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COMPILATION OF GEOPHYSICAL/GEOLOGICAL DATA NEAR GOLDEN, B.C.

R.M. CLOWES

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FINAL REPORT

COMPILATION OF GEOPHYSICAL/GEOLOGICAL DATA NEAR GOLDEN, B.C. IN SUPPORT OF THE 1978 DEEP SEISMIC REFLECTION PROGRAM

DSS Contract for Energy, Mines & Resources (Earth Physics)

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Submitted by

Dr. Ron M. Clowes

Associate Professor

Department of Geophysics and Astronomy

University of British Columbia

Vancouver, B.C. V6T 1W5

INTRODUCTION

The Rocky Mountain Trench, a long, narrow intermontane valley stretching for more than 1600 km from Montana to the Yukon, continues to be an enigma for earth scientists. It lies close to the boundary between the Omineca crystalline belt to the west and the Rocky Mountain thrust belt to the east, but does not coincide exactly with this boundary. The crystalline belt is characterized by the occurrence of Jurassic to Paleocene metamorphism and granitic intrusions, and the Rockies have been formed by northeasterly thrusting of sedimentary miogeosynclinal strata. Thus in general, widely disparate geological provinces exist on either side of the Rocky Mountain trench. In spite of numerous completed and continuing studies, our detailed knowledge of the sub-surface structure associated with the trench is minimal. Understanding the origin (or origins) of the trench is complicated by the fact that it may be different in different regions.

As part of a continuing program of detailed studies of the earth's crust and upper mantle in areas of particular interest to Canadian earth scientists, the Division of Seismology and Geothermal Studies, Earth Physics Branch, contracted a deep seismic reflection profile north of Golden, B.C. The 40 km profile was run from the western Rocky Mountains, westward across the Rocky Mountain Trench, to the Eastern Metamorphic belt (or Omineca crystalline belt). The seismic survey was carried out by a Vibroseis crew from Vibro-X Explorations Ltd. using 48-channel recording and 1200% subsurface coverage. Four months after completion of the seismic survey, Vibro-X informed the Division that instrumental difficulties associated with the digital recording were insurmountable and the data were rendered useless. Unfortunately, there was no time to repeat the survey and so the experiment was unsuccessful, but, a discussion concerning another attempt at the experiment, perhaps in 1981, has already taken place and further discussions will be held.

In order to enable the most complete interpretation of a seismic reflection profile, complementary geophysical and geological data in the area of the survey are required. Consequently, this investigator received a DSS contract for the acquisition, compilation and integration of gravimetric, magnetic, seismological and geological data pertaining to the area around Golden, B.C. In particular, the compilation concentrated on map sheet 82N (Golden) of the Canadian Topographic series; i.e. from 51°N to 52°N and 116°W to 118°W. Where appropriate, data outside this area were included also. Details of the compilation are described in the individual sections which follow.

GRAVIMETRIC DATA

On the Bouguer Anomaly Map of Canada (Earth Physics Branch, 1974), the region of the southern Rocky Mountain Trench is the locus of a prominent gravity low - less than -200 mgals in some parts. But the scale of the map is not appropriate for the current study.

Consequently a listing and computer plot of Bouguer gravity values for the region bounded by 50°N and 53°N and 114°W and 120°W was obtained from the Gravity and Geodynamics Division, Earth Physics Branch. The gravity data were compiled into a map at a scale of 1:500,000 and contoured by hand at 5 mgal intervals. Figure 1, shows the resulting map for the area specified. For the small region bounded by 50°20'N and 50°52'N and 115°50'W and 116°25'W the contours were taken from the detailed study of Spence et al. (1977). Between

50°N and 52°N and from 114°W to 116°W, the map of Figure 1 is completely consistent with the Bouguer gravity map presented by Clowes (1969) and Kanasewich et al. (1969).

The gravity low trending from northwest to southeast across the map of Figure 1 is a pronounced feature. At the southeastern end, an explanation of the low lies principally in the fact that the Trench is filled with unconsolidated Cenozoic sediments. Spence et al. (1977) have shown that the residual Bouguer anomaly values, derived by removing the regional trend, are about -10 mgals over the Trench in the southeast part of the map, near 116°W. These are modelled well by an 8 km wide bedrock trench with sloping slides, having a depth of about 500 m, and filled with unconsolidated sediments. Such an interpretation is consistent with two other detailed gravity studies in the southern Rocky Mountain Trench (Garland et al. 1961; Garland and Tanner 1957). But for the gravity low extending northwestward from 51°, this simple interpretation is not adequate. In this region, the low coincides with a part of the Rocky Mountain Trench in which most of the floor consists of bedrock with a thin veneer of glacial drift (Balkwill 1969; Price and Simony 1971). Thus a different explanation must be sought.

Stacey's (1973) study of gravity anomalies in the Canadian Cordillera included a Bouguer anomaly map between 49°N and 51°N extending from 112°W to 132°W and an interpretation of a profile at latitude 50°N. That part of his map which overlaps the map of Figure 1 shows the same general trends, but less detail since the contour interval is 10 mgals. Stacey's profile interpretation is based on the reasonable assumption that residual anomalies from an average crustal model are related to changes in crustal thickness and to lateral density variations in the crust and/or upper mantle. In the vicinity of the Rocky Mountain Trench at 50°N, his preferred models show a thick crust of nearly 60 km, a crustal density that is greater than normal, and a mantle density that is just slightly greater than normal. The combination is consistent with the broad, regional gravity low in the area. Stacey relates the decrease in the crustal and upper mantle densities west of the trench to the western edge of the Precambrian basement.

Whatever crustal/upper mantle model is derived for the Rocky Mountains, the Trench, and the Eastern Metamorphic belt north of Golden, B.C., this model must be consistent with the gravity data included in Figure 1.

MAGNETIC DATA

In 1969, the Division of Geomagnetism, Earth Physics Branch flew a regional aeromagnetic survey over western Canada and the adjacent Pacific Ocean. These data were supplemented and extended to the western Arctic during a survey in 1972. The results of the original survey have been presented in a series of publications (Haines et al. 1971, Haines and Hannaford 1972, Hannaford and Haines 1974) while Coles et al. (1976) have provided a more extensive discussion based on the combined surveys. These papers include contour maps of vertical component magnetic field residuals relative to the IGRF and maps showing comparison of magnetic anomalies with major tectonic features.

However, the maps are on such a large scale that no details for the area of interest in this report can be seen. Consequently, 30s time-averages of the total magnetic field between 50°N and 53°N, 114°W and 120°W were obtained on computer cards. About 60% of the data were acquired by a proton precession magnetometer mounted in a stinger at the tail of the aircraft. The remaining 40% were derived from measurements taken by a fluxgate magnetometer inside the aircraft and corrected to agree in level with the proton measurements. The average altitude was approximately 5 km above sea level. The navigational accuracy was considered to be ± 5 km and the relative accuracy of the field values is estimated to be ± 30 gammas between profiles and ± 5 gammas within a profile (Coles et al. 1976). Figure 2 shows a map of the total magnetic field compiled by computer plotting the individual data and contouring by hand at an interval of 100 gammas.

Within the region of the Golden map sheet, low level aeromagnetic data (survey 305m above ground level) have been compiled by the Geological Survey of Canada. In particular maps 7219G, 7216G and 3236G are within the area covered by the map of Figure 2. On these maps, the 100 gamma contours were emphasized with a black pen and the maps reduced photographically to a scale of 1:500,000. The reduced maps were spliced into one map showing the total magnetic field from low-level surveys (see Figure 3). Because the surveys were flown in different years and have not been corrected to any reference field the contour values vary between different segments of the map.

The only additional magnetic data available for the area of interest was compiled by the University of Alberta as part of their geophysical studies in southern Alberta (see Clowes 1969 and Kanasewich et al 1969). For their ground magnetometer survey, a Barringer nuclear precession magnetometer with an accuracy of about 10 gammas was used. The data recorded in the field were adjusted to minimize any differences in readings at repeated stations. By computing the magnetic field due to dipole and higher order effects by means of a seventh-degree spherical harmonic analysis, then subtracting these values from the observed ones, a residual total magnetic field map was derived. The northwestern segment of this map (see Figure 4) covers part of the general area included in Figure 2.

Coles et al. (1976) have summarized the principal information to be derived from their large scale map of vertical component magnetic field residuals. The southern Rocky Mountain Trench forms a boundary between two very different magnetic signatures. To the west, the region is characterized by a generally small amplitude anomaly field with a northwesterly trend. To the east, broad, high amplitude anomalies having northeasterly trends characterize a region typical of the Precambrian shield area. These contrasting patterns are evident in Figure 2 where a diagonal from northwest to southeast would separate (approximately) a northwesterly trending zone to the left from a northeasterly trending one to the right. A prominent exception lies southeast of map sheet 82N where the northeasterly trending magnetic field pattern extends across the Trench and into the Purcell Mountains (Figure 4; see discussion below). The northwesterly trend can also be discerned on Figure 3 but the many small-scale, high amplitude anomalies tend to obscure it.

As both Haines et al. (1971) and Coles et al. (1976) have pointed out, magnetic 'quiet' zones are evident even within the relatively low amplitude anomalies west of the Trench. The southern and central parts of one such zone correspond closely with the Omineca Crystalline Belt and Purcell Anticlinorium (in the south) which are located immediately west of the Trench. Coles et al. (1976) mention three possible causes of the quiet zone: 1) the Precambrian crystalline basement is not present; 2) the rocks throughout the quiet zone have undergone sufficient remobilization that the magnetic minerals and structures have been largely destroyed or dispersed; and 3) much of the upper crust may be at temperatures above the Curie points of the magnetic minerals, as suggested by Caner (1969). The deep reflection profile could have immediate relevance to the first mentioned possibility and provide some insight about the second one.

On the basis of the strong westerly trending anomalies south of Calgary (Figure 4), Kanasewich et al. (1969) extended an ancient Precambrian rift valley beneath the Rocky Mountains and into southeastern British Columbia. The rift valley had been interpreted on the basis of a detailed reflection seismic study carried out along the marked profiles southeast of Calgary. Kanasewich (1968) had suggested the possibility that the rift was associated with the genesis of the ore deposits near Kimberley, B.C. At about 51°N and 115°30'W (Figure 4), a northeasterly trending anomaly similar to the one south and east is observed. Similarly, a 'nose' occurs in this location in the contours of Figure 2. The significance, if any, cannot be ascertained with the data available.

Since the early 1960's, another type of magnetic study - geomagnetic depth sounding (GDS) - has been taking place in the Canadian Cordillera. Caner et al. (1971) provided a review of such studies to 1970. Camfield and Gough (1975) reported additional results. These GDS investigations have established that the dominant geomagnetic feature of the Canadian Cordillera is the presence of a zone of low magnetic intensity I where $I = Z/(H^2 + D^2)^{1/2}$. Vertical field variations having periods less than 30 min are greatly attenuated in the Cordillera compared to variations recorded further east. Of particular interest to this report is the fact that the transition zone roughly follows a line along the western front of the Rocky Mountains from 54°N to 51°N and then bends southward along the Kootenay Arc. This geomagnetic transition zone is interpreted to represent a relatively abrupt lateral conductivity change in the lower crust or upper mantle.

Subsequently Dragert and Clarke (1977) undertook a detailed investigation of the nature of the lateral conductivity changes which occur in the transition zone. In their interpretation, they were able to resolve three separate conductivity features (see Figure 4A). (1) The trench acts as a near-surface, two-dimensional conductor, probably due to conductive sediments. They suggest a depth extent of the order 1-2 km but caution that the values are not well defined. Gravity studies further south in the Trench indicate unconsolidated sediments about 0.5 km thick (see section on 'Gravimetric Data'). (2) The conductive layer with thickness of about 15-20 km that underlies the western Cordillera (Caner et al. 1971; Camfield and Gough 1975) is probably at or dips to a depth of the order of 40-50 km beneath the Trench. Dragert and Clarke (1977) follow Caner's (1970) suggestion that the conductive region is due to hydration or partial melting along a thrust zone parallel to the crust/mantle interface. Since the layer is proposed to terminate beneath the transition zone, which coincides with the Rocky Mountain Trench throughout most of map 82N, the Trench in this area may mark the eastern limit of the underthrust. Immediately south of map 82N, the transition zone follows the Kootenay arc, which thus may mark the western limit of geophysically distinguishable Precambrian (Hudsonian) crystalline continental crust (Monger and Price 1979). Detailed crustal information from reflection studies might provide additional information relevant to these interpretations. (3) A third conductivity structure may be associated with the buried Precambrian rift (Kanasewich et al. 1969) mentioned previously. The structure strikes nearly perpendicular to the I-transition zone and probably connects with the conductivity anomaly along the Kootenay Arc.

SEISMOLOGICAL DATA

Seismological investigations in the Canadian Cordillera have mainly been of the regional reconnaissance type through refraction profiles. Berry et al. (1971) provide a review of the earlier studies while Berry and Forsyth (1975) update this information from projects undertaken in 1969 and 1970. Both of these papers concentrate on the western Cordillera where most of the work had been carried out. Cumming et al. (1979) give an interpretation of a reversed refraction profile across southern British Columbia. They provide a good review of seismic studies within the general region of the Rocky Mountain Trench. These refraction studies have been complemented by the interpretation of a series of crust/mantle models in the Cordillera based on surface wave analyses (Wickens 1977).

For this report a new diagram, summarizing all the relevant seismic refraction interpretations in the area surrounding the location of the 1978 deep reflection profile, has been prepared (Figure 5). On this diagram the similarities, and differences, in crustal structure are more readily seen. For example, the interpretation of Berry and Forsyth (1975) closely resembles the model of Cumming et al. (1979) at the western end of the latter's profile. The depth, thickness and average velocity of the deep crustal layer and depth to Moho are all consistent. But the model given by Hales and Nation (1973) has a broad, low velocity zone above a deep crustal layer with velocity 6.4 km/s. None of the other profiles show such a layer. Yet the crustal thickness where their profile crosses that of Cumming et al. (1979) is consistent, especially if the differences in interpreted crustal velocities are considered.

Chandra and Cumming (1972) show a deep crustal layer with velocity 7.15 km/s thinning to the west. They also include an intermediate crustal layer of velocity 6.5 km/s. It is interesting to note that at the western end of their profile, the averaging of these two layers would give a model closer to that of Cumming et al. (1979) if their results were projected northwestward along the tectonic trends. Then the major difference would be in the velocity of the upper crust, 6.00 km/s compared with 6.2 km/s.

In the northwest along the Rocky Mountain Trench, Bennett et al. (1975) find no evidence for a deep crustal layer. A strong velocity gradient provides an adequate fit to their data. The crustal thickness from their interpretation is greater than 50 km and an apparent Pn velocity of 8.2 km/s is determined. On the basis of extremal analysis techniques and any reasonable crustal model, Spence et al. (1977) used the same data to show that the crustal thickness beneath the Trench is between 50 and 60 km. This is consistent with Mereu et al's (1977) interpretation for data beneath the westernmost Rockies at latitudes greater than 52°N. Their model shows a positive velocity gradient in the crust, a Moho depth of about 50 km and Pn velocities of 8.0 - 8.1 km/s. They also suggest a rapid velocity increase with depth (to 8.4 km/s) about 10 km below Moho.

By combining the recent study of Cumming et al. (1979) with the other studies shown in Figure 5, a summary of the variable crustal structure throughout the region can be given. South of 50°N, a deep crustal layer, probably with laterally varying velocity and thickness, extends from the plains across the southern Canadian Cordillera, at least as far as 120°W. In addition the crustal thickness decreases to the west from about 50 km beneath the plains to 40 km beneath the Purcell Anticlinorium (between the Trench and the Kootenay Arc) and to about 30 km near 120°. Topographic changes along the Moho and variations in upper mantle velocity from 8.2 km/s beneath the plains to 7.8 km/s beneath the central Cordillera are inferred. The data also suggest that the deep crustal layer, probably with laterally varying velocity and thickness, extends to the southeast from the Kaiser Resources shot point, along the strike of the Rocky Mountains. But to the northwest, the existing data indicate that the deep crustal layer terminates, or at least its character changes to the extent that observable seismic arrivals are not generated from near its top. We do note that the largest velocity gradients in the model of Bennett et al. (1975) are in the lower 15 km of the crust. However, crustal thickness increases at least by 10 km some 400 km northwest from the Kaiser source and the Pn velocity increases as well. Detailed crustal reflection data along the profile (asterisk) in Figure 5 would enable a much better definition of the crustal model in the region of the trench.

Mair and Lyons (1976) have demonstrated that crustal reflection studies can be successfully undertaken in a cordilleran environment. For comparison purposes, they ran both an explosion reflection profile and Vibroseis profile in the vicinity of Ahbau Lake near 53°N, 122°W. In their paper, they discuss both the successes and failures of their investigations with respect to recording reflections and determining structure and velocities. Berry and Mair (1977) also summarize some of the results from this survey. A 10 km continuous reflector at a two-way traveltime of 11s probably correlates with the Moho. But many other phase correlations, usually of lesser continuity, throughout the record section can be made. The nature of the M-discontinuity is discussed at some length by Berry and Mair (1977). They conclude that a transition zone consisting of a many-layered complex of alternating high- and low- velocity lamina with a total depth extent of a few kilometers best explains their observations. This is consistent with the conclusions of other authors who have studied the Moho in detail (e.g. Fuchs 1969; Clowes and Kanasewich 1970; and Meissner 1973).

The only other published reflection study in the Cordillera near the Trench is an industry type (100% coverage) detailed reflection investigation through the Rocky Mountains (Bally et al. 1966). In the Front Ranges they found a high velocity Paleozoic sequence (6.1 km/s), covered by Mesozoics (4.0 - 4.6 km/s) in the east, and overlying Precambrian Purcell or Windermere sediments (5.5. km/s) in the west. These sequences are thrust into imbricate sheets with an older layer overthrusting a younger sequence. The relatively passive basement (6.5 km/s) dips gently about 2° to the west. Their most westerly profile (Figure 5) extends from the westernmost Rockies into the Trench, and after a 25 km offset, continues across the trench into the Purcell Anticlinorium. The data below the Rockies showed evidence of the thrusting and the gently sloping basement. In the Trench, the data were noisy and showed no coherent reflections. To the west, some poor quality reflections were observed late in the seismic section. These have been interpreted by Bally et al. (1966) as reflections from the Precambrian basement on the assumption that the basement east of the trench continues to dip westward with a slope of about 2°.

Shell Canada Resources Ltd. has rerun that part of the Bally et al. (1966) profile (Figure 5) which is in the western Rockies with modern recording techniques - 1200% common reflection point (CRP) data (P.L. Gordy, private communication, 1978). I have seen the data and all the reflections throughout the sedimentary sequence are more continuous and more clearly observed than in the old data. This is true also for the reflections from the Precambrian basement.

Two 100% coverage reflection profiles extending from the western Rockies into the Trench at a latitude of 50°N were contracted in 1966 by the Geological Survey of Canada (Hobson 1967), but the data have never been analysed. This may be due to the poor quality of the record sections. I have copies of the preliminary sections provided by the contractor and finding phase correlatable reflections is difficult, although there is definite evidence for reflected seismic energy. With our current interest in the Trench, it would be worthwhile investigating the data further. This would require digitization of the old analog tapes and application of modern computer processing technology to enhance the reflections. Such an investigation must form a separate study.

Within the western Rocky Mountains, south of a line between Kaiser Resources and the eastern edge of the Trench (see 1000 m contour on Figure 5), the petroleum industry has pursued exploration programs. Many of these were in the mid-1960's and consist of only 100% sub-surface coverage. Others were shot in the early 1970's with 1200% CRP methods. For information about the sedimentary and basement structure in this region, I have obtained copies of three record sections which are relevant to a shallow refraction study being conducted by Dr. R.M. Ellis and myself to provide better control on the structure of the Rocky Mountain Trench between Kimberley and Kaiser Resources (Ellis 1978). The two older reflection sections are of moderate quality while the newer one is of good quality. Reflections correlating with a major thrust fault and with the crystalline basement can be observed, but the section does not extend much below the latter. Unfortunately, no equivalent data have been recorded in the western Rockies in the region of Golden, B.C.

GEOLOGICAL DATA

Geological studies in the region of map sheet 82N (Golden) date back as far as Dawson (1891), who worked along the line of the Canadian Pacific Railway, and are continuing at the present time with work by a number of scientists throughout the area. Wheeler (1963) gives the first comprehensive report, including a map of the western half of 82N on a scale of 1:253440 (1 inch = 4 miles). Since then a number of relevant articles have been published. A regional geological map of part of the southeastern Cordillera, including all of sheet 82N (see Figures 5A and 5B), is contained in a field excursion guidebook prepared for the International Geological Congress in Montreal (Wheeler et al. 1972).

The location of the 1978 seismic line is within the boundaries of detailed geological mapping by Balkwill (1969), Simony and Wind (1970) and de Vries (1971). Most of this information is included in a subsequent compilation (Price and Simony 1971) which is centred about the Trans-Canada Highway and covers nearly all of the southern half of map sheet 82N on a scale of 1:126720 (1 inch = 2 miles). High quality colored maps with representative geological cross sections are a particular feature of the compilation.

Since the latter work, additional studies have been undertaken both within and just outside the area covered by sheet 82N (e.g. Ghent et al. 1977; Craw 1978; P.S. Simony, personal communication, 1979). In particular, Dr. R.A. Price of Queen's University is compiling a complete set of geological maps covering sheet 82N on a scale of 1:50000 for the Geological Survey of Canada (R.A. Price, personal communication, 1980). Many of these are in preparation for publication by the G.S.C. and Dr. Price expects to complete the work in 1980. Concurrently, he is preparing a geological map for sheet 82N on a scale of 1:250000. As this map should be completed during 1979, I have made no attempt to compile the existing, published geological data on the same scale. The maps in preparation by Dr. Price will provide the most comprehensive and current geological information available for the Golden map sheet.

Within the area covered by map 82N, several geological zones are included. From northeast to southwest these are the Rocky Mountain thrust belt, comprising the Main Ranges, Western Main Ranges and Western Ranges; the Rocky Mountain Trench; the Purcell Anticlinorium; and the Omineca Crystalline Belt, or Eastern Metamorphic Complex. The location of the 1978 reflection profile (Figure 5A) runs across the Western Main Ranges and Western Ranges to the eastern edge of the trench. After a northwesterly offset of about 20 km, the profile continues across the trench at the northern extent of the Purcells.

Because of the new compilation which Price will soon complete, only the regional geological map (Figures 5A and 5B) taken from Wheeler et al. (1972) is included with this report. However, to provide a sense of the geological structures with depth, three sections which cross the Trench at different locations (see Figure 5) are included as Figures 6, 7 and 8. These cross-sections represent recently completed work (Figure 6) or work currently in progress (Figures 7 and 8) and do take into account the most recent information available in the regions which they cover. Profile CD (Figure 7) is located just northwest of the 1978 seismic reflection profile.

During the 1970's, plate-tectonic models were developed to explain in some detail the evolution of the Canadian Cordillera, including the geological zones identified in Figures 6-8 (see Monger et al. 1972; Dercourt 1972). Recently, Monger and Price (1979) have provided an up-dated development which takes into account the new geological and geophysical data. According to these authors, the earliest stage in the evolution of the Canadian Cordillera appears to have been the lengthy (from 1500 Ma to 0 Ma) development of a northeasterly tapering sedimentary wedge which discordantly overlaps the stable cratonic platform of Hudsonian crystalline rocks. These miogeoclinal rocks of the continental terrace wedge and their thinner lateral equivalents, which formed the platformal cover on the craton east of the miogeocline, form the lower part of all the thrust sheets in the Foothills and Front Ranges and all of the thrust sheets in the Main Ranges and Purcell Mountains as shown in the cross-sections. An earlier interpretation (Monger et al. 1972) suggested that the sediments may be a wedge which prograded into an ocean basin of the Atlantic type. But from the fact that volcanic rocks and volcanic-derived sedimentary rocks are interbedded with the miogeoclinal sedimentary rocks, Monger and Price (1979) argue for an interpretation suggesting the sediments prograded into a marginal basin in which there was intermittent volcanic activity.

Following the development of the continental terrace wedge, late Jurassic to Paleocene sedimentary rocks were deposited over the future site of the eastern part of the thrust and fold belt. The sediments were derived from areas to the west that were uplifted by thrust faulting and folding that marked the beginning of the evolution of the thrust belt. As the locus of thrusting migrated eastward, the locus of deposition of Jurassic and Paleocene exogeoclinal rocks migrated eastward in front of it. Now these sediments form the upper part of the thrust sheets in the Foothills and Front Ranges. Within the Main Ranges of the Rockies, the dominant structures are the series of low-angle thrust sheets of pre-Jurassic sediments that have been stacked progressively eastward with accompanying crustal shortening. In the Western

Ranges and in the Purcell Mountains, these miogeoclinal sediments (of the continental terrace wedge), thrust faulted and folded, also are the dominant features (Figures 6 to 8). There is general agreement that the crystalline basement beneath the Rockies was not involved in the thrusting. Bally et al. (1966) and P.L. Gordy (personal communication, 1978) have shown seismic profiles which clearly substantiate this view in the southwestern Rocky Mountains.

As shown by Figure 6, geological sections extending from the western Rockies across the Trench and into the Purcells show no evidence of basement involvement. Monger and Price (1979) argue that the Hudsonian basement extends westward to the Kootenay Arc which is the locus of geomagnetic anomalies (see section on Magnetic Data) and crustal structure variations (see Figure 5). However the seismic data of Cumming et al. (1979) and a more extensive data set across the Trench acquired by Ellis (1978) require some type of upper crustal heterogeneity in the region of the Trench. Further north, near Golden, Simony (personal communication, 1979; see Figure 7) suggests the basement may be involved in a minor way in the vicinity of the Trench and there seems to be general agreement that north of this, the western limit of the Rockies is also the western limit of the cratonic basement (Monger and Price 1979).

The Rocky Mountain Trench is an impressive physiographic feature which lies close to the boundary between the thrust belt of the Rockies and the Eastern Metamorphic Belt (Purcell Anticlinorium in its southern part). Yet the origin of its structure is still not known. And, indeed, the geological formations along its great length vary in structural detail. The main control on the Trench in its southern part is a series of en echelon normal faults, west side down. This is consistent with the extensional tectonics that have characterized that part of the Cordillera since the Eocene. But in the Golden area, there is no evidence for normal faulting and the control on the west side of the Trench is the Purcell thrust fault (Figure 7). By the latitude of profile EF (Figure 8), this thrust fault is found in the Rockies east of the trench. In this area, the eastern wall of the Trench is a steep fault (west side down, but probably right-hand strike-slip) which offsets the Purcell thrust and Malton gneiss which lie above the Purcell thrust (R.A. Price, personal communication, 1979). As discussed by Monger and Price (1979), the northern Rocky Mountain Trench has been the locus of major right lateral strike-slip motion. Thus the Trench is a complex feature which has different structures and origins along its length.

West of the southern Rocky Mountain Trench, the Purcell Anticlinorium is a thick (12 km) wedge of sediments formed during the earliest stage of Cordilleran evolution. These are the Purcell series of rocks which are clearly shown in Figure 6. After experiencing mild deformation during the East Kootenay orogeny (1000 - 800 Ma), the Purcell group was uncomformably overlain by Proterozoic-Windermere and the Paleozoic rocks. Monger and Price (1979) point out that block faulting occurred during deposition of the Windermere assemblage and this resulted in local uplift and erosion of the Purcell series. Basic volcanism is spatially related to the main loci of faulting and is associated with the mild deformation. The main present day configuration was established when the entire sedimentary section was folded, thrusted, intruded and mildly metamorphosed during a series of phases in the Mesozoic. As indicated previously, there is some question as to whether crystalline basement has or has not been involved, and if so, to what extent.

To the west of the Purcell Anticlinorium and the Kootenay Arc boundary, and to the west of the Trench north of Golden, lies the Omineca Crystalline Belt. It is distinguished by its high degree of metamorphism and widespread granitic intrusions. The isograds on Figure 5A delineate part of the boundary. According to Monger and Price (1979), there is little evidence for the existence of the Omineca Crystalline Belt in anything like its present form prior to late Jurassic. It was probably established with the initial uplift and intrusion of granitic rocks in Middle and Late Jurassic time. Its development continued through Cretaceous and Tertiary time. Convergence between this complex and the Precambrian craton also took place, as concluded from analysis of the structure of the fold and thrust belt of the Rockies. At the same time, the magmatism accompanying subduction in the western Cordillera contributed to the development of the Eastern Metamorphic Belt. This complex is usually referred to as the 'core zone' of the late Mesozoic deformation.

Within the region of map sheet 82N, geological data are continuing to be acquired, and geological models are continually evolving. With respect to a deep crustal seismic reflection profile, a few prominent geological features or characteristics can be emphasized.

(1) Within the western Rocky Mountains, the Porcupine Creek Anticlinorium is a major structure which has no seismic control on its proposed sub-surface layering (Figures 7 and 8).

(2) Surface geology within the western Rocky Mountains and in the Trench is most consistent with basement not being involved in the thrust faulting (Figure 6).

(3) Within the Purcell Anticlinorium a lack of basement involvement in the thrusting is also inferred from geological data. But recent seismic data require some type of major lateral heteorogeneity in the upper crust.

(4) The main structural control on the southern Rocky Mountain Trench is a series of en-echelon normal faults, but in the Golden area no evidence for normal faulting exists. Control on the west side of the Trench is the Purcell thrust fault.

(5) The Purcell thrust fault is a major geological structure which forms the western boundary of the Trench near Golden, but occurs in the Rockies east of it further north (see Figures 7 and 8).

(6) Precambrian cratonic basement probably extends to the Kootenay Arc in the southern region but is terminated at the location of the Trench from Golden northwards. Any basement rocks which did exist outside the craton would have been involved in the more recent deformations.

(7) Southwest of the garnet isograd (Figure 5A), intensely metamorphosed rocks of the Omineca crystalline belt exist.

However, the fundamental question that may be answered by a deep reflection seismic experiment of the type attempted in 1978 is "Where is the western limit of unfaulted Precambrian basement under the eastern Cordillera?"

ACKNOWLEDGEMENTS

I wish to thank P.J. Winter of the Gravity and Geodynamics Division and G.V. Haines of the Division of Geomagnetism of the Earth Physics Branch for their prompt response to my requests for data. I particularly acknowledge Dr. P.S. Simony of the Department of Geology, University of Calgary and Dr. R.A. Price of the Department of Geological Sciences, Queen's University for providing the geological cross sections from which Figures 6, 7 and 8 were drafted. I have also benefited from discussions about Cordilleran geology with both of them. The final report has been improved substantially through a critical review by Dr. Price.

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FIGURE CAPTIONS

Figure 1. Bouguer gravity anomaly map for the region between 50°N and 53°N, 114°W and 120°W. Individual gravity stations with their Bouguer values are indicated. The contour interval is 5 mgals. The region of map sheet 82N (Golden) is outlined by the dash-dot lines in the middle of the map. Dashed lines indicate contours with few control stations.

Figure 2. Total field aeromagnetic map for the region between 50°N and 53°N, 114°W and 120°W (survey flown in 1969). Numbers are the total field in gammas and represent 30s time averages (approximately 3.5 km of flight track). The lowermost part of the first digit in each number is the location for that datum. The region of map sheet 82N (Golden) is shown by the box drawn with dash-dot lines. (One gamma equals one nanotesla.)

Figure 3. Total field aeromagnetic map compiled from aeromagnetic maps 7219G, 7216G and 3236G published by the Geological Survey of Canada in cooperation with the Department of Mines and Petroleum Resources, British Columbia. Year of the survey for different blocks is indicated. Contour interval is 100 gammas.

Figure 4. Residual total magnetic field map for southern Alberta and southeastern British Columbia. The data are ground magnetic measurements (dots show the station locations) from which the first eight spherical harmonic components of the earth's field have been removed. The area within the block outlined corresponds to the southeastern part of Figure 2. Solid

lines southeast of Calgary show the location of continuous deep reflection profiles. (Map from Clowes 1969 and Kanasewich et al. 1969).

Figure 4A. Location of three conductivity structures proposed by Dragert and Clarke (1977) on the basis of a geomagnetic depth sounding profile across the Rocky Mountain Trench. 1. near-surface conductor probably associated with the sediments of the trench; 2. a lower crust/upper mantle conductivity heterogeneity at a depth of 40-50 km; 3. a second deep conductivity structure possibly associated with a buried Precambrian rift. Square outlines area covered by map 82N. Open circles are GDS station locations. (From Dragert and Clarke 1977.)

Figure 5. Interpretations of seismic refraction data in the southeastern Cordillera. The thick, black line marked with an asterisk shows the location of the unsuccessful 1978 deep reflection profile. The interpretations by Chandra and Cumming (1972), Hales and Nation (1973), Berry and Forsyth (1975) and Mereu et al. (1977) are based on data for which the explosive sources were detonated in Greenbush Lake. Bennett et al. (1975) used data for which mine explosions at Kaiser Resources were the source. Cumming et al. (1979) is a reversed profile using the Kaiser source on the east and explosions from two copper mines on the west. The triangles show the locations of the start of each profile and the solid lines extending from them show the azimuths of the profiles. The short profile near 49°N, 115°W marks the location of one profile in Bally et al's (1966) reflection study. Lines marked AB, CD and EF show the location of geological cross-sections presented in the next section (Figures 6, 7 and 8, respectively).

Figure 5A. Generalized geological map covering sheet 82N (Golden). The heavy solid lines show the location of the 1978 deep crustal seismic reflection profile. The legends for the geology are given in Figure 5B. (Map from Wheeler et al. 1972.)

Figure 5B. Legends for the geological map of Figure 5A. (Legends according to Wheeler et al. 1972.)

Figure 6. Geological cross-section from the western Rocky Mounains through the Purcell Anticlinorium (AB on Figure 5). The horizontal and vertical scales are the same.

Key to symbols, western facies (west of Purcell Thrust)

1 - Hudsonian crystalline basement

2 - Windermere system (Upper Proterozoic) Horsetheif Creek group; underlain by Toby fm (blank)

3 - Purcell system (Middle Proterozoic), Aldridge group

4 - Purcell system, Creston group

5 - Purcell system, Kitchener group

6 - Purcell system, Dutch Creek group

7 - Purcell system, Mount Nelson group

8 - Lower Cambrian, Hamill fm.

Key to symbols, eastern facies (east of Purcell Thrust)

1 - Hudsonian crystalline basement

2 - Windermere equivalent, (Upper Proterozoic) Mietle group

3 - Lower Cambrian, Gog group

5 - Upper Cambrian - Lower Ordovician, McKay group

7 - Middle-Upper Cambrian, Chancellor fm

9 - Lower Cambrian

10 - Upper Cambrian

11 - Upper Cambrian, Ottertail fm

0 - Ordovician formations

ME - Middle Cambrian

PE - Purcell Cambrian

P - Purcell

(Cross-section courtesy of R.A. Price, from Price and Fermor 1978)

Figure 7. Geological cross-section near Golden, B.C. from the western Rocky Mountains across the northern Purcell Anticlinorium and into the Eastern Metamorphic Belt (CD on Figure 5). The horizontal and vertical scales are the same.

Key to symbols:

1 - Hudsonian crystalline basement

2 - Windermere system (Upper Proterozoic), Horsethief Creek group; (slate and quartzite) underlain by Toby fm (blank)

3 - Lower Cambrian, Gog group

4 - Windermere equivalent (Upper Proterozoic), Mietle Group

5 - Upper Cambrian - Lower Ordovician, McKay group

6 - Post Lower Cambrian granitic rocks

7 - Middle - Upper Cambrian, Chancellor fm

8 - Lower Cambrian, Hamill fm

9 - Windermere system (Upper Proterozoic), Horsethief Creek group (limestone marble)

10 - Upper Cambrian, Ottertail fm.

(Cross-section courtesy of P.S. Simony, unpublished, work in progress.)

Figure 8. Geological cross-section from the western Rocky Mountain to the Eastern Metamorphic Belt (EF on Figure 5). The scale is at the lower left of the diagram. Key to units is given on the diagram. (Cross-section courtesy of P.S. Simony, unpublished, work in progress.)

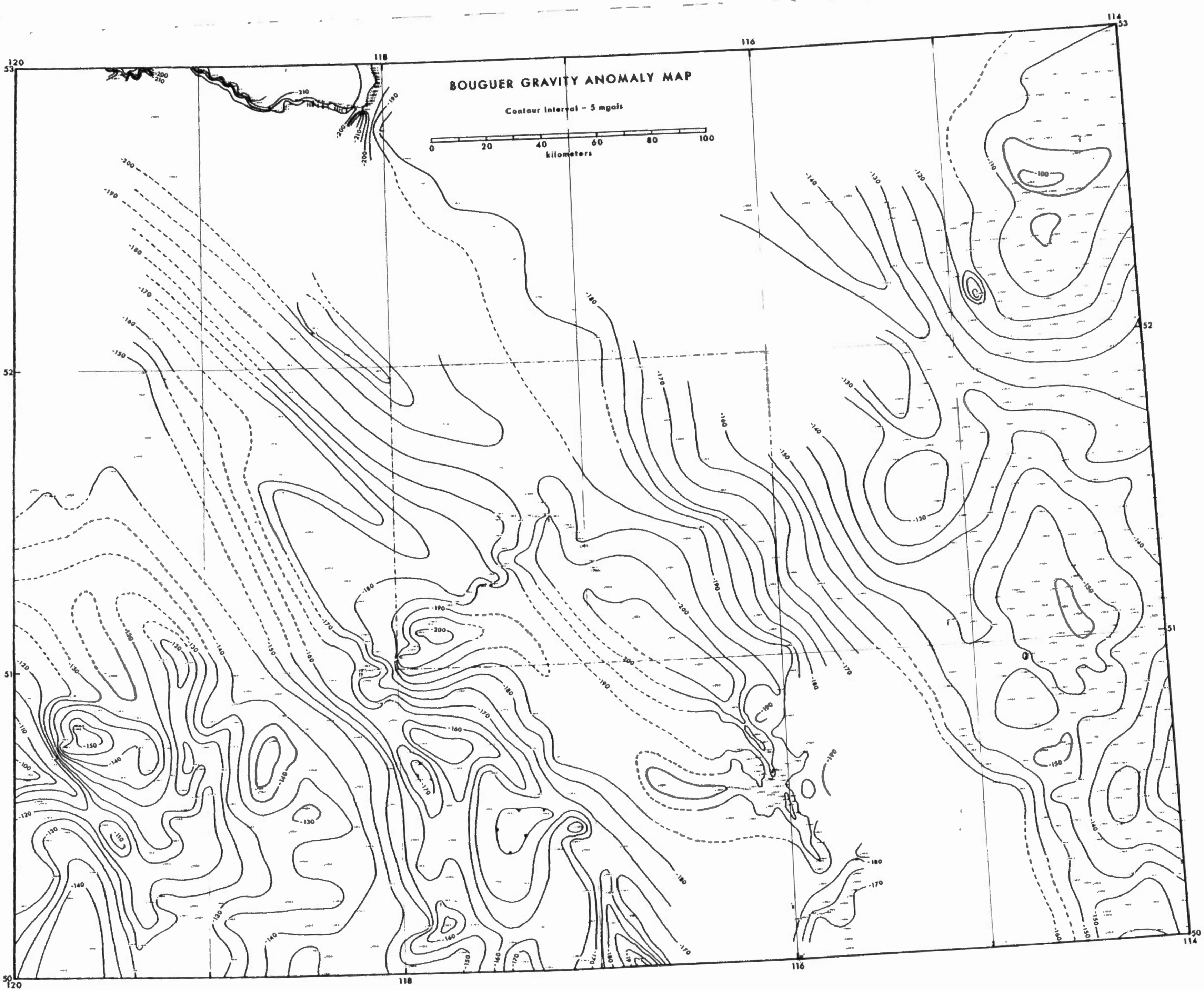
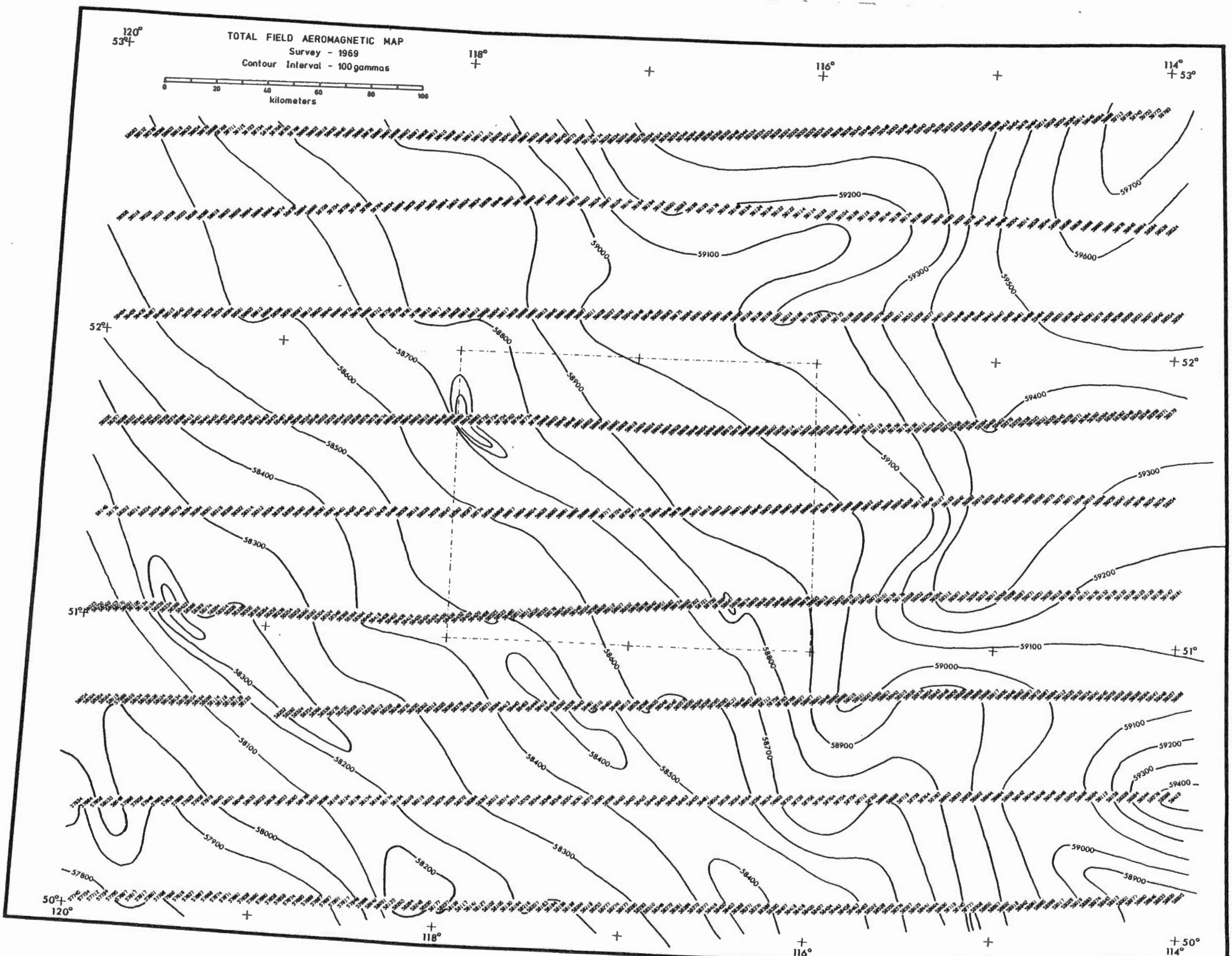

BOUGUER GRAVITY ANOMALY MAP
Contour Interval - 5 mgals
0 20 40 60 80 100
kilometers
120
118
116
114
53
52
51
50

Figure 1



TOTAL FIELD AEROMAGNETIC MAP
Survey - 1969
Contour Interval - 100 gammas
0 20 40 60 80 100
kilometers
120°
53°
118°
116°
114°
53°
52°
52°
51°
51°
50°
120°
118°
116°
50°
114°
59700
59200
59600
59100
59000
59300
59500
58800
58700
58600
58900
59400
58500
58400
59100
59300
58300
59200
58600
58800
59100
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58700
58100
58200
58400
58400
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58300
58200
58400
59000
58900
57800

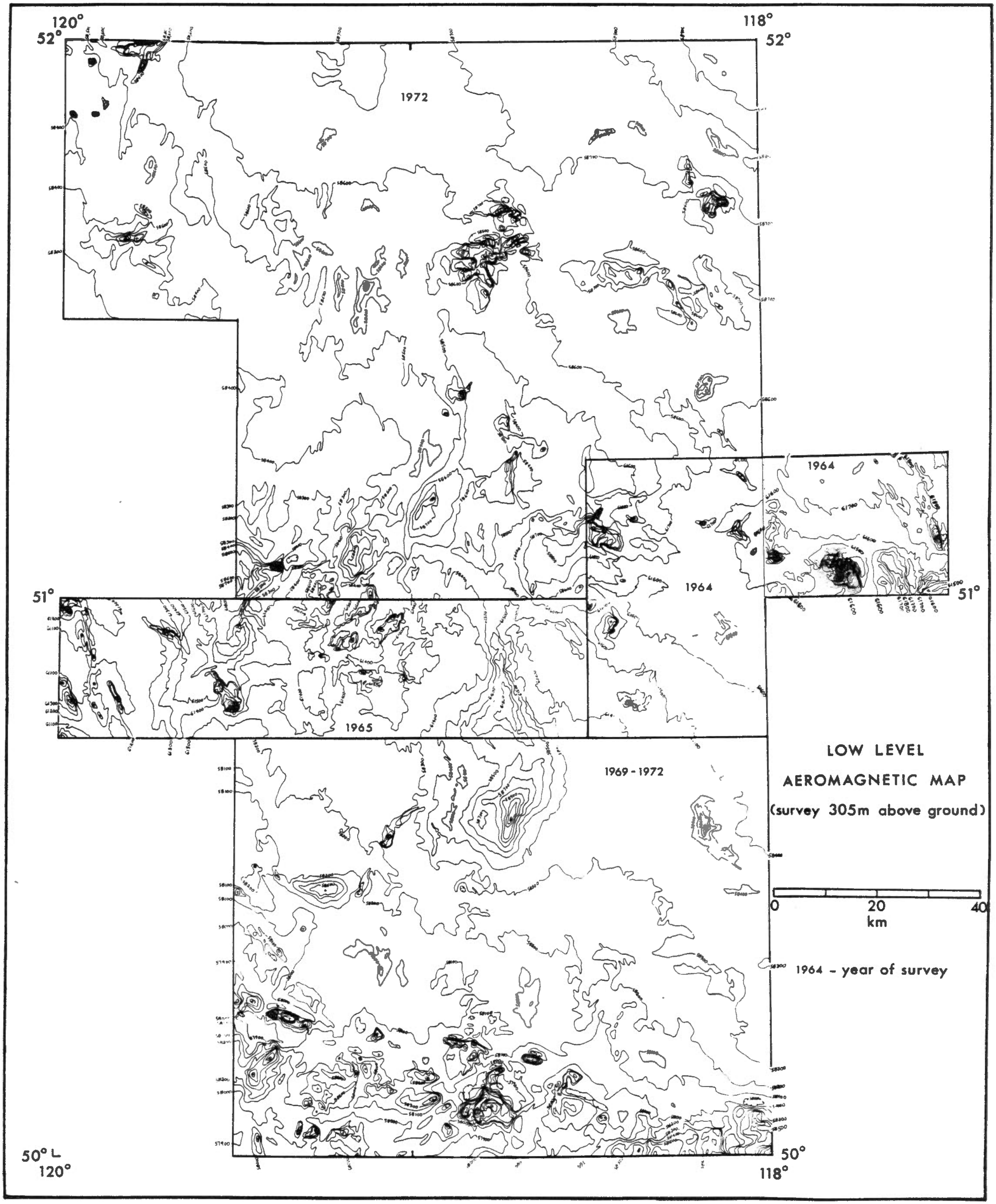

120°
52°
118°
52°
1972
1964
1964
51°
51°
1965
1969 - 1972
LOW LEVEL
AEROMAGNETIC MAP
(survey 305m above ground)
0
20
40
km
1964 - year of survey
50°
120°
50°
118°

Figure 3

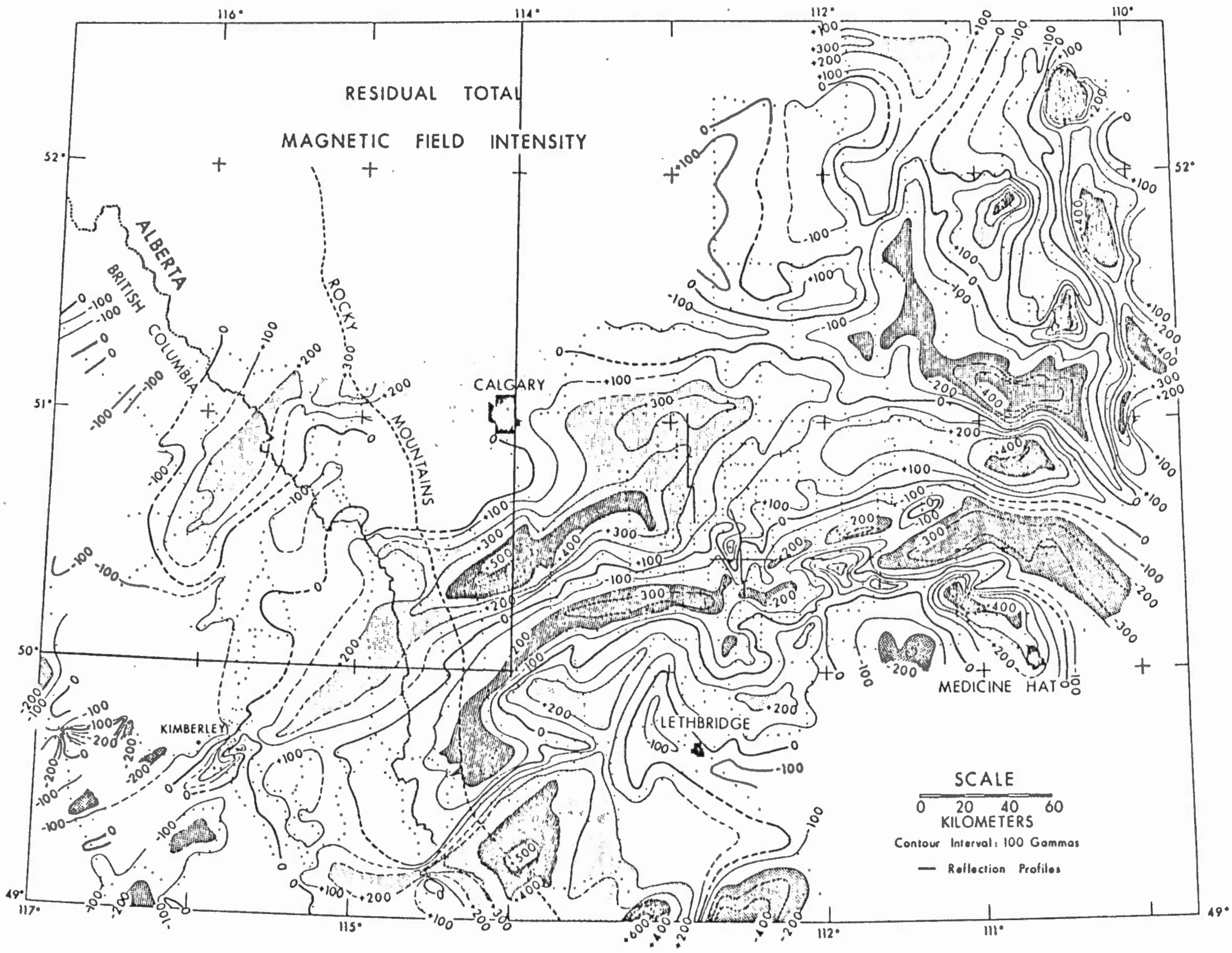

RESIDUAL TOTAL
MAGNETIC FIELD INTENSITY
ALBERTA
BRITISH COLUMBIA
ROCKY MOUNTAINS
CALGARY
LETHBRIDGE
MEDICINE HAT
KIMBERLEY
SCALE
0 20 40 60
KILOMETERS
Contour Interval: 100 Gammas
— Reflection Profiles

Figure 4

Energy, Mines and
Resources Canada

Énergie, Mines et
Ressources Canada

Earth Physics Branch

Direction de la physique du globe

1 Observatory Crescent
Ottawa Canada
K1A 0Y3

1 Place de l'Observatoire
Ottawa Canada
K1A 0Y3

Seismological Service of Canada

Service séismologique du Canada

COMPILATION OF GEOPHYSICAL/GEOLOGICAL DATA NEAR GOLDEN, B.C.

R.M. CLOWES

41 pp. including II illustrations

Earth Physics Branch Open File Number 80-14
Ottawa, Canada 1980.

Price/Prix $13.25

Not for Reproduction

80-14 Compilation of Geophysical/Geological Data Near Golden, B.C.

- by Dr. R.M. Clowes, University of British Columbia

  - 41 pages, including 11 illustrations, Price _______

The report presents the available geological/geophysical data and current ideas as to the structure and genesis of the Canadian Cordillera, near Golden B.C.

Recueil de données géophysiques/géologiques près de Golden C.B.

- par Dr. R.M. Clowes, Université de Colombie Britannique,

  - 41 pages, incluant 11 illustrations, prix _______

Le rapport présente les données géologiques/géophysiques disponibles et les idées admises quant à la structure et à la genèse de la Cordillère canadienne près de Golden, C.B..

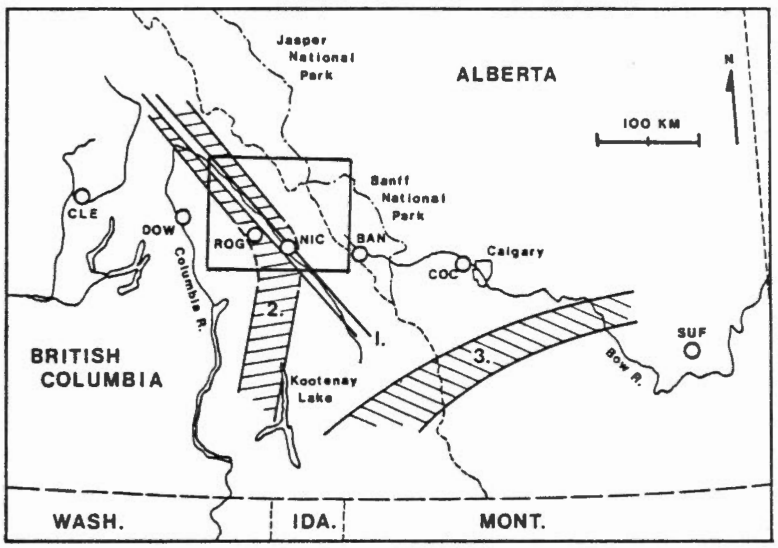
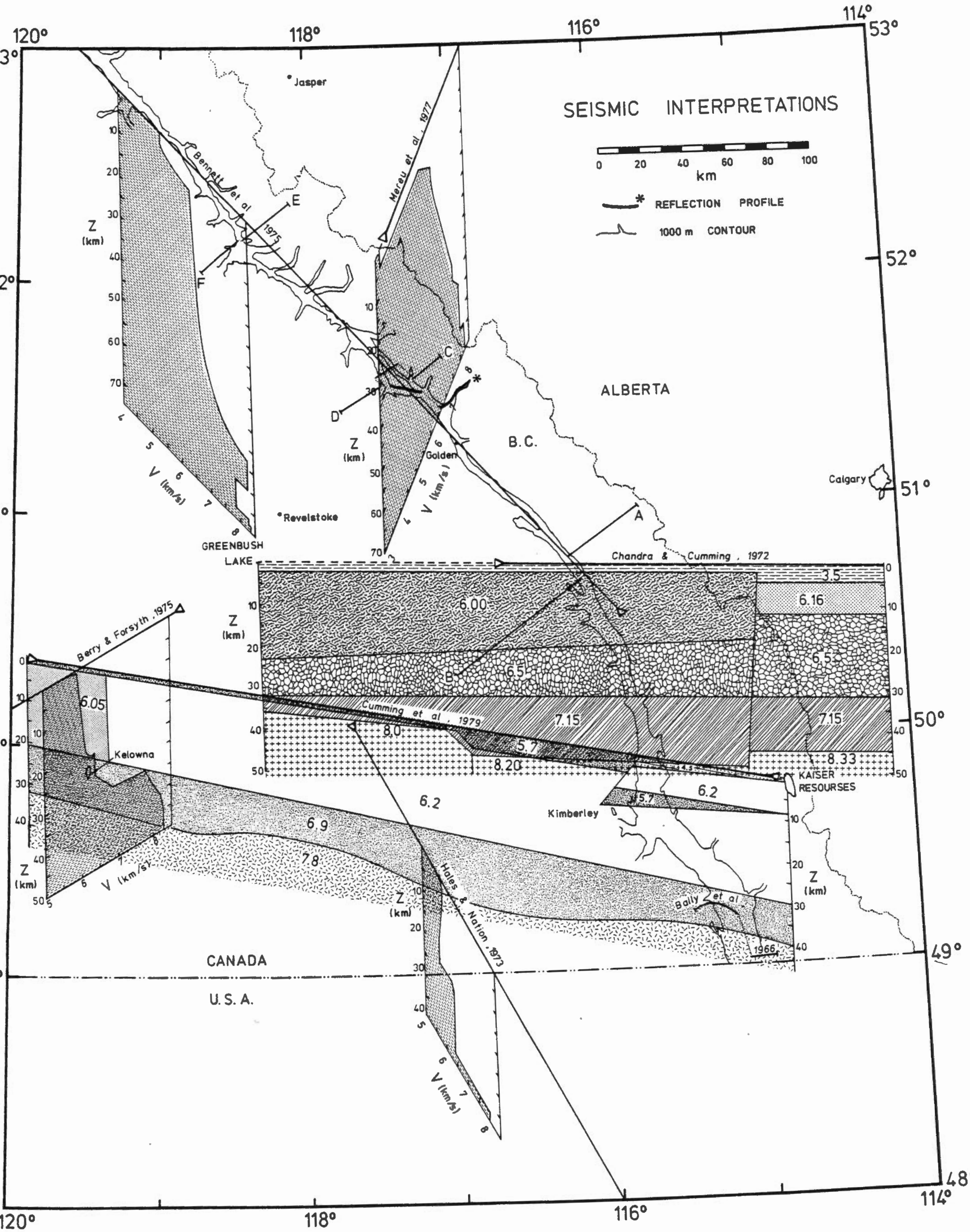
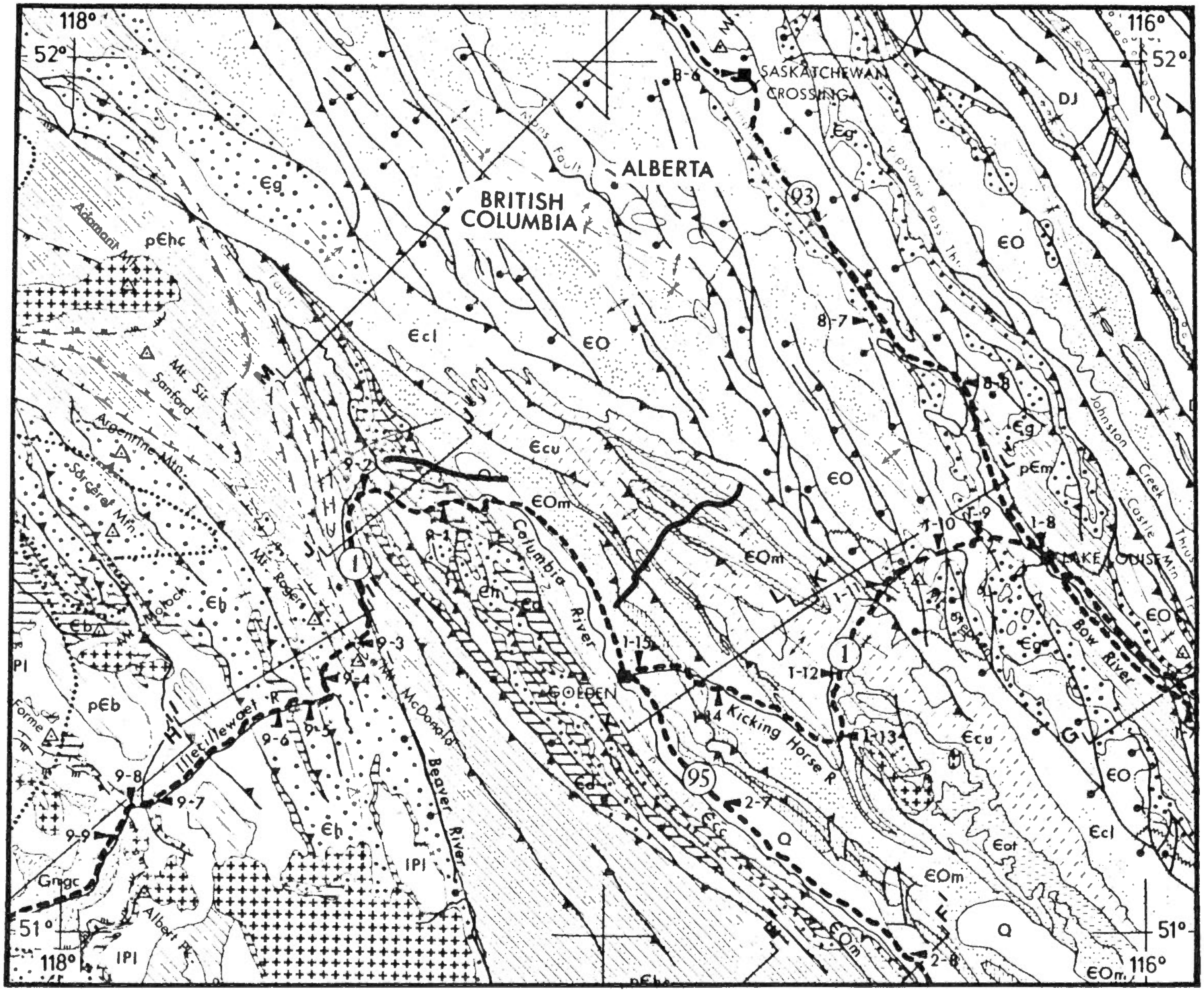

Jasper
National
Park
ALBERTA
N
100 KM
Banff
National
Park
CLE
DOW
ROG
NIC
BAN
Calgary
COC
Columbia R.
2.
1.
SUF
3.
Bow R.
BRITISH
COLUMBIA
Kootenay
Lake
WASH.
IDA.
MONT.

Figure 4A



SEISMIC INTERPRETATIONS
0 20 40 60 80 100
km
REFLECTION PROFILE
1000 m CONTOUR
Jasper
Revelstoke
Golden
Calgary
Kelowna
Kimberley
ALBERTA
B.C.
CANADA
U.S.A.
GREENBUSH LAKE
KAISER RESOURSES
Bennett et al 1975
Mereu et al. 1977
Chandra & Cumming, 1972
Berry & Forsyth, 1975
Cumming et al., 1979
Hales & Nation, 1973
Bally et al. 1966
Z (km)
V (km/s)
6.00
6.5
7.15
8.0
5.7
8.20
3.5
6.16
8.33
6.05
6.2
6.9
7.8
120°
118°
116°
114°
53°
52°
51°
50°
49°
48°

Figure 5



GEOLOGICAL MAP

0 20 40 60

KILOMETERS

Figure 5A

LEGEND 2

PURCELL AND SELKIRK MOUNTAINS

RECENT

Q — Glacial deposits, alluvium, etc.

UPPER CAMBRIAN AND LOWER ORDOVICIAN

ЄOm: McKay Group, shale and carbonate (included with Jubilee Formation (Єj) on Mount Forster)

UPPER CAMBRIAN

Єj: Jubilee Formation, carbonate (equivalent to Ottertail Formation (Єot) of Rocky Mountains)

LOWER CAMBRIAN AND/OR YOUNGER (LOWER PALEOZOIC)

lPl: Lardeau Group, argillite, limestone, sandstone and volcanics and metamorphic equivalents: lPlj, Jowett Formation, mainly volcanic: lPls, Sharon Creek Formation, argillite, Ajax Formation, sandstone (quartzite), and Triune Formation, argillite: lPli, Index Formation, argillite, minor limestone and volcanics

LOWER CAMBRIAN

Єb: Badshot and Mohican Formations, limestone, argillite, and metamorphic equivalents (in Selkirk Mtns.)
Єd: Donald Formation, limestone, argillite and sandstone (in Purcell Mtns.)

Єh: Hamill Group, sandstone (quartzite) and minor volcanics Єranbrook Formation in southern Purcell Mtns. is equivalent)

PRECAMBRIAN (WINDERMERE-LATE PROTEROZOIC)

pЄhc: Horsethief Creek Group, impure sandstone, grit, shale, limestone and metamorphic equivalents

pЄb: Broadview Formation, impure sandstone, grit, shale, volcanics and metamorphic equivalents (tectonically emplaced equivalent of pЄhc?) (pЄbv: volcanic member)

PRECAMBRIAN(PURCELL-BELT-PROTEROZOIC)

pЄp: Purcell Group, argillite, sandstone, carbonate, minor volcanics and metamorphic equivalents: pЄpm, Mount Nelson Formation, carbonate, argillite, quartzite: pЄpk, Dutch Creek Formation, argillite, carbonate, quartzite; and Kitchener-Siyeh Formation, dolomitic and calcareous argillite and quartzite, argillite, quartzite: pЄpc, Creston Formation, quartzite and argillite.

GRANITIC ROCKS

gr: Quartz diorite to granite - mainly UPPER TRIASSIC TO TERTIARY: LOWER PALEOZOIC - alkalic rocks in Rocky Mountains

SHUSWAP METAMORPHIC COMPLEX

Gnm: Mantling gneiss; paragneiss, quartzite, marble, nepheline syenite (mantling domes of granitoid gneiss)

Gngc: Domal core gneiss; granitoid gneiss

LEGEND 1

ROCKY MOUNTAINS

RECENT

Q — glacial deposits, alluvium, etc.

UPPER JURASSIC TO UPPER CRETACEOUS

UPPER DEVONIAN TO UPPER JURASSIC

DJ

MIDDLE ORDOVICIAN TO MIDDLE DEVONIAN

OSb: DEVONIAN Harrogate and Cedared Formations, carbonate and shale; mainly ORDOVICIAN and SILURIAN Beaverfoot Formation, carbonate; and ORDOVICIAN Mount Wilson Formation, sandstone.

UPPER CAMBRIAN TO MIDDLE ORDOVICIAN

ЄOm: LOWER and MIDDLE ORDOVICIAN Glenogle Formation, shale; mainly UPPER CAMBRIAN and LOWER ORDOVICIAN McKay Group, shale and carbonate.

UPPER CAMBRIAN

Єcc: Canyon Creek Formation, shale

Єot: Ottertail Formation, carbonate (equivalent to Jubilee Formation (Єj) of Purcell Mountains and to Lyell Formation of carbonate facies)

Єcu: upper part, Chancellor Formation, shale and minor carbonate.

MIDDLE AND UPPER CAMBRIAN

Єcl: lower and middle part, Chancellor Formation, carbonate and shale.

LOWER CAMBRIAN

Єg: Gog Group: Mahto Formation, sandstone and shale; Mural Formation, carbonate and shale; and McNaughton Formation, sandstone and shale

PRECAMBRIAN (WINDERMERE)

pЄm: Miette Group, sandstone, shale, minor carbonate and conglomerate: pЄmu, upper Miette Group, mainly shale local carbonate at top: pЄmm, middle Miette Group, sandstone and shale: pЄml, lower Miette Group, shale, carbonate, and sandstone

LEGEND 3

Geological contact

Approximate facies boundary

Fault

Thrust or reverse fault (teeth on upthrust side)

Steep normal or reverse fault (dots on downthrown side)

Anticline, anticlinorium, antiform

Syncline, synclinorium

Fan axis

Shear zone

Isograds (ticks on higher grade side)

Figure 5B

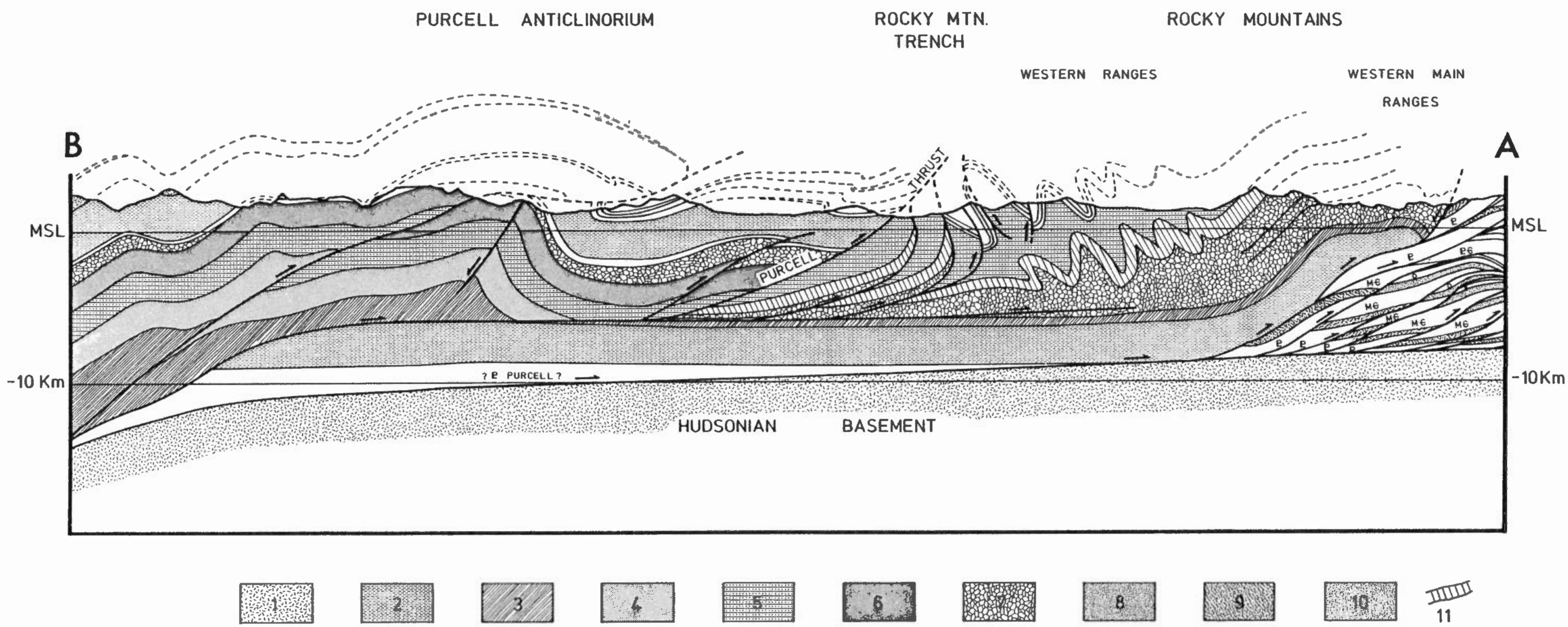


FIG.6

Figure 6

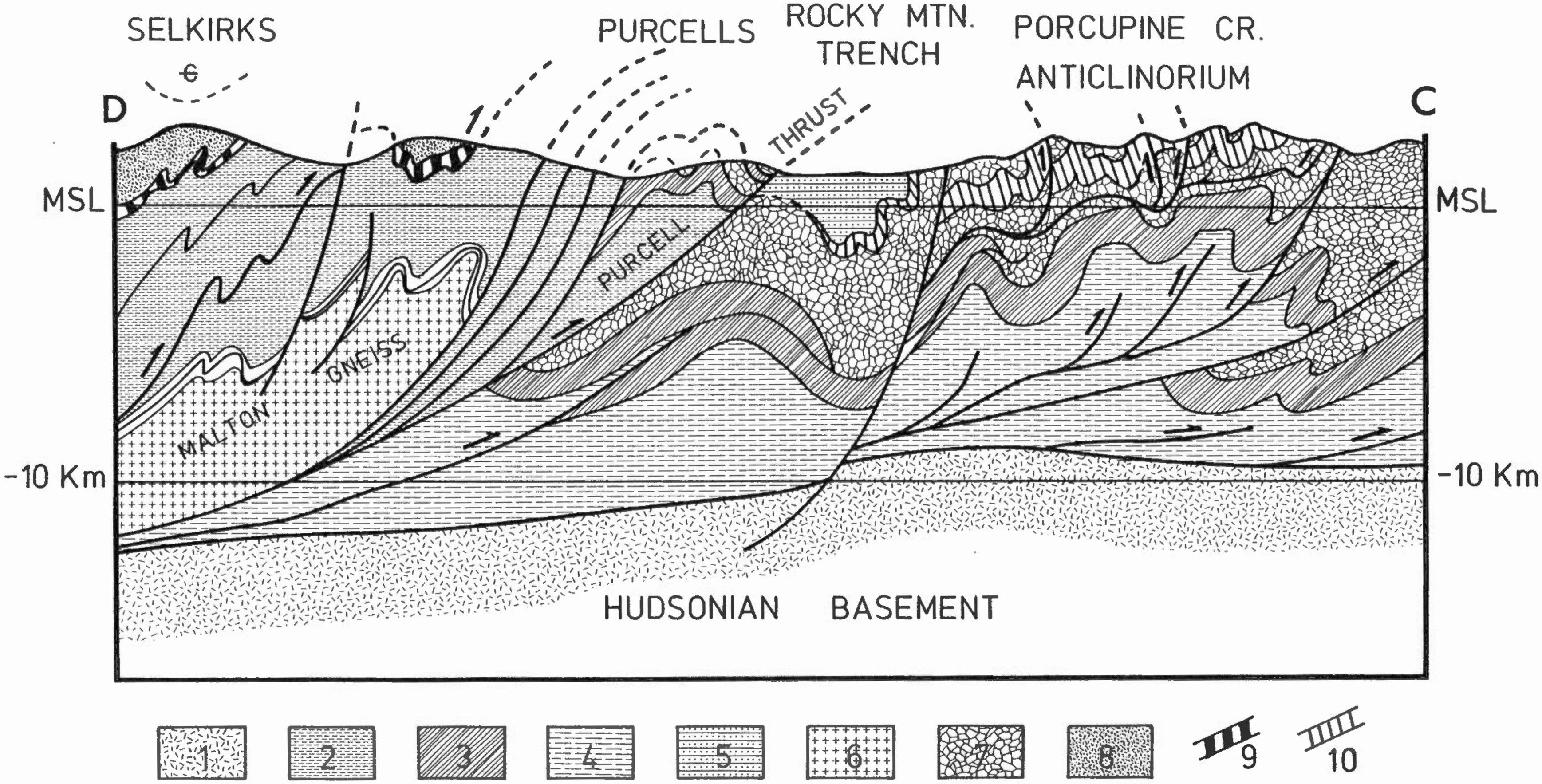


FIG. 7

Figure 7

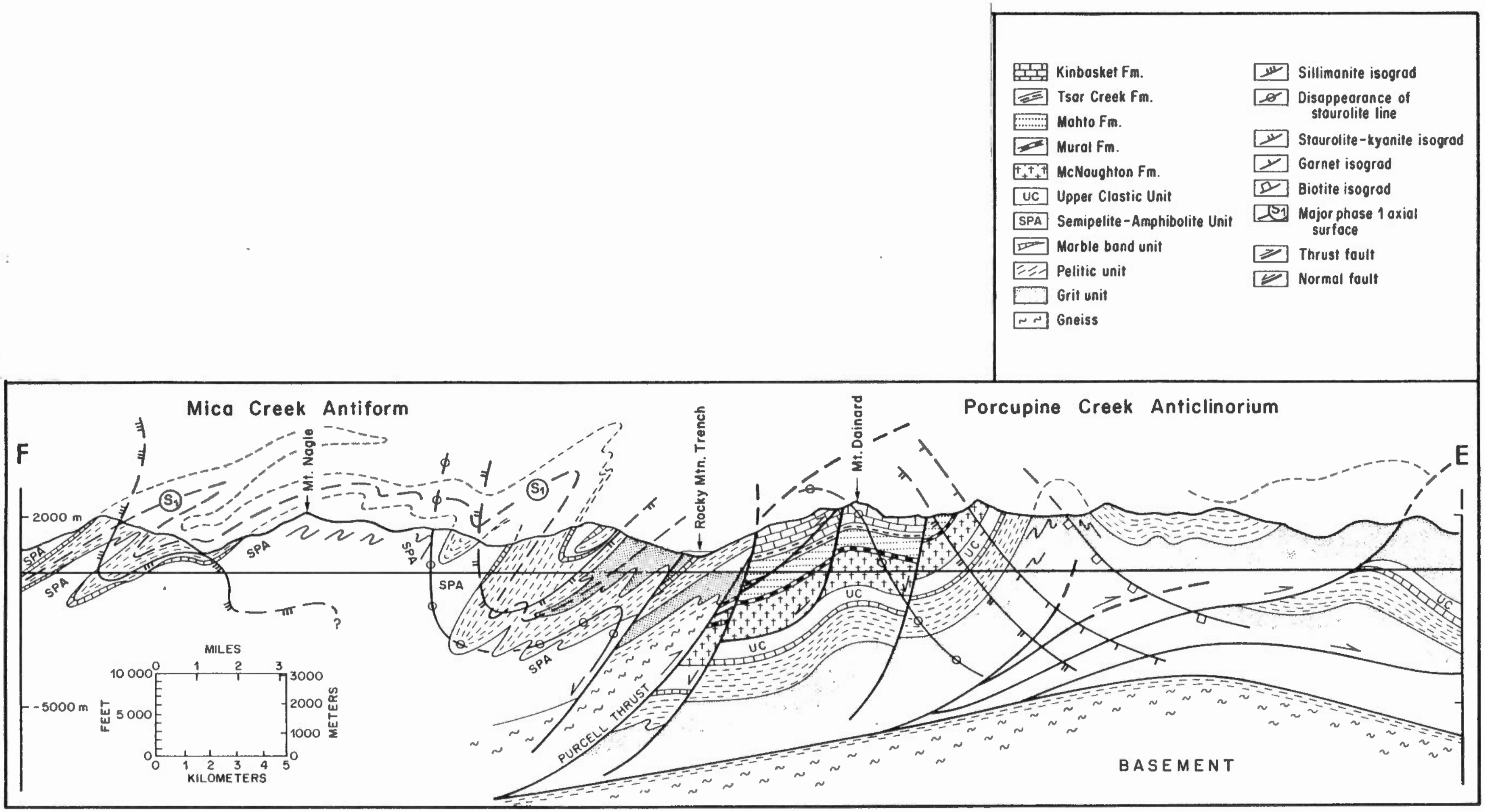


FIG. 8

Figure 8