broad areas in which positive gravity anomalies intrude within the confines of the postulated rift valley, both of which are accounted for by available data: the first, southwest of Cranbrook, British Columbia, is associated with the Moyie Intrusion, a group of thick sills of dense basaltic lava of Precambrian age; the second is over a prominent gravity feature called the Princess High, northeast of Brooks, Alberta. A wildcat well drilled to this feature (*6*) indicates that it was an island that protruded from the Middle Cambrian seas; probably it is the remnant of a basic volcano and was eventually covered by Upper Cambrian clastics.

Because Sullivan (at Kimberley) and Coeur d'Alene ore bodies appear to lie within the Precambrian rift zone, it is natural to investigate a possible relation between formation of these ore bodies and igneous activity associated with the development of a rift. I shall briefly review the evidence. The Sullivan ore body is an example of a strata-bound or conformable deposit (*7*). A hydrothermal theory, according to which thermal waters transport the metals from a magma at depth, has been postulated by some geologists, while others favor a syngenetic origin in which deposition of sulfides is contemporaneous with sedimentation.

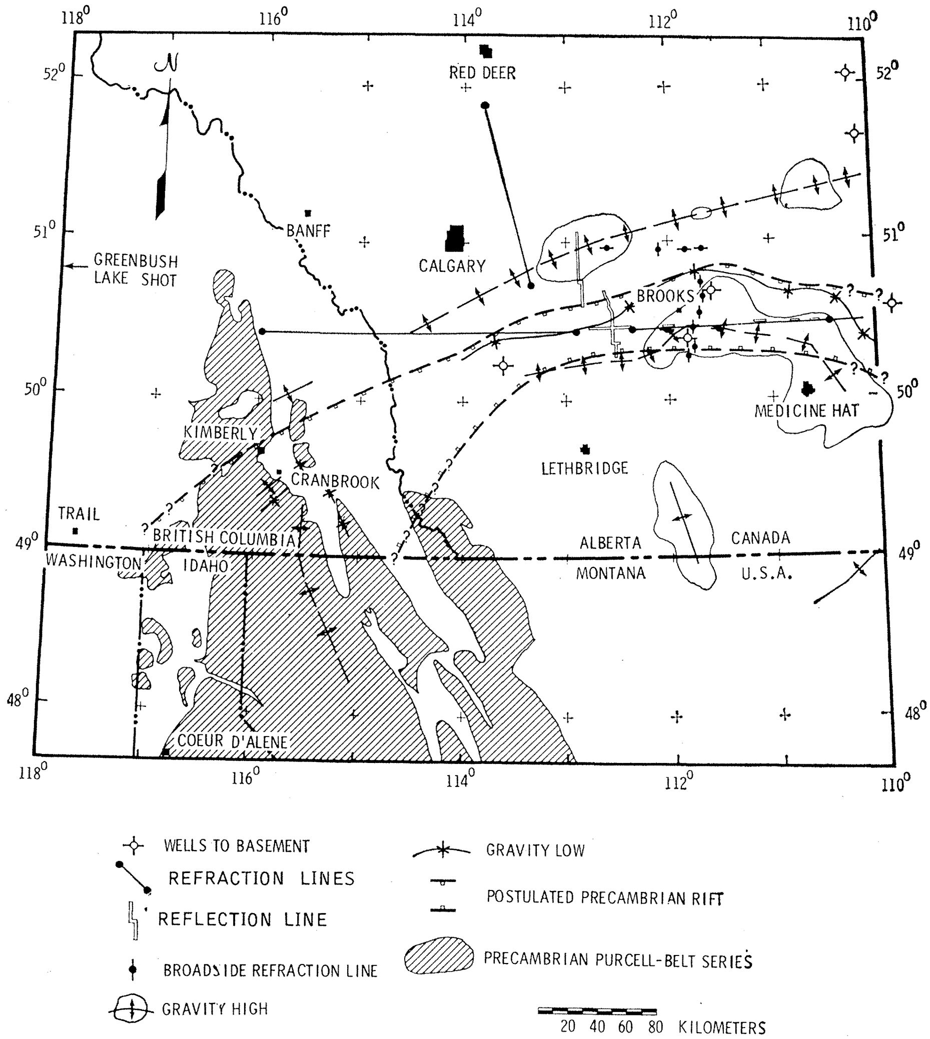

Fig. 2. The postulated trace of the Precambrian rift as determined by geophysical evidence. Reflection and refraction profiles and prominent Bouguer gravity anomalies are located, together with Precambrian outcrops in the area.

Other deposits in this category are the lead-zinc mines in Australia (Mount Isa, Broken Hill, Captain's Flat, Read Roseberry, Hall's Peak), Canada (Bathurst, Buchans, Lake Geneva, Yukon Treadwell, Manitouwadge), and Austria (Bleiberg), and the copper ores in Rhodesia. The lead from the strataform deposits often has isotope ratios that are very uniform within each district, and are related on a worldwide basis by a simple physical model, with ages correlating with an early stage in the development of crustal material in the area (*8*). A single average growth curve has been shown to fit all lead-isotope ratios of ordinary leads (*8*) within 1 percent. It is argued (*9*) that only leads not having traversed crustal rocks are most likely to satisfy the requirements for an ordinary lead, and Stanton suggested that many lead-zinc-copper ores are of syngenetic origin, deriving from volcanoes, and were concentrated in nearshore sediments around islands in an active island arc (*10*).

The syngenetic hypothesis, with biogenic reduction in an island-arc environment, has been criticized by many geologists more familiar with individual mines. Sulfur-isotope measurements on minerals from these deposits (*11*) suggest a more variable mechanism, and furthermore the model lead ages are inconsistent with the ages of the rocks in the general areas of many of these deposits (*12*). Despite the difficulties with the postulated geological environment and the mechanism for concentrating the metal, the evidence of a unique growth curve for ordinary leads has increased as more-precise mass spectrometry has become available (*8*, *12*). A deep source is necessary for the worldwide uniformity, over a long period of time, of the parent uranium and thorium whose daughter products are lead.

The Red Sea is the site of an active rift zone as Africa and the Arabian peninsula break up and drift apart. In the deepest part of the Red Sea rift

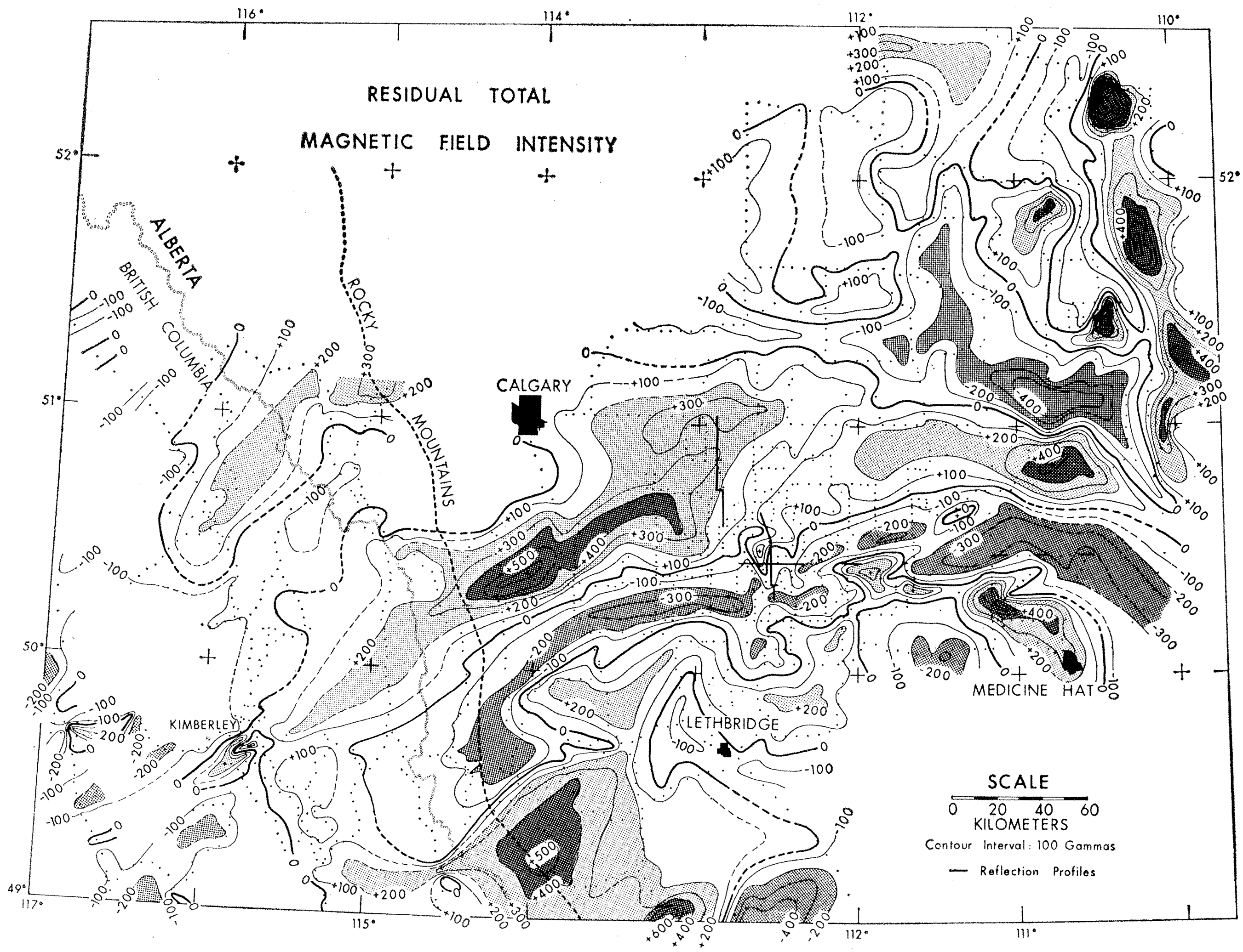

Fig. 3. Residual total-magnetic-field map for southern Alberta and southeastern British Columbia. This is formed by removal of the first six spherical harmonics from the raw data by use of a program from Lamont; essentially a slightly curved surface (due mainly to Earth's dipole field) is thus removed without distortion of magnetic anomalies due to geologic features.

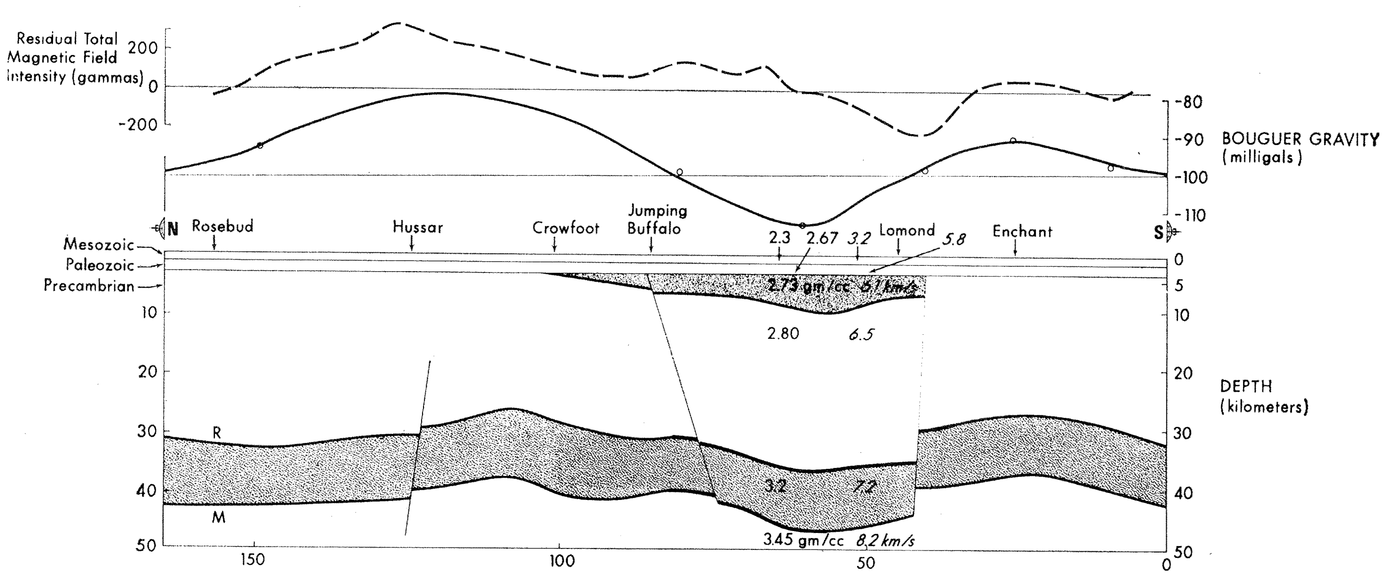

Fig. 4. Generalized crustal section across southern Alberta. Dashed curve, residual total-magnetic-field intensity. Solid curve, Bouguer gravity profile; the circles show the fit of the proposed crustal model depicted at the bottom.

valley have been found (*13, 14*) three pools of hot acidic brines with heavy-metal concentrations as high as 50,000 times those in normal ocean waters. Red Sea water is normally 20°C at *p*H 8.5; the deep brines at 2000 m may be as hot as 56°C at *p*H 4. Under the hot pools is a sedimentary layer consisting mainly of metal oxides and sulfides that is 10 to 100 m thick (*14*). The pools appear to be large natural chemical laboratories in which metals that have migrated from the upper mantle, through faults, are concentrated and precipitated, from colloidal suspension, on the sea floor. The Coeur d'Alene mining district was used (*14*) to show that the value of ore was probably greater in the Red Sea sediments.

The graben structure of and a similar origin for Coeur d'Alene have been discussed (*15*), as have the subsequent diagenesis, metasomatism, and metamorphism (*16*). Areas similar to the Red Sea pools have been found over the East Pacific Rise and its extensions into continental North America (*17*).

I suggest that the strata-form deposits at Kimberley originated within the bounds of the Precambrian rift that crosses western Canada. The method of ore concentration may have been similar to that now occurring in the Red Sea hot brines. Lead isotopes from the Sullivan body (*18*) yield an age of 1340 ± 50 million years for the time of mineralization. Model lead ages of 1340 to 1500 million years have been calculated by me from older measurements (*19*) from nearby in British Columbia and from the Coeur d'Alene district. A syngenetic origin is supported by a rubidium-strontium isochron age of 1315 ± 35 million years (*20*) from rocks from the lower part of the Belt Series in Montana; the intercept of the isochron has an initial $Sr^{87}:Sr^{86}$ ratio of 0.7075, which is consistent with a subsialic or mantle origin for the strontium (*21*).

Thus there is evidence that strata-form deposits, and possibly some having characteristics of a hydrothermal origin, were formed in active rift valleys or in areas under so much tension that fractures extended into the mantle to form channels for mineralizing solutions. The lead-isotope ratios for such deposits may be interpreted with a simple single-stage model (*11*). Measurements (*22*) on a sample from the Red Sea brine shows that the model lead age is zero as it should be. However, if the crust is very old and thick, some modification of the lead-isotope ratios may be anticipated because of contamination with lead formed in a sialic environment having highly variable lead, uranium, and thorium ratios. If rifting and the formation of hot pools were under a deep sea, the sulfur-isotope ratio would probably be close to the meteoritic value, since only chemical fractionation is involved. Under shallow seas, biogenic activity may be important, and the sulfur ratios may show large amounts of fractionation.

Perhaps the most significant finding is that the seismic-reflection method may be used to discover and map an ancient rift zone. In the search for oil it is used indirectly to locate suitable structural or stratigraphic traps. If major ore deposits lie within the confines of rift zones, seismology may be successful in mining exploration also.

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Alga-Like Forms in Onverwacht Series, South Africa: Oldest Recognized Lifelike Forms on Earth

Abstract. *Spheroidal and cupshaped, carbonaceous alga-like bodies, as well as filamentous structures and amorphous carbonaceous matter occur in sedimentary rocks of the Onverwacht Series (Swaziland System) in South Africa. The Onverwacht sediments are older than 3.2 eons, and they are probably the oldest, little-altered sedimentary rocks on Earth. The basal Onverwacht sediments lie approximately 10,000 meters stratigraphically below the Fig Tree sedimentary rocks, from which similar organic microstructures have been interpreted as alga-like microfossils. The Onverwacht spheroids and filaments are best preserved in black, carbon-rich cherts and siliceous argillites interlayered with thick sequences of lavas. These lifelike forms and the associated carbonaceous substances are probably biological in origin. If so, the origins of unicellular life on Earth are buried in older rocks now obliterated by igneous and metamorphic events.*

The search for evidence of early terrestrial life in the better preserved, old Precambrian sedimentary rocks has revealed a wide variety of unequivocal fossils as well as problematical structures and carbonaceous materials of uncertain origin (*1*). Some of the microstructures referred to as exhibiting "alga-like" and "filamentous" morphologies occur in carbonaceous argillites, siltstones, and cherts from South Africa that are more than 3 eons (3×10^9 years) old (*2, 3*).

The oldest unequivocal fossils are