

STRUCTURE, SEISMIC DATA, AND OROGENIC EVOLUTION OF SOUTHERN CANADIAN ROCKY MOUNTAINS¹

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ABSTRACT

In the Rocky Mountain Foothills, major oil and gas accumulations occur in the folded and faulted leading edges of thrust sheets involving Paleozoic carbonates. These structures underlie a complex of imbrications involving Mesozoic clastic rocks. In this area the integration of seismic and geologic data leads to the definition of prospects and also illustrates concepts fundamental to an understanding of mountain building.

Reflection data show that for its entire width of about 80 miles, the Rocky Mountain fold belt is underlain by the gently westward dipping extension of the crystalline Precambrian Shield. Shortening, exceeding 100 miles in Paleozoic beds, takes place along décollement zones and curved thrust faults which flatten at depth (listric thrust faults). Late Mesozoic and early Tertiary thrusting was followed by late Tertiary normal faulting. Reflection data suggest that these normal faults, which are steep at the surface, also flatten at depth (listric normal faults) and may merge with older thrust faults.

Reflection sections show that at depth the structural style on both sides of the Rocky Mountain Trench is similar and they suggest a continuation of the westward dipping basement beneath, and well to the west of the Trench. Therefore the Trench and the associated post-orogenic Tertiary basins are probably related to a system of shallow, listric, normal faults that are responsible for the location and direction of this morphologic feature.

A palinspastic reconstruction based on seismic and subsurface data is essential background for discussions concerning the relations between the Rocky Mountains and the igneous and metamorphic western half of the Cordillera. More generally, relations between continental drift and the formation of the Western Cordillera are placed in perspective using such reconstructions.

The seismic reflection data shown provide insight into the structure of the crust down to depths of ten kilometers, and effectively bridge the gap between surface geology and deep crustal refraction data.

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INTRODUCTION

Some one hundred years ago the British Government issued a "Blue Book" reporting the results of Captain Palliser's expedition to the Canadian west in which James Hector (1863) published the first geologic observations on the Canadian Rocky Mountains. Today the Southern Canadian Rockies rank among the best known mountain ranges of the world, both geologically and geophysically.

Pioneer work by Dawson, McConnell, Willis and Daly, to name a few, established basic stratigraphy and led to the recognition of widespread overthrust and folding phenomena. This period was followed by mapping, done mainly by officers of the Geological Survey of Canada, a project that is still in progress. The discovery of gas, and later of oil, at Turner Valley stimulated the search for additional hydrocarbon accumulations. Petroleum geologists have published many valuable contributions to the geology of the area. Excellent summaries of the state of knowledge of the time are given in the "Western Canada Sedimentary Basin Symposium" (Clark, 1954), North and Henderson (1954a), Hume (1957), Fox (1959), and Shaw (1963). Recently, the stratigraphy of western Canada has been compiled in the "Geological History of Western Canada" (A.S.P.G., 1964b).

During the early Forties the first geophysical surveys (gravity and seismic) were undertaken in selected areas. They led to discovery of the Jumping Pound, Sarcee and Pincher Creek gas fields. A stimulating synthesis of geologic and geophysical data was published by Link (1949). During the Fifties extensive regional seismic surveys were undertaken, culminating in discovery of the Waterton, Wildcat Hills, West Jumping Pound and other, not yet fully evaluated gas fields. During this period only one field, Savanna Creek, was discovered using surface geologic methods.

It soon became apparent that seismic data were not only valuable from an economic point of view, but that they contributed greatly to a better understanding of regional structure and problems related to mountain building. The importance of widespread décollement phenomena was clearly demonstrated. Fox (1959), Shaw (1963) and others published regional sections which evidently were based on seismic information, but only recently has Keating (1966) published some of the supporting data.

Because of the lack of geophysical documentation relating to the geology of the Rockies and Foothills of Alberta and southeastern British Columbia, the authors consider it desirable to publish basic seismic reflection data at this time. The seismic sections presented provide illustrations of the internal structure of a typical thrust and folded mountain belt and permit dealing with the "shortening" aspects of mountain building in a reasonably quantitative manner.

This paper is based on the fundamental contributions of many predecessors. It is not possible to credit all who have contributed to a better understanding of the geology of the Rockies but we must single out the work of the Geological Survey of Canada, particularly its fine surface maps and Memoirs. Publications of the Alberta Society of Petroleum Geologists have also added much to a geological understanding of the Rockies.

We thank Shell Canada Limited for releasing the seismic information and allowing publication of this paper.

A judicious amalgamation of geophysical and geological talents and know-how is the key to an adequate understanding of most geologic problems. We cannot name all the numerous past and present colleagues at Shell who helped us to arrive at a better understanding of the geology and geophysics of the Rockies and Foothills, but we wish to thank our closest associates: among the geophysicists, A. Junger, G. Robertson, D. W. Smith and F. Van Goor, and among the geologists, J. M. Alston, J. E. Davidson, G. I. Lewis and O. L. Slind.

We also extend our thanks to G. E. Merritt who critically reviewed the manuscript and to C. G. Devenyi who is responsible for the majority of the drawings in this report.

REGIONAL FRAMEWORK

Three major fold belts rim the North American craton. They are the Appalachian-Ouachita system on the southeast and east, the Innuitian system on the north and the Western Cordillera on the west. The first two, folded during Late Paleozoic time, were later eroded deeply and partly buried, whereas the Western Cordillera, folded during Late Mesozoic and Tertiary time, is better exposed.

Each system can be divided into an inner igneous belt and an outer non-igneous fold belt. The former was characterized by eugeosynclinal sedimentation followed by a breakup into epi-eugeosynclines accompanied by the emplacement of igneous intrusions and metamorphism. The outer fold belt evolved through a miogeosynclinal and exogeosynclinal

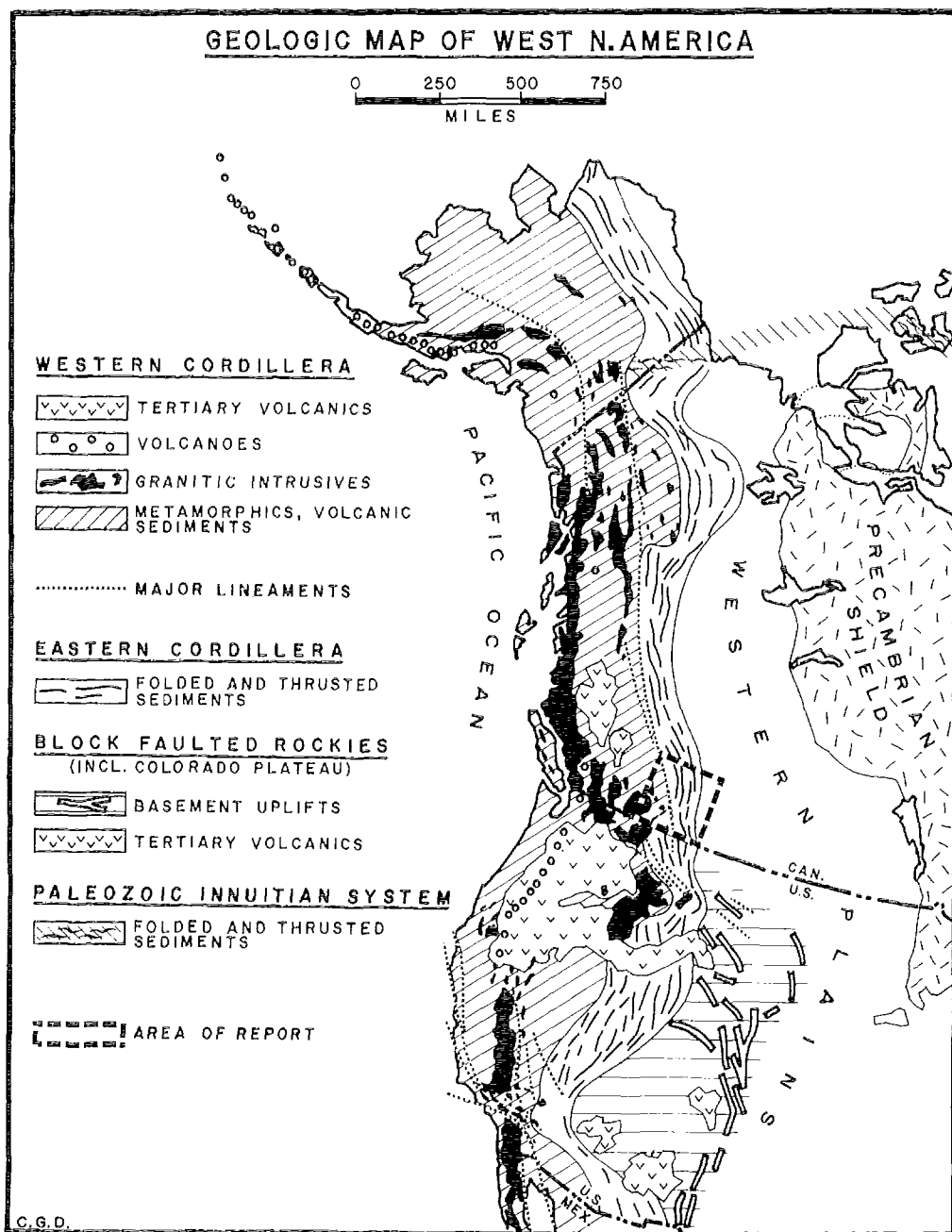


FIG. 1.—Geologic map of western North America, showing location of report-area.

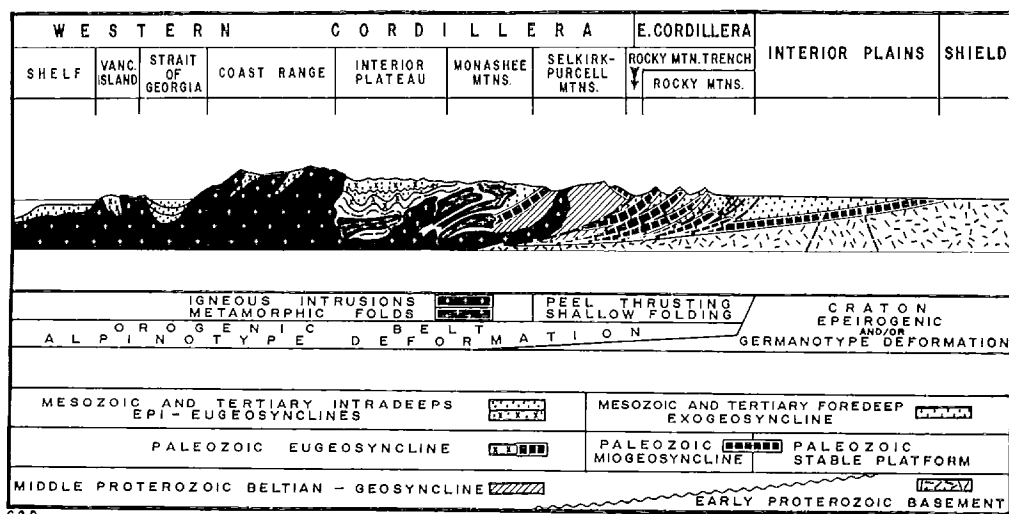


FIG. 2.—Sketch showing relationship of geosynclinal, structural and physiographic units.

phase into a fold belt characterized by peel-thrusting, that is, décollement folding and thrust faulting. Large block-faulted (germanotype) uplifts involving crystalline basement and the overlying cratonic cover form the transition zone between the outer miogeosynclinal fold belt and the adjacent shield. The application of these subdivisions to the Canadian Cordillera is shown on a map (Fig. 1) and sketch section (Fig. 2). The sketch shows major physiographic subdivisions at the top, and structural styles and geosynclinal phases below.

Any attempt to understand the phenomenon of mountain building has to relate the geology of these belts to a unified and evolutionary concept. This paper is an attempt to improve the foundations for such a concept. We plan to document the internal structure of a typical outer, non-igneous fold belt. Most of this paper is devoted to the evidence for widespread décollement over a gently westward dipping shield-type basement. Some conclusions are particularly relevant to an understanding of the evolution of the adjacent igneous belt.

It must be emphasized that the Canadian Rocky Mountains (or Canadian Rockies) strike into the folded belts of Montana, Wyoming, Idaho, Utah and Nevada. The Rocky Mountains and foothills of central Montana, Wyoming, Colorado and New Mexico form a different structural province with predominant germanotype block-faulting involving the Precambrian basement. The Mackenzie and Franklin Mountains of the Northwest Territories are a branch of the Canadian Rockies also characterized by variations on the theme of décollement folding and thrust faulting.

SUBDIVISIONS OF EASTERN CORDILLERA

The major geologic and physiographic subdivisions shown on the geologic map (Fig. 3) and the provinces map (Fig. 4) are based largely on proposals by Bostock (1948) and North and Henderson (1954a). From east to west, the main subdivisions are:

1. *The Interior Plains*, underlain by a relatively undisturbed sequence of Paleozoic, Mesozoic and Cenozoic sediments directly overlying a gently westward dipping Canadian Shield.
2. *The Foothills*, whose structural skeleton is formed by relatively large and flat thrust sheets involving Paleozoic carbonates, with some frontal imbrications. Intensive imbrications of Mesozoic clastic rocks drape this Paleozoic "skeleton." The whole is underlain by the relatively undisturbed westward continuation of the Canadian Shield. A large portion of this paper is devoted to the evidence for this.
3. *The Front Ranges*, formed by thrust sheets, stacked in imbricate fashion, mainly involving Paleozoic carbonates and Precambrian (Beltian) carbonate and clastic rocks. This province is also underlain by a basically undisturbed westward extension of the Canadian Shield.

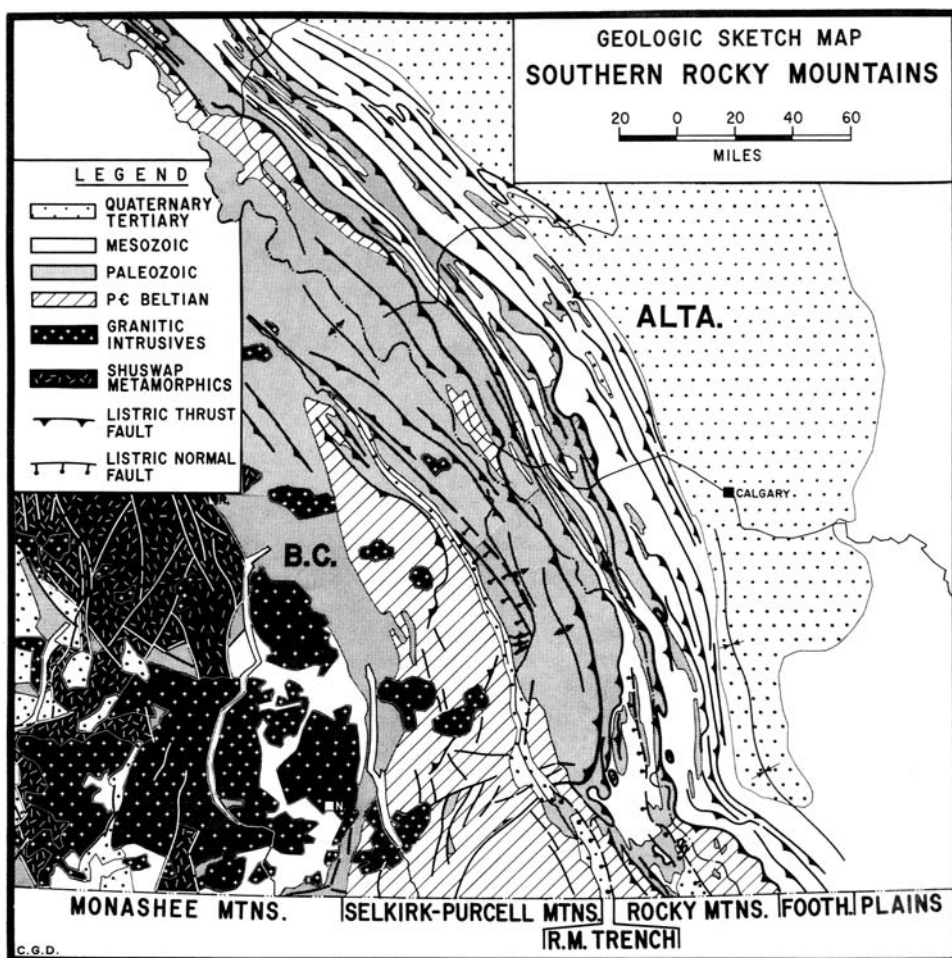


FIG. 3.—Geologic sketch map, Southern Rocky Mountains.

and lower Paleozoic sediments, intruded by large, more or less discordant granitic batholiths.

8. *The Selkirk-Monashee Mountains*, characterized by extensive gneiss complexes (Shuswap and Valhalla), by more or less discordant granitic intrusives (Nelson batholith) and by eu- and epieugeosynclinal Paleozoic and Mesozoic clastic rocks and volcanics.

SIMPLIFIED STRATIGRAPHY

The amount of stratigraphic information on the area is overwhelming; fortunately an outstanding synthesis is available in the "Geological History of Western Canada" (A.S.P.G., 1964b). Table 1 is a table of formations expanded to indicate lithologies, thicknesses, velocity distributions, and the stratigraphic position of two major reflection events. The area described on Table 1 is shown on Figure 5.

For purposes of regional structural analysis the stratigraphy can be simplified as follows.

Two types of Precambrian rock occur: (1) Metamorphic and igneous rocks of the western extension of the Canadian Shield formed during the Hudsonian orogeny 1,640-1,820 m.y. ago (Burwash *et al.*, 1964), and (2) a thick series in excess of 45,000 feet of Beltian (Proterozoic) quartzites, argillites, and carbonates, with basic intrusives and extrusives. The Beltian disconformably overlies the Canadian Shield. An unconformity separates the Beltian Purcell Series from the younger Proterozoic Windermere Series.

The Paleozoic succession consists primarily of carbonates and some shales with thicknesses generally increasing towards the west. Three groups of unconformities occur, one below the Cambrian, another between the Middle Ordovician and the base of the upper Middle Devonian, and the third between the Pennsylvanian and the base of the Lower Cretaceous. They indicate gentle tilting movements but no effects of true alpinotype orogenic movements can be observed.

The lower Mesozoic succession (Triassic and Jurassic) is incomplete due to the above mentioned group of unconformities, caused by tilting movements during late Paleozoic and early Mesozoic time. Where present, shales, some coarse clastic rocks, and rare carbonates characterize the succession.

Uppermost Jurassic, Cretaceous, and Tertiary sediments consist of conglomerates, sandstones, and shales of marine and continental character, showing some affinities to Alpine molasse sediments. With the possible exception of some beds in the Kootenay Formation, no equivalent to "flysch-like" deposits occurs in the Canadian Rocky Mountains.

SUMMARY OF SEISMIC PROCEDURES

The structural style of the Foothills and Rocky Mountains can be understood by the integration of geological and seismic data. Both reflection and refraction seismic techniques are used in the Foothills.

TABLE 1.—Table of formations.

		FORMATION	LITHOLOGY	THICKNESS	AV. VELOCITY (MAX. DEVIATION) IN FEET/ SEC.	RANGE OF VELOCITIES	REMARKS		
TERTIARY CLASTICS	PLEISTOCENE- RECENT	UNCONFORMITY ST. EUGENE (CONFINED TO CRANBROOK AREA)	GRAVEL, SAND, SILT, GLACIAL DRIFT	0-5000'	11,000 (1000)	10,000-12,000			
	MIOCENE	UNCONFORMITY KISHENENA (FLATHEAD VALLEY)	GRAVEL, SAND, SILT						
	EOCENE AND OLIGOCENE	UNCONFORMITY PASKAPOO - PORCUPINE HILLS	NON-MARINE MUDSTONE, MARL, SILTSTONE, SAND- STONE, CONGLOMERATE	6000'+					
	PALEOCENE	UNCONFORMITY WILLOW CREEK	NON-MARINE SANDSTONE, SHALE, COAL, BASAL CONGLOMERATE	4000'+					
MESOZOIC EXOGEOSYNCLINAL (FOREDEEP)	PALEOCENE AND/OR UPPER CRETACEOUS	EDMONTON (BLOOD RESERVE, ST. MARY RIVER)	NON-MARINE SANDSTONE, SHALE, COAL, BASAL CONGLOMERATE	1000-3100'	11,400 (400)	12,000-14,000			
	UPPER CRETACEOUS	BEARPAW	MARINE BLACK SHALE	0-60'					
		BELLY RIVER	NON-MARINE SANDSTONE, MUDSTONE, SHALE	1200-4000'	12,600 (1700)				
		WAPIABI	MARINE SHALE, SILTSTONE	1100-1800'	12,800 (1000)				
		CARDIUM	MARINE SANDSTONE, SILTSTONE, SHALE	30-450'	13,400 (2400)				
		BLACKSTONE	MARINE SHALE, SILTSTONE, BASAL GRIT	400-1000'	13,100 (1900)				
		LOWER CRETACEOUS	CROWSNEST VOLCANICS (CONFINED TO CROWSNEST AREA)	VOLCANIC AGGLOMERATE, TUFF	0-1800'				
	LOWER CRETACEOUS & UPPER JURASSIC	INTRUSIVES (CONFINED TO FLATHEAD AREA)	TRACHYTE, SYENITE 95-112 M.Y. OLD						
		BLAIRMORE	NON-MARINE SANDSTONE, SILTSTONE, SHALE, BASAL CONGLOMERATE	1000-6500'	14,700 (1900)				
		KOOTENAY	NON-MARINE SANDSTONE, SILTSTONE, SHALE, COAL	0-4000'	14,800 (2600)		BASAL MESOZOIC REFLECTION EVENT "NEAR MISS."		
	JURASSIC	FERNIE UNCONFORMITY WHITEHORSE	MARINE SHALE, SILTSTONE, LIMESTONE, SANDSTONE	100-1000'+	13,700 (3000)				
	TRIASSIC	SULPHUR MOUNTAIN	DOLOMITE, SANDSTONE	0-800'					
	PALEOZOIC CARBONATES EXOGEOSYNCLINAL	PERMIAN	UNCONFORMITY ISHBEL	QUARTZITIC SANDSTONE, SILTSTONE, CHERT	0-2000'			20,000-21,000	
		PENNSYLVANIAN	UNCONFORMITY KANANASKIS	MARINE CHERTY DOLOMITE	0-170'				
SPRAY LAKES GROUP TUNNEL MTH. (CONTAINS MINOR DISCONFORMITIES)			MARINE DOLOMITIC SILTSTONE, SANDSTONE	0-1800'					
ETHERINGTON			MARINE LIMESTONE, SILTY DOLOMITE, ANHYDRITE	0-850'					
MOUNT HEAD			MARINE THIN-BEDDED LIME- STONE, SILTY DOLOMITE	0-1000'					
MISSISSIPPIAN		LIVINGSTONE (TURNER VALLEY-SHUNDA-PEKISKO)	MARINE CRINOIDAL CHERTY LIMESTONE	800-1400'	20,400 (2500)				
		BANFF	MARINE, DARK ARGILLACEOUS, CHERTY LIMESTONE	500-1050'					
		EXSHAW	MARINE, BLACK SHALE	10-40'					
		UNCONFORMITY PALLISER	MARINE, MASSIVE LIMESTONE, DOLOMITE	900-1200'					
UPPER DEVONIAN		ALEXO	MARINE, SILTY LIMESTONE, DOLOMITE, SILTSTONE	20-600'	20,000-21,000				
		FAIRHOLME	MARINE LIMESTONE, SHALE, DOLOMITE, DOLOMITIZED REEFS	950-1500'					
LOWER AND/OR MIDDLE DEVONIAN		UNCONFORMITY BASAL DEVONIAN CLASTICS	SILTY & SANDY DOLOMITE, RED BEDS	0-120'					
ORDOVICIAN		UNCONFORMITY MONS & SARBACH (FRONT RANGES OF BOW VALLEY & NORTH)	LIMESTONE, DOLOMITE, PUTTY- COLOURED SHALE	0-1500'					
UPPER CAMBRIAN		LYNX (ELKO) (FRONT RANGES)	MARINE DOLOMITE, SILTY DOLOMITE, SHALE, LIMESTONE	0-1800'+					
MIDDLE CAMBRIAN		ARCTOMYS (FRONT RANGES)	SILTSTONE, SILTY DOLOMITE, SHALE (SHALLOW WATER)	0-200'+					
		PIKA (FRONT RANGES)	MARINE LIMESTONE, DOLOMITE	0-320'					
		ELDON	MARINE LIMESTONE, DOLOMITE	700-1000'					
		STEPHEN	MARINE LIMESTONE, SHALE	100-400'					
		CATHEDRAL (BURTON)	MARINE DOLOMITE, LIMESTONE	200-1000'					
		MOUNT WHITE (EAGER)	MARINE SHALE, SANDSTONE, QUARTZITE, LIMESTONE	500-1500'					
		LOWER CAMBRIAN	ST. PIRAN-GOG (CRANBROOK)	QUARTZITE, SHALE	20-8000'				
BELTIAN		UNCONFORMITY							
		MIDDLE-LOWER LATE PROTEROZOIC	UPPER PURCELL (CRANBROOK WATERTON AREA) NOT PRESENT IN FOOTHILLS	ARGILLITE, DOLOMITE, QUARTZITE, PURCELL LAVA	8000-12,000'	17,000 - 18,000			
			LOWER PURCELL (CRANBROOK WATERTON AREA) NOT PRESENT IN FOOTHILLS BASE OF PURCELL NOT OBSERVED	QUARTZITE, ARGILLITE, LIMESTONE, DOLOMITE	8000- 20,000'				
	BASE- MENT	EARLY PROTEROZOIC	UNCONFORMITY BASEMENT	IGN. & METAMORPHIC "SHIELD" TYPE ROCKS, CONSOLIDATED DURING HUDSONIAN (1600-1900 M.Y.)			7,000-16,000	CAMBRIAN REFLECTION EVENT "NEAR BASEMENT"	

Generally, fair quality reflection data are obtained by conventional methods, that is, continuous profiling, split shots, single holes, 20 to 80-pound charges with geophone spreads of about 1,800-2,400 feet. For reasons of accessibility and costs the lines generally follow the stream valleys (the majority of which are in the dip direction). Operational procedures have been summarized recently by Keating (1966).

The reflection-record sections used in the Plates were prepared from field records corrected for elevation and weathering effects. They are variable-area recorded (VAR) time sections, and are compressed somewhat vertically. As a purpose of this paper is to show good representative data, some sections have been pieced together from projected line segments (Fig. 5).

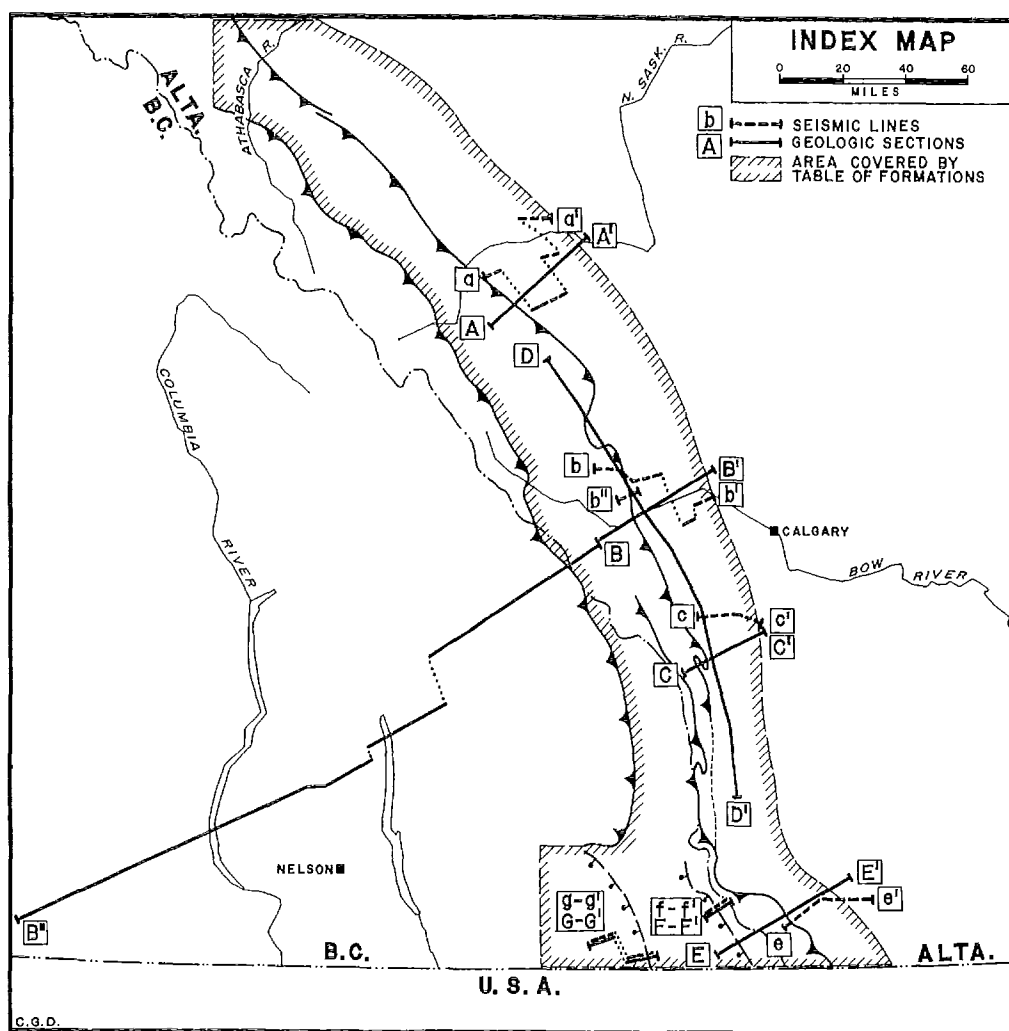


FIG. 5.—Index map, locations of geologic and seismic sections.

Although a large velocity contrast occurs at the Mississippian-Mesozoic interface, a corresponding reflection is rarely observed. Instead, an excellent reflection comes from the Lower Blairmore-Jurassic interval (see also Keating, 1966). Where Mesozoic and Paleozoic strata are structurally conformable, the correct Mississippian pick is a late phase of this Lower Blairmore-Jurassic band. However, where Lower Mesozoic rocks are thrust over younger Mesozoics, the question of conformity is in many cases uncertain from reflection data alone and is usually established from refraction data.

A strong, persistent arrival from the Mississippian is usually obtained from late-arrival refraction shooting (second event refraction technique of Keating, 1966). The shooting distance chosen is greater than the critical distance (the minimum distance a refraction may be recorded from the refractor) but less than the distance where the time of arrival of the refraction would equal the arrival time of the direct wave from shotpoint to geophone. The in-line refraction method (along strike) is valuable for velocity identification of the Paleozoic top. The broadside method of second arrival refraction profiling is useful for defining Mississippian structure and establishing the location of the leading edges of Paleozoic thrust sheets (Richards, 1959; Blundun, 1956). While refraction outlines the Paleozoic skeleton, the mapping of Mesozoic structure and estimation of the internal structure of multiple thrust sheets can be done only with reflection data.

Numerous steep dips, and even intersecting dips evident on the VAR sections, obviously require migration for accuracy of structural interpretation. However, due to the complex geometry of seismic trajectories and velocity variations, only an approximation of the true position for steeply dipping events can be achieved.

The most consistent event obtained in Foothills shooting is a wide-band reflection from the Cambrian. This event is calibrated by wells in the Plains east of the Foothills. It has two important characteristics: (1) Usually it is identifiable (even in bad-record areas), and (2) it is the only event that shows time variations due to all the changes in velocity and thickness of the Mesozoic and Paleozoic strata from surface to basement. From regional studies the underlying basement is interpreted to be essentially autochthonous, dipping smoothly to the west at about 200 feet per mile. With this assumption one can use the Cambrian event to predict the amount of Paleozoic section above regional, once the Mesozoic velocities have been estimated. Examples of Cambrian time uplifts are illustrated in the description of characteristic sections.

We generally assume that in an autochthonous position the Cambrian event is always immediately underlain by the crystalline Precambrian basement and therefore often call the event a "near-basement event." We have discarded the alternative that the Cambrian event is underlain by Proterozoic sediments because experience elsewhere in western Canada shows that Beltian sediments are seismically characterized by prominent reflections. An exception to this will be described in the section discussing the west side of the Rocky Mountain Trench.

DESCRIPTION OF CHARACTERISTIC SECTIONS

The location of the sections is indicated on Figure 5. Note again that the seismic sections are spliced together to provide continuity. The geologic sections are located subparallel to the seismic lines and incorporate pertinent surface, subsurface and seismic data. Although the sections are largely self-explanatory, the following comments provide additional background and emphasize pertinent points. Relevant reference material to each of the sections is listed chronologically in Part C of the References.

A. *Geologic Section A-A' and Seismic Section a-a', Ram River-Stolberg Area (Plates 1, 2)*

The Cambrian event is outstanding on seismic section a-a'. The event has not been identified nearby, but numerous penetrations into the carbonate sequence by wells (e.g. Phillips Ancona) and the high quality of the seismic data leave little doubt as to its near-basement Cambrian origin.

Proceeding from east to west, a velocity uplift of the Cambrian event due to the stacked carbonate imbrications of the Stolberg structure can be seen. A second velocity uplift farther west is due to the carbonates of the outcropping Brazeau thrust sheet. Note there is no sizable velocity uplift corresponding to the Ram River feature, suggesting that the total amount of carbonates overlying the basement event does not change because of "redistribution" of the carbonates from the Brazeau sheet to the Ram sheet.

The geologic section displays many characteristic features: (1) The basement dips gently to the west, after correction of velocity effects on the Cambrian event. (2) Faults tend to be steep at surface but they flatten out at depth, where they ultimately merge into bedding planes (listric thrust faults). (3) In a westward direction faults always cut deeper into the section. (4) The Cambrian is involved in the thrusting and forms the base of the Brazeau thrust sheet. The westward root of this sheet is clearly indicated on the seismic section. The Brazeau sheet has been penetrated by a number of wells which show that Cambrian overlies the main fault (see also Imperial Cal. Stan. Nordegg 6-17, on Shaw's (1963) cross-section). (5) On surface, a stratigraphic displacement in the order of 10,000 feet along the front of the Brazeau sheet largely conceals the established thrusting distance of at least 20 miles. This phenomenon occurs elsewhere in the Foothills and can be explained by splitting of the main thrust fault into a number of smaller thrusts that distribute the total displacement.

B. *Geologic Section B-B' and Seismic Section b-b', Bow Valley Area (Plates 1, 3, 4)*

If a prototype structure section for the Canadian Rockies and Foothills had to be selected, the authors would probably choose this section. Again, three characteristic seismic reflection sections have been spliced together and the geologic section attempts to synthesize all available information. Because the seismic and geologic sections are not located on the same line, different wells are shown as calibration. Many other

wells have been drilled in the area, all of which support the interpretation shown on section B-B'.

The nearest basement well is California Standard Parkland 4-12, about 60 miles southeast; regional seismic data leave little doubt that the Cambrian event represents the section immediately overlying the crystalline basement. On seismic section b-b' the Cambrian event can be traced well into the Front Ranges of the Rockies. Small velocity uplifts occur below the Jumping Pound and West Jumping Pound structures, but no sizable velocity uplift is recognized beneath the leading edges of the two western thrust sheets. We assume this is due to a thin wedge-like leading edge which causes the velocity uplift to be very gradual. After correction only an increased tilt of the Cambrian event can be seen.

In the area of sections B-B' and b-b' the carbonate skeleton consists of a lower sheet, an intermediate sheet which outcrops about 10 miles south at Moose Mountain, and an uppermost sheet, the McConnell thrust.

The lower sheet can be split into three parts: (1) The gas-bearing structures of Jumping Pound and West Jumping Pound-Morley (frontal offshoots underlain by a common bedding fault and showing cumulative thrust slip of three to four miles). (2) An intermediate flat part of normal stratigraphic thickness that evidently conceals the displacement of the frontal offshoots in the form of a basal Mississippian bedding-plane fault. (3) A rearward lens-like feature at the place where the bedding-plane fault cuts into deeper Paleozoic strata, thus forming a broad anticline.

Douglas (1950) described similar features observed at the surface and interpreted them following a mechanism suggested by Rich (1934) and others for the Appalachians. The mechanism is shown on the two lower sections of Figure 13. Because the transition between the rearward and the middle sector is so critical we include a detailed closeup of another seismic section, shot in the valley of the south branch of Ghost River (Pl. 4).

Overlying the Paleozoic carbonate skeleton is an envelope of complex Mesozoic imbrications. Most should be considered as being sheared off the top of the lower sheet by the higher Moose Mountain sheet. To construct a consistent cross-section we must then assume that the cumulative length of any Mesozoic stratum (e.g. the Cardium) should correspond to at least the cumulative length of the underlying Paleozoic top. One important restriction must be placed on this statement. Some of the Mesozoic imbrications may be sheared off the top of a Paleozoic sheet located farther west than the western margin of the section. That this is in some instances the case is suggested on our section B-B' east of the Morley well where we show thrust displacements of the Cardium Formation that greatly exceed the slip shown for the underlying frontal offshoots. This implies that the Moose Mountain sheet sheared Mesozoic beds off their carbonate substratum before the more easterly lower thrust sheet was formed. Formation of the lower element warped or folded the overlying Moose Mountain and McConnell sheets and simultaneously the faults underlying the frontal offshoots folded and faulted the bedding-plane fault connecting the Mesozoic imbrications. This is illustrated on Figure 6. If there are differences in strike between the upper and lower fault systems one will observe a map picture whereby a younger

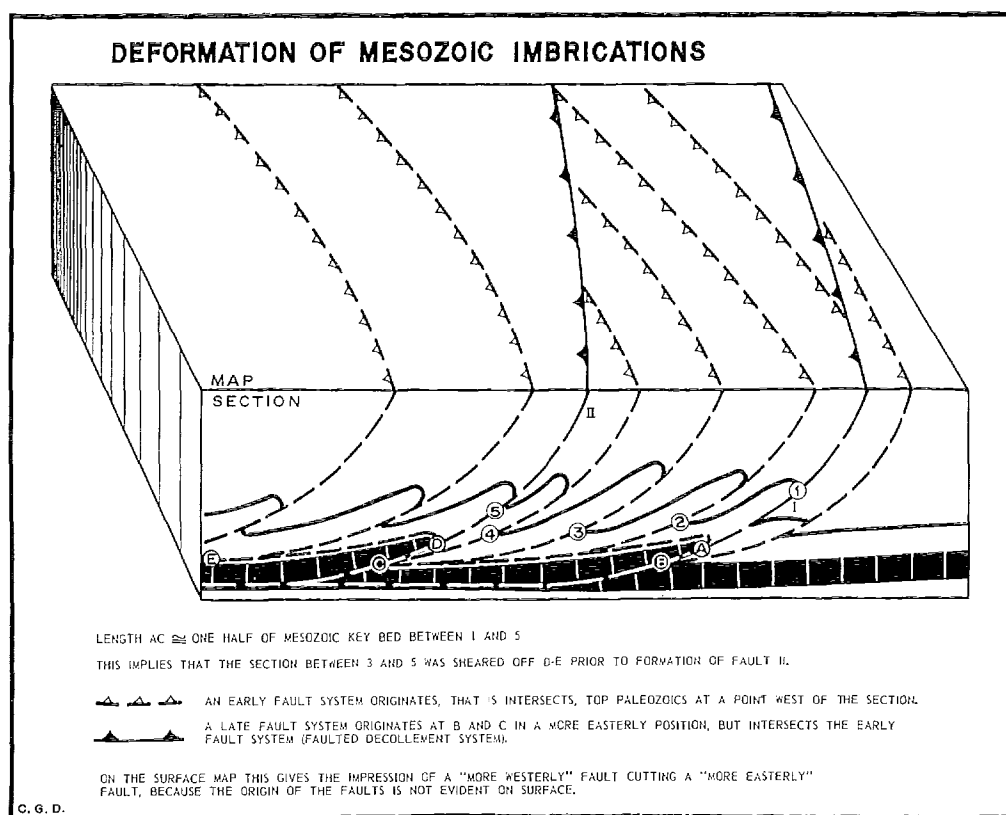


Fig. 6.—Deformation of Mesozoic imbrications.

fault cuts older faults, suggesting that a more westerly element was formed later and intersected more easterly elements. In reality we are dealing with a deeper and more easterly fault system that broke through an earlier formed system.

When section B-B' is related to the longitudinal section (Pl. 8), the lens-like western portion of the lower sheet can be seen to split into several imbrications below the Moose Mountain culmination to the south, but to remain intact in the more northerly Panther culmination. In both localities the existence of the lower feature was predicted and subsequently confirmed by wells.

A comparison between section A-A' and section B-B' shows differences in structural style. In the Ram-Stolberg section fewer imbrications involving Mesozoic clastic rocks occur because the Paleozoic sheets do not lie "flush" on top of each other and therefore much of the Mesozoic sequence is undisturbed and preserved below the Brazeau thrust sheet. This enables us to better understand surface maps. It appears that areas marked by a multitude of Mesozoic imbrications indicate the presence of carbonate sheets stacked on top of each other without intervening Mesozoic clastic strata.

C. *Geologic Section C-C' and Seismic Section c-c', Turner Valley-Highwood Area (Plates 5, 6)*

This section, located about 50 miles southeast of the one preceding, illustrates the structure of the Turner Valley oil field and the neighbouring Highwood and Sullivan Creek structures, which are located to the west and are non-productive. The geologic section C-C' extends farther west than the seismic section in order to tie to the Front Ranges and provide some continuity with longitudinal section D-D'.

The sections illustrate a classic oil exploration area with particularly good seismic data. Compared with the two preceding sections, we can observe elements of both structural styles, that is, thrust sheets that override the relatively intact Mesozoic sequence, and thrust sheets that sheared off a considerable amount of Mesozoics from their substratum (Sullivan Creek structure and Mesozoic imbrications to the east).

D. *Geologic Section D-D' Longitudinal Section Scalp Creek to Oldman River (Plate 8)*

On the preceding C-C' and B-B' sections we observed a gently west-dipping basement and in the west two structural highs (the projection of the Moose Mountain structure and the Sullivan Creek feature). Both structures are on an anticlinal trend which can be traced from the Scalp Creek area via Panther River-Moose Mountain-Sullivan Creek into the area of the Savanna Creek gas field and beyond. The anticlinal trend is characterized by axial culminations and depressions designated on the longitudinal section. Extensive drilling has been done on top and on the flanks of these culminations and some of the more important wells are shown on the section. The section is based on numerous seismic lines, many of which show the presence of the undisturbed Cambrian event.

It is important to recognize regional axial culminations and depressions in order to utilize the information for axial projections into cross-sections. In the Alps and in many other areas of alpinotype deformation, axial projections from culminations into the neighbouring depressions have frequently been the key to an understanding of complex structural problems. It is, however, often difficult to explain the nature of the axial culminations themselves. Frequently based on analogy with the Alps, it has been concluded that major culminations represent autochthonous basement highs.

Section D-D' gives insight into the nature of axial culminations and depressions in the Rockies. Clearly, there are no basement highs underlying the culminations, and basement depressions are also absent. Proper correction for velocity effects has removed anomalies evident on the raw data, leaving only a possibility for minor features smaller than the resolution power of reflection seismic, i.e. about 1,000 feet, by present seismic methods. We therefore conclude that the occurrence of axial culminations is due either to deeper imbrications and thrust sheets or to local variations in thickness of the stratigraphic sequence involved in the thrust sheet or else to a combination of both. Although seismic and drilling have convincingly eliminated the possibility of major basement highs, it is often difficult to conclude which of the above alternatives is likely because the internal structure of stacks of carbonate imbrications is rather difficult to unravel on reflection lines. Erdman (1950) pointed

out that axial culminations and depressions tend to line up. The authors also have qualitatively plotted culminations and depressions on a regional map and found they tend to line up in predominantly northeasterly directions. Because this was not done in a strictly quantitative manner it was of course difficult to decide which culmination is minor and which is major. Also, to be meaningful, plotting should be done on a palinspastic base.

E. *Geologic Section E-E' and Seismic Section e-e', Lewis Overthrust Area (Plates 5, 7)*

Figure 7 illustrates the surface geology in a simplified manner. Two major gas fields, Waterton and Pincher Creek, are shown on the sections. On seismic section e-e' the Cambrian event can be followed with reasonable continuity under the Waterton structure and the Lewis overthrust. Adjacent to the east end of this section, another seismic line published by Robertson (1963) revealed the presence of an intra-base-ment reflection dipping from 7.5 km depth in the east to 14 km depth in the west.

The Pincher Creek structure is rather obscure on this section, due to the small throw on the fault (between 500 and 1,000 feet). The structure is better recognized on refraction data. The Waterton structure is readily recognizable by its large velocity uplift and the anticlinal form of the composite Mesozoic envelope. The internal structure of this stack of Paleozoic imbrications is difficult to unravel seismically but is evident in numerous wells that have penetrated this feature.

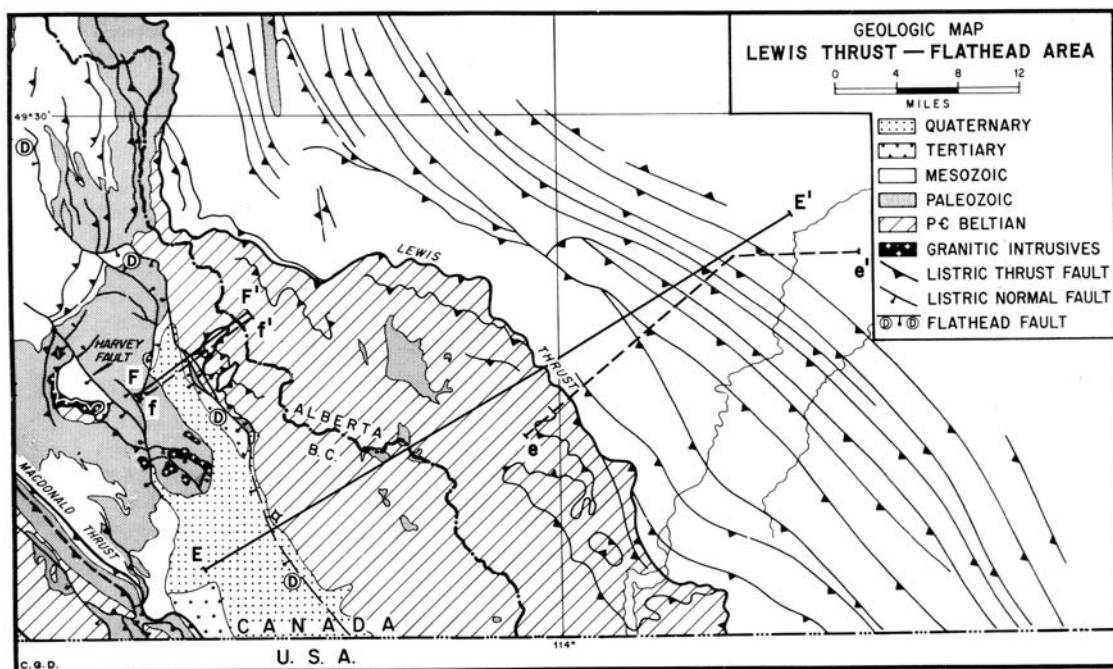


FIG. 7.—Geologic map of Lewis thrust-Flathead area.

Discordance of 15° in the strike between the Mesozoic imbrications and the underlying Pincher Creek structure has been discussed by Erdman *et al.* (1953) and Fox (1959). Erdman *et al.* suggest that the Paleozoic rocks of the Pincher Creek structure were deformed in early Laramide time and later overridden by Mesozoic imbrications (see also Gallup, 1955). Fox prefers the reverse sequence of events, that is, the Lewis overthrust mass formed first, moving and rotating Cretaceous imbrications in front of it, with the Pincher Creek structure formed after this early phase.

Our cross-section shows that the imbrications overlying the Pincher Creek structures are sheared off the top of the complex Waterton structure and strike parallel to that feature. Whether the Pincher Creek structure was formed prior to, or after, the deformation of the overlying Mesozoic imbrications, cannot be decided with the data available, but we feel that evidence elsewhere in the Foothills and Rockies strongly favours a deformation progression from west to east as suggested by Fox, and illustrated in a generalized manner on Figures 6 and 13.

F. *Geologic Section F-F' and Seismic Section f-f', Flathead Area (Plate 9)*

To the west, the Precambrian masses of the Lewis overthrust are limited by a normal fault dipping about 40° to the west, which at places on surface shows stratigraphic throws exceeding 10,000 feet and dies out to the north (see Flathead fault on Fig. 7). Associated with the fault is a narrow fault basin filled with continental clastic rocks of early Oligocene to late Eocene age (Russell, 1964). These beds contain pebbles derived from the neighbouring mountains. The beds are deformed in proximity to the fault and generally dip into the fault. Hence the clastics were deposited after emplacement of the Lewis overthrust and the normal fault formed during, but mostly after, deposition of the Tertiary beds (Pardee, 1950).

On surface (Fig. 7), the Lewis overthrust is offset by the Flathead fault and regional mapping shows clearly that the Lewis overthrust lies at depth under the mountains to the west. Many interpretations have been suggested for the Flathead fault. They cover the spectrum from normal faults to east-dipping reverse faults and overthrusts; recently, Oswald (1964) and Dahlstrom, Daniel, and Henderson (1962) published a sequence of interpretations illustrating low-angle normal faults.

With many other geologists we think that the Flathead fault and the adjacent Tertiary basin are part of a large province characterized by the faulted Tertiary basins in Montana. The Rocky Mountain Trench may be an extension of this province, which to the south probably extends into the Basin and Range province of Nevada. The seismic documentation of the Flathead fault shown will aid our understanding of the Tertiary structural evolution of this whole province.

In places the Flathead fault is a complex zone containing elements of Beltian and Paleozoic rocks (Price, 1965). Seismic section f-f' and geologic section F-F' illustrate a strong "basal Mesozoic" event which can be followed with continuity and which dips to the west. Refraction data calibrated by drilling show that this event is underlain by Paleozoic

carbonates, and that it has not been displaced by the Flathead fault as far west as data are available. It must be concluded that the Flathead normal fault flattens at shallow depth and, as shown, we believe it merges with the Lewis overthrust. This suggests the Lewis overthrust has been "stretched" or "bottlenecked" after its emplacement, an event also related to the formation of the Tertiary basins.

The conclusion is that the Flathead fault is a listric normal fault formed after emplacement of the Lewis overthrust by "back-slippage" along a pre-existing thrust during a phase of post-orogenic uplifting. The predominance of east dips in the Tertiary beds west of the fault is perhaps due to rotation along a listric normal fault. A similar situation, largely supported by surface geology and drilling, was reported by Dahlstrom *et al.* (1962).

G. *Geologic Section G-G' and Seismic Section g-g', Rocky Mountain Trench (Plates 10, 11)*

The Rocky Mountain Trench is a linear topographic depression extending well over 1,000 miles, generally regarded as separating the eastern from the western Cordillera. Structures on both sides of the Trench are commonly truncated and in many places faulting is associated with its margins. Within it, Tertiary and younger sediments predominate.

Some mapping and a fair amount of speculative material have been published on the Trench. Its origin is still debated and opinions range from formation due to thrust faulting, normal faulting, and transcurrent faulting, to glaciation and stream erosion.

Our seismic data are located in the southern portion of the Rocky Mountain Trench, in an area that has recently been remapped. Figure 8 is based essentially on this work. Leech (1959) points out that this area is not necessarily characteristic of other portions of the Trench, and this implies that conclusions based on information here should not be generalized too eagerly. At the same time this portion of the Trench is the only one mapped and studied in reasonable detail, whereas the remainder of the Trench is less well known.

In our area both sides of the Trench are flanked by mountains underlain by generally east-dipping Beltian strata. The Trench is characterized by block-faulting of a type also observed in neighbouring Montana; the faults appear to be antithetic normal faults separating blocks tilted towards the east. The valley of the Trench contains some outcrops of Upper Paleozoic carbonates, and Miocene sands, silts and gravels occur in one area. Fluvial and glacial deposits fill several bedrock depressions in the Trench with thicknesses in the order of 1,500 to 5,000 feet (Lamb and Smith, 1962; Thompson, 1962).

Seismic data (section g-g') were obtained on both sides of the Trench; however, reflection data across its floor are too poor to be of use. By Foothills standards the quality of the reflections is poor, but the few data obtained are of considerable interest.

On the east side of the Trench we see a continuation of the Cambrian event which can be followed with continuity from the Plains across the Foothills and the Fernie Basin. At about 2.0 seconds we observe some flat bands of energy which are characteristic for the "seismic-structural

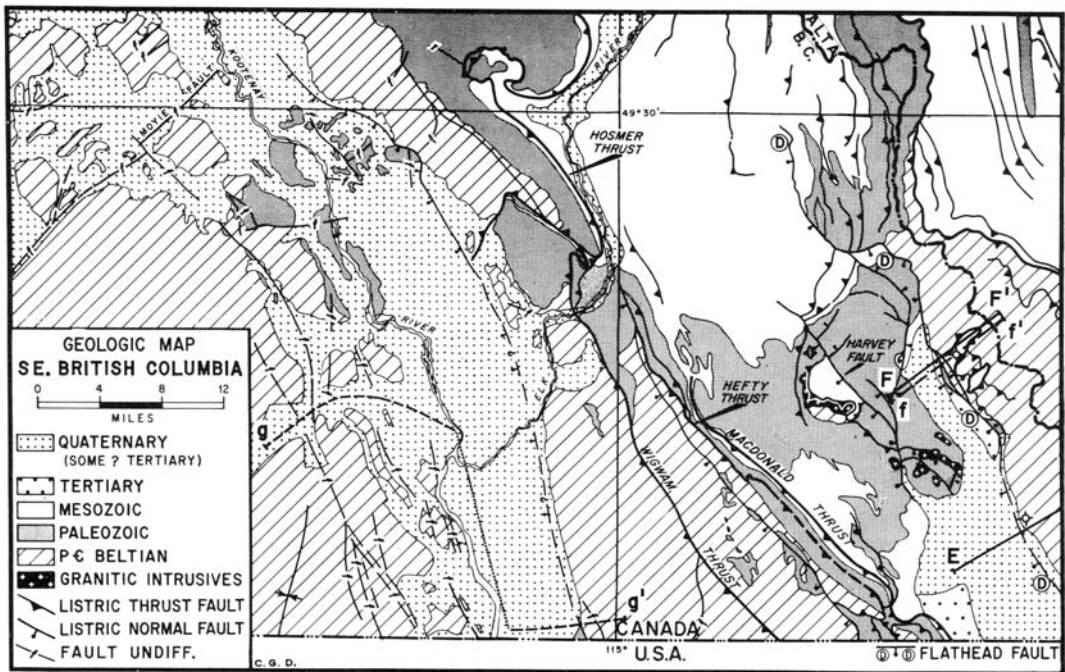


FIG. 8.—Geologic map of southern British Columbia.

style" of the Rocky Mountains. Regional data indicate that the extension of the major thrust faults, located east of the Trench and shown on the east half of section G-G', project into this zone of flat reflections.

On the west side of the Trench we observe an event that falls in the projected extension of the "Cambrian" event; but we also observe an indication of another reflection that diverges from it. We like to speculate that the wedge contained between both events may be the autochthonous eastern wedge-edge of the Belt Series. The lower event therefore cannot be here approximated with the Cambrian as previously assumed for all Foothills sections, but it would still represent the top of the "shield-type basement." If we assume average overlying velocities of 17,000 feet per second, the top of the Precambrian Shield would lie at a depth of about 36,000 feet. An alternative interpretation would suggest that the divergent dip is the root zone of a major thrust, e.g. the Lewis thrust.

On the west side we again observe some flat and some converging dips, suggesting a layered structure. Converging dips are in many instances symptomatic of leading edges of thrust sheets (i.e. the intersection of beds with thrust faults).

Because our conclusions will be subject to controversy we list below what we consider to be reasonably well established geophysical facts concerning this part of the Trench:

1. At depth, the structure on both sides of the Trench appears to be essentially similar and is layered.

2. The Cambrian event of the Foothills can be traced to the east side of the Trench.
3. On the west side of the Trench we recognize a reflection that is on the regional projection of the Cambrian event of the Foothills. This reflection appears to branch out to the west into two events.

We now combine these points with the following geological surface observations:

1. Major normal faults occur on the east side of the Trench; some also are observed on the west side.
2. Farther north in the Cranbrook-Fort Steele area, a complex system of transverse faults (Moyie-Dibble Creek faults) crosses the Trench and can be seen on both sides. Although the exact relations between these faults are obscure, the suggestion is that major strike-slip movements have not occurred along the Trench.
3. The observed normal faults form part of a regional system that includes the faults on flanks of the Tertiary basins of Montana and the Flathead fault. The latter is therefore an adequate analog and could serve as a model to explain normal faulting in the Rocky Mountain Trench.

In addition, based on reconstructions discussed in the following paragraph (see also Plate 12), it must be pointed out that until late Late Cretaceous time the area of the Trench was occupied on both sides by sedimentary sequences that are presently "stacked up" in the Front Ranges of Alberta.

Consideration of these geophysical and geological points suggests the propositions (1) that the Trench was formed in Tertiary time and after the main thrusting phase, (2) that the Trench is underlain by an undisturbed gently westward dipping basement, and (3) that location and strike of the Trench is dictated by a complex system of curved low-angle normal faults or "listric normal faults." The eastward tilting of the associated fault blocks is explained in terms of reverse drag (Hamblin, 1965). We agree with Leech (1965) that at least the southern portion of the Trench is structurally controlled and that stream erosion and depositional filling "were governed directly by topography consequent upon block faulting."

REGIONAL CONSIDERATIONS AND PALINOSPASTIC RESTORATION

The basement contours shown on Figure 9 are based on seismic control combined with subsurface information from the Plains, the Foothills and the eastern Front Ranges. For the westerly zones of the Rocky Mountains control is limited to the area south of Latitude 50°N. and based only on a few regional reflection lines. Accessibility considerations and the location of National Parks preclude obtaining more data to the north. There is, however, little doubt in our minds that a gently westward dipping basement is characteristic for the Rocky Mountains of Alberta and British Columbia.

The most intriguing aspect of the data presented in this paper is the seismic definition of a Cambrian event and the underlying basement top below the Rocky Mountains, which together with the surface geology set clearly defined boundaries for the construction of structural cross-sections. This in turn drastically limits speculations concerning the deep structure of the Rocky Mountains. It also enables us to construct reasonably accurate palinspastic restorations.

On Plate 12 each imbrication and thrust sheet is shown in its present and restored position. Offsets in the line of section are disregarded, and for ease of construction the restoration is tied to the present basement gradient, whereas to the west no specific datum was assumed. Note that nowhere in the structure section or in its restoration is the Paleozoic section completely missing. We assume that no major structural units

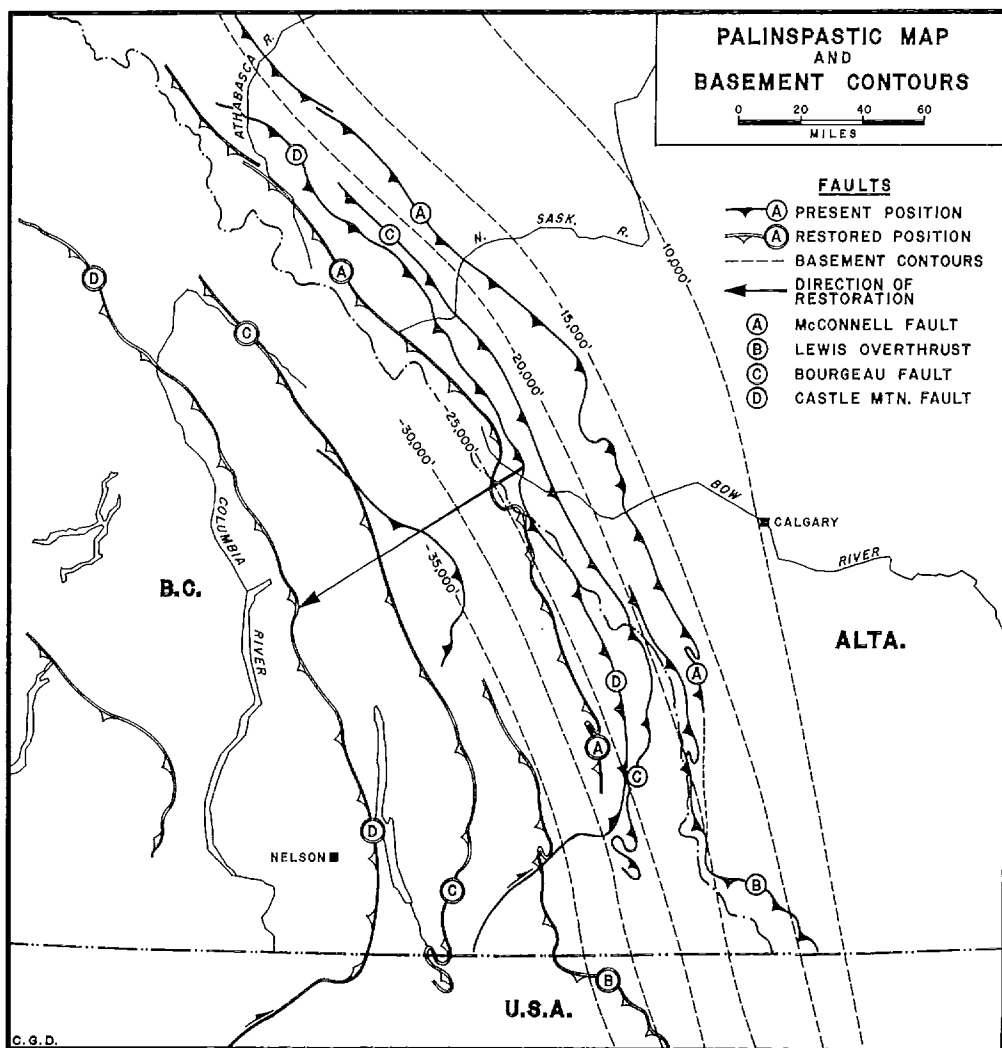


FIG. 9.—Palinspastic map and basement contours, Southern Rocky Mountains.

have been removed by erosion; therefore, our construction is considered conservative.

It appears that shortening in the Rocky Mountains is in the order of 50 per cent, or about 100 miles for the Main Ranges, and about 120 miles for the eastern Purcell Mountains. Comparable amounts of shortening have been postulated by others (North and Henderson, 1954a; Shaw, 1963).

It is instructive to show the present geology of the areas that apparently once were occupied by the Paleozoic and Mesozoic sediments now "piled up" in the Rocky Mountains (Fig. 8). The western half of structural cross-section B'-B'' across the Selkirk and Purcell Mountains is based on maps and sections published by the Geological Survey of Canada. We are particularly grateful to J. E. Reesor who provided manuscript maps and cross-sections across the Valhalla complex and who reviewed the structure section. His comments induced us to modify our previous interpretations. We also wish to thank G. B. Leech, J. D. Aitken, G. G. L. Henderson and C. D. A. Dahlstrom for their comments. Responsibility for the interpretation is of course ours, but their critical review helped us to avoid extravagant interpretations in areas unfamiliar to us.

The restoration shown on Plate 12 assumes that the Alberta Plains at the east end of the section have remained geographically fixed, and that the Rocky Mountains, as well as the granite and gneiss masses of interior British Columbia, all were folded and thrust from the west, onto and over the neighbouring craton. However, geologists familiar with the Purcell and Selkirk Mountains are reluctant to assume extensive allochthoneity of gneiss domes and discordant batholiths (see also Reesor, 1965). Our own interpretation can be supported only with reference to analogs, such as the Penninic zone of the Alps.

The restoration implies that the space presently occupied by igneous rocks, yielding Jurassic, Cretaceous and Tertiary radiometric ages (Fig. 12), was occupied by Paleozoic and Mesozoic geosynclinal sequences until the end of the Cretaceous. We therefore postulate that the igneous rocks, which probably contain metamorphic equivalents of Precambrian to Jurassic sediments, were moved into their present position during Late Cretaceous and Tertiary time. In this context it is interesting to note that K-Ar radiometric ages from interior British Columbia appear to correlate with the ages of deposition of sandstone sequences in the Foothills and Plains of southern Alberta, indicating that metamorphic events coincide roughly with the deposition of coarse clastics to the east. In a much broader sense, our restoration agrees with Shaw's (1963) suggestion that the Pacific shelf edge may have been extended westward by an amount exceeding 100 miles.

There is, however, an alternative to the proposed restoration. Rather than assuming a fixed position for the Plains, it could be postulated that the inner igneous portion of the Cordillera was geographically fixed during Mesozoic and Tertiary time. According to this mechanism, the Precambrian Shield-type basement was dragged under the batholiths and gneiss domes of British Columbia, which in part would represent the remobilized part of the downfolded craton. Charlesworth (1959) expressed a similar view in proposing shield underthrusting.

Because the craton represents the main portion of the North American continent, this alternative in effect assumes continental drift during Mesozoic and Tertiary times. Such a proposition is strengthened by the observation that the formation and subsidence of the Atlantic shelf occurred during Jurassic to Tertiary time, that is, simultaneous with deformation indicated for the Western Cordillera.

Mechanically, the two alternatives appear to be similar and describe relative movements (underthrust versus overthrust). A decision is difficult and not within the scope of this paper. It must be considered however, that any synthesis of Cordilleran mountain building must also reconcile observations made on the Pacific side of this mountain belt.¹ Recent studies show that the western Cordillera is characterized by extensive thrusting towards the west involving igneous and metamorphic rocks, as well as sediments of Mesozoic and younger age. The considerable shortening observed at the surface on both sides of the Cordillera is likely to be coupled to shortening within deeper portions of the continental crust.

The palinspastic position of major Paleozoic structural elements of the Foothills and Rockies is shown on Figure 9. Because of differential décollement movement, this reconstruction is not necessarily valid for the overlying Mesozoic sequences.

Inspection of a structural map (e.g. Fig. 3) of the Foothills indicates that it is not possible to restore units along directions perpendicular to their present strike, without crowding the restored units in the west. The best palinspastic restoration results from selection of a particular arbitrary direction (roughly N.E.-S.W.) perpendicular to the overall strike of the Rocky Mountains. However, this procedure is probably basically incorrect because its application to similar mountain ranges with greater plan curvature, such as the Alps, the Carpathians and the Himalayas, would lead to sizable difficulties. Therefore, our reconstruction should be viewed as an approximation that is adequate because it is based on seismic data, but, less adequate because it uses a constructional procedure that is not fully acceptable.

SUMMARY OF STRUCTURAL EVOLUTION OF SOUTHERN CANADIAN ROCKY MOUNTAINS

A. INTRODUCTION

In discussing various aspects of the structural evolution of the Rocky Mountains several authors have suggested a succession of structural events, mainly inspired by the interrelations of folds and faults. Stratigraphic evidence has been used only to indicate that formations involved in the structural deformation give a lower time limit to the process of deformation, and most discussions revolve around these main questions:

1. Does folding precede thrust faulting?
2. Are "folded" faults formed during or after the faulting process?
3. Does deformation proceed from west to east or from east to west?
4. Does normal faulting precede or follow thrust faulting?

¹Readers are referred to "Tectonic History and Mineral Deposits of the Western Cordillera," (Canadian Inst. Mining and Metallurgy, Spec. Vol. 8, 353 p.), published after this paper was in press. Ed.

Another group of authors has attempted to reconstruct the history of the Rocky Mountains by using mainly stratigraphic and paleogeographic deductions. The bulk of the stratigraphic evidence indicates that structural deformation has proceeded from west to east, and that therefore the easternmost elements of the Cordillera were the last formed. Thus, many authors assume earlier deformation in the western eugeosynclinal belt. Documentation for such movements during Paleozoic time is extremely meagre, but there is no doubt that the western geosyncline was deformed during early Mesozoic time. Often overlooked is the fact that the type of deformation in the western eugeosynclinal belt is characterized by intrusive and metamorphic events, in contrast to the peel-thrusting style exhibited in the Rocky Mountains proper. The igneous and metamorphic events are frequently dated by radiometric methods and labeled as "orogenic" events. Problems relating to this practice have been reviewed recently by Gilluly (1966).

A few authors (e.g. Alden, 1932; Pardee, 1950) have used a geomorphic approach to unravel the late structural evolution of the Rocky Mountains. This is rather astonishing, because only the latest phase of deformation triggered the erosional processes that led to formation of a spectacular mountain range.

Any discussion of structural events faces semantic problems concerned with the questions: What is a geosyncline? What is an orogeny? What is a foredeep? Reference to our preferred usage of some terms on Figure 2, Figures 10 to 14, and Plate 13 may avoid terminological problems with the following brief summary of the sequence of structural events related to the evolution of the Southern Canadian Rocky Mountains.

B. GEOSYNCLINAL PHASE (PLATE 13)

Plates 12 and 13 illustrate the restored Rocky Mountain geosyncline. The boundary between stable platform sediments and geosynclinal sediments is arbitrarily drawn at the Foothills boundary where the carbonate skeleton is involved in thrust faulting. The boundary between eu- and miogeosyncline straddles the Purcell Mountains, which contain the first major granitic intrusives (Fig. 2).

Relations with the western extension of the eugeosyncline are obscure because the record has been destroyed by numerous granitic intrusions. What little evidence there is suggests some continuity with the eugeosynclinal sequences of Prince of Wales Islands in Alaska and the Orcas Island Group in the Strait of Georgia.

It appears that rocks of the miogeosyncline were deposited on the peneplained extension of the Canadian Shield, which had been consolidated during the Hudsonian orogeny (about 1,700 m.y. ago). We interpret this basement also to underlie the eugeosynclinal portion of the Cordilleran geosyncline. This is suggested by Precambrian age determinations reported from California (Wasserburg *et al.*, 1959) and more generally by the fact that some better known eugeosynclinal systems (e.g. Alps and Appalachians) are clearly underlain by a sialic, shield-type, pre-geosynclinal basement.

Miogeosynclinal subsidence began in Middle Proterozoic time (Helikian of Stockwell, 1965) with Purcell strata and lasted some 1,100 m. years

to the end of the Paleozoic. This enormous span of overall subsidence was interrupted by epirogenic events identified by interregional unconformities that subdivide the geosyncline into sequences (Sloss, 1963; Webb, 1964).

Westward from the stable cratonic platform of the western Plains, the stratigraphic sequences become more complete and unconformities less pronounced. The origin of these unconformities is obscure, but we believe they are due to warping of the entire North American continent related to early deformation of the Appalachian and Innuitian fold belts. There is, however, no reason to link unconformities with major mountain building events in the western Cordillera. A brief description of the stratigraphic sequences and their deformation follows.

1. *Purcell Series*

This series appears to be an unconformity-bounded sequence, and following Sloss' practice it could perhaps be designated by a name of Indian origin (e.g. Skookumchuk sequence). It represents a time span of at least 600 m.y., as indicated by "common lead" ages of about 1,300-1,400 m.y. (Lang *et al.*, 1960; Wanless *et al.*, 1958) and 700-800 m.y. indicated by K-Ar ages of granitic intrusions of probable pre-Windermere age (Leech, 1962b). During this time 30,000 to 40,000 feet of clastic and carbonate rocks were deposited in a sequence that is frequently compared with the Tertiary of the Gulf Coast. However, the apparent rate of deposition of the Purcell is much lower.

2. *Windermere Unconformity*

This unconformity has been described by Walker (1926) and Reesor (1957a), who point out that deformation was limited to the formation of gentle open folds which, however, in places led to erosion of up to 20,000 feet of Purcell rocks. A major geanticline was formed in the Purcell Mountains. Leech (1962b) suggests that the above mentioned granitic intrusion and deformation preceding deposition of the Windermere system were related. This in effect means that the Grenville orogeny affected the Rocky Mountains (East Kootenay orogeny of White, 1959). Although the evidence indicates the occurrence of a major structural event, we question the advisability of calling it an orogeny, because subsidence resumed subsequently. What little can be seen does not suggest the presence of a major folded belt with its intensive folding and widespread granitic intrusion.

3. *Sauk Sequence (Windermere-Cambrian-Lower Ordovician)*

This sequence includes more than 4,000 feet of Windermere clastic rocks, Lower Cambrian quartzites and about 16,000 feet of Middle and Upper Cambrian and Lower Ordovician carbonates. The inclusion of the Windermere system in this sequence may be debatable because it is generally assumed that the Lower Cambrian is underlain by an unconformity. However, Windermere rocks are commonly conformably overlain by the Lower Cambrian, and it appears that the Lower Cambrian onlaps a sub-Windermere erosional surface.

An anomaly occurs in the Mount Forster section (Pl. 12, sec. B'-B'') where Upper Cambrian directly overlies Windermere beds (Walker, 1926; Reesor, 1957b) and only rudiments of the Sauk sequence (about 450 feet of Upper Cambrian Jubilee and McKay) are preserved, whereas in the surrounding area the sequence is represented by thicknesses exceeding 15,000 feet (see also North, 1964). Whether this "Mount Forster high" is of local or regional significance remains a question.

4. *Middle Ordovician Unconformity*

Probably only a minor unconformity underlies the Middle Ordovician Mount Wilson Quartzite in the Southern Canadian Rocky Mountains (Norford, 1964) and there is little evidence for any significant structural deformation preceding deposition of the overlying sequence.

5. *Tipppecanoe Sequence (Ordovician-Silurian-Lower Devonian)*

Due to extensive pre-Middle Devonian erosion, the record of this sequence is poorly preserved. About 1,500 feet of Upper Ordovician-Silurian Beaverfoot-Brisco carbonates overlie the Mount Wilson Quartzite.

6. *Sub-Middle Devonian Unconformity*

Next to the sub-Windermere unconformity, this is by far the most important break in deposition in the Rocky Mountain geosyncline. The significance of this unconformity can best be grasped by a study of published subcrop maps (A.S.P.G., 1964b). Prominent subsurface features in the Western Plains such as the Peace River Arch, the Western Alberta Arch, and the land-mass of Montana had been already formed by Middle Devonian time. Uplift causing these features possibly started towards the end of the Silurian Period and lasted through Early Devonian and early Middle Devonian time, although evidence for this in the Southern Rocky Mountains is meagre. As previously mentioned, we visualize tilting and warping of large areas of the continent being related to major events in the Appalachian and Innuitian fold belts.

It is conceivable that the intrusion of the Ice River syenites (K-Ar dates between 330 and 392 m.y., Baadsgaard *et al.*, 1961; Rapson, 1963) is related to deformation preceding deposition of the Middle Devonian-Mississippian sequence. Here again however, we are reluctant to equate such an intrusion with the occurrence of a major orogenic event. Clearly, in the Southern Canadian Rocky Mountains there is no evidence for the existence of such an event, with its associated intensive folding, faulting and extensive granitic intrusion.

7. *Kaskaskia Sequence (Middle Devonian, Upper Devonian, Mississippian and Pennsylvanian)*

This sequence contains all the major Paleozoic hydrocarbon accumulations of western Canada. A gradual transgression began with

red beds, clastic rocks and evaporites of the Middle Devonian Elk Point Group, followed by the overall transgressive reefal sequences of the Middle and Upper Devonian. The latter contains a minor erosional unconformity at the base of the Fammenian (McLaren and Mountjoy, 1962). During Mississippian time the sequence changed to a major regressive cycle, culminating with siltstones, sandstones and carbonates during Chester and Early and Middle Pennsylvanian time, which concluded the geosynclinal phase.

In British Columbia, Pennsylvanian and Permian beds unconformably overlie intensely folded and metamorphosed rocks of the Shuswap complex and related formations, a relationship which led White (1959) to postulate the Cariboo orogeny. This deformation could be an extension of the Antler orogenic zone of Nevada. It suggests the end of the geosynclinal regime and the beginning of orogenic movements heralding formation of the Rocky Mountains. However, evidence in southern British Columbia for such an orogeny is limited and, until more information becomes available, we prefer not to emphasize its importance.

To sum up, it can be stated that geosynclinal sedimentation persisted over a period exceeding 1,100 m. years. We recognize two major breaks, the first preceding deposition of the Windermere system, and the second preceding the Middle Devonian. In our opinion neither break can be viewed as manifesting true orogenic disturbances because in the Rocky Mountains they are not related to the full development of a folded belt. More likely, the unconformities are related to warping of the North American continent in response to orogenic phases in the Grenville, Appalachian and/or Innuitian systems. Only towards the very end of the geosynclinal phase (i.e. Pennsylvanian) can we observe meagre indications of orogenic activity in interior British Columbia.

C. PERMIAN TO MIDDLE JURASSIC WEDGE OF MULTIPLE UNCONFORMITIES (FIGURE 10)

In discussing stratigraphic data from a structural point of view, it is often convenient to differentiate periods and areas of increased tectonic activity from periods and areas of tectonic quiescence. Such separation leads to a simple subdivision of a stratigraphic time interval as illustrated on Figure 10. The time interval A-A' is represented by the extremes of a complete hiatus and the complete sequence. Between the two is a transition zone of partial sequences and hiati, which we designate as a "wedge of multiple unconformities." The term refers to the phenomenon of one major unconformity branching into wedges of lesser or short stratigraphic sequences and minor unconformities. On a map, the zero isopachs of the short sequences, which in most cases represent the intersection of two unconformities, will tend to be regionally subparallel if the warping or tilting movements systematically affected the same area and are of related origin. Note also that stratigraphic units predating the wedge of multiple unconformities subcrop in the realm of the complete hiatus. Depending on the nature of local uplifts these subcrops are not necessarily parallel to the strike of the adjacent fold belt.

This wedge of multiple unconformities may be viewed as the transition of an intracratonic hiatus into a geosynclinal sequence which lasted for about 100 m. years.

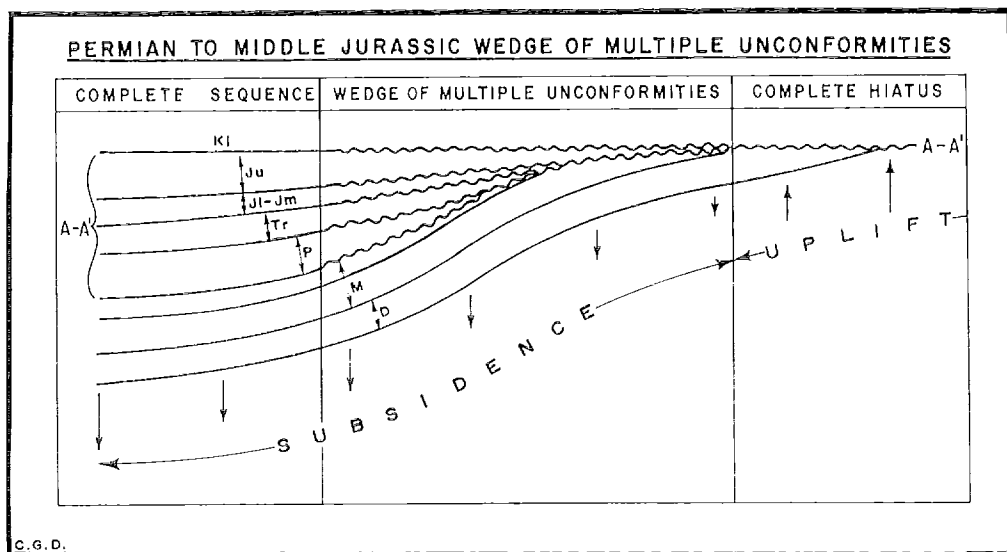


FIG. 10.—Permian to Middle Jurassic wedge of multiple unconformities.

The interval from Permian to Jurassic is represented by a wedge of multiple unconformities. In the Alberta Plains, the Lower Cretaceous laps on to a sub-Cretaceous subcrop. In a westerly direction this unconformity branches out and separates, respectively, relatively thin Permian, Triassic and Lower and Middle Jurassic beds. This suggests a tilting movement, with uplift in the east and subsidence in the west, a concept corroborated by evidence for an eastern source of the sandstones found in the Triassic and Lower-Middle Jurassic sequences.

In the interior of British Columbia, about 20,000 feet of Permian Cache Creek beds occur, consisting of basal greenstones, overlying cherts, argillites and tuffs, and an upper section of carbonates. In places this succession, which may be of Pennsylvanian age, is reported (White, 1959) to unconformably overlie older folded and metamorphosed beds. The intrusion of ultramafics characterizes the Triassic, and during Triassic and Jurassic time thick marine and continental volcanic sequences, in places exceeding 20,000 feet, were deposited in basins separated by major structural highs, which in turn were the source for clastic rocks deposited in the adjacent basins (see also Wheeler, 1965).

In summary, the Permian to Middle Jurassic interval marks the beginning of genuine orogenic deformation in the eugeosyncline, with the intrusion of ultramafics and granites, metamorphism, and the formation of land masses that rimmed epi-eugeosynclinal basins. However, the breakup of the geosyncline had not yet directly affected sedimentation in the Rocky Mountains, although it caused westward tilting.

D. MIGRATING FOREDEEP (FIGURE 11)

During this phase and for the first time, an enormous influx of clastic material derived from the west was deposited as a clastic wedge over the miogeosynclinal sequence of the Rocky Mountains and the stable platform of the Plains (exogeosyncline of Kay, 1951; clastic wedge of King, 1959).

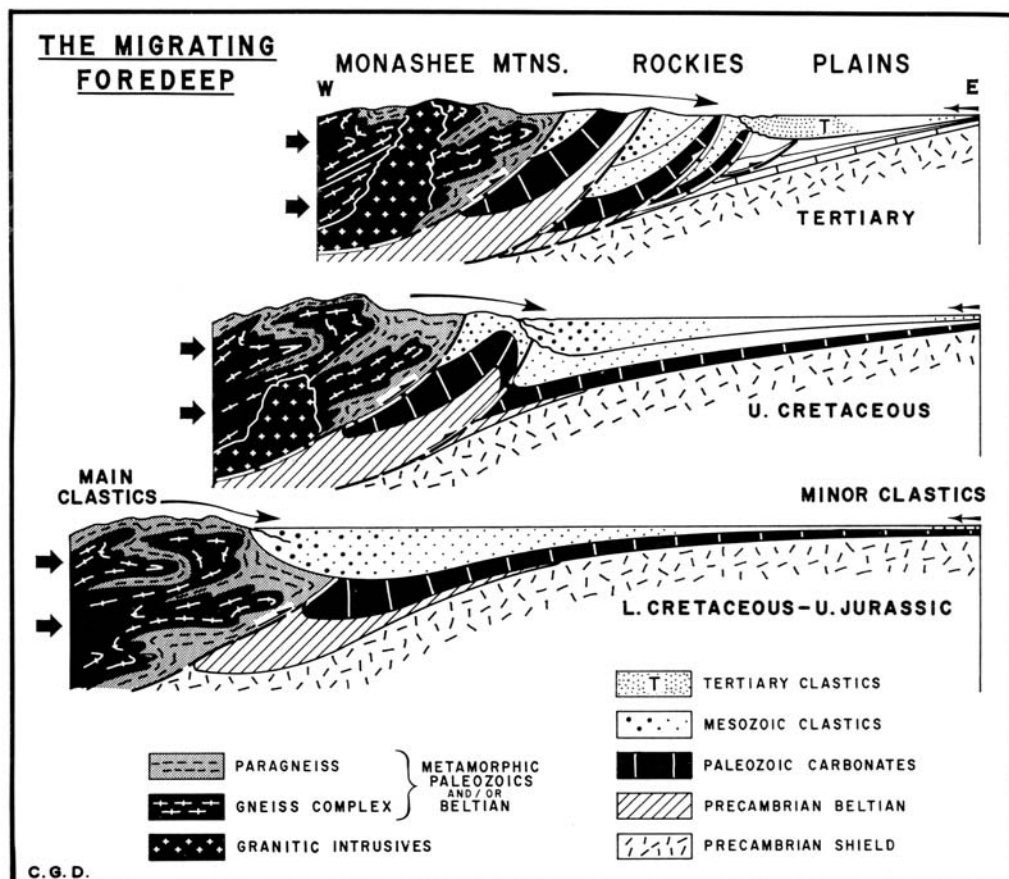


FIG. 11—The migrating foredeep.

1. Upper Jurassic Kootenay-Nikanassin transition sequence

This sequence can be viewed as part of the preceding wedge of multiple unconformities because it wedges out in the Plains and appears to be bounded by two unconformities in the Foothills and Plains. In the Front Ranges however, contact between Kootenay and Lower Cretaceous Blairmore appears to be transitional. More important than this transitional contact, is the appearance of thick sequences of coarse clastic rocks (up to 4,000 feet in the Fernie area) clearly derived from a western source area (Newmarch, 1953; Springer *et al.*, 1964; Rapson, 1964).

2. Lower Cretaceous

This is an essentially transgressive sequence composed mainly of alluvial and deltaic coarse clastic sediments derived from the west. Published maps suggest depocentres in the form of coalescing fans which shifted along the mountain front. Interpretations of multiple minor transgressions and regressions are probably due to failure to recognize lateral shift of these depocentres. In the

southern Foothills and Front Ranges, the top of the Lower Cretaceous is marked by the Crowsnest volcanics, a sequence of volcanic breccias, flows, and tuff beds yielding a K-Ar age determination of 96 m.y. (Folinsbee *et al.*, 1957). Nearby alkaline intrusives of the Flathead area yield ages of between 61 and 126 m.y. (Gordy and Edwards, 1962; Leech *et al.*, 1963). The igneous bodies in this area are considered to be allochthonous and the intrusions are not associated with major contemporaneous dislocations in the Flathead area.

3. *Upper Cretaceous*

The base of the Upper Cretaceous marks the climax of the transgression that started in late Jurassic time and roughly coincides with the worldwide Cenomanian transgression. Only during the Late Cretaceous (Campanian-Maestrichtian) do we recognize a widespread regression. Here again we visualize a major source area in the west, as shown by the occurrence of thick sequences (exceeding 5,000 feet) of clastic rocks in the Foothills and Front Ranges. During early Late Cretaceous time minor coarse clastic rocks were deposited in the area, although an important depocentre (Dunvegan) occurred in northeastern British Columbia. Later, the deposition of sandstones resumed in the southern Foothills, as shown by thick alluvial sequences of Belly River and Edmonton strata.

4. *Paleocene*

Although Paleocene clastic rocks could be grouped with the Upper Cretaceous because they mark the climax of the regressive phase, they deserve special attention in a discussion dating structural events. Paleocene beds are involved in the deformation of the Foothills, e.g. the Willow Creek Formation in the southern Foothills (Douglas, 1950), Paleocene beds in the Nordegg area (A.S.P.G., 1958a), and the Foothills east of Jasper National Park (Lang, 1947; Irish, 1965). In the southern Foothills, Douglas (1950) described an erosional unconformity separating Willow Creek (uppermost Cretaceous-Paleocene) from the Porcupine Hills Formation (Paleocene). The latter does not appear to be involved in the Foothills deformation. The Porcupine Hills Formation is presently correlated with the Paleocene Paskapoo Formation, which farther north is involved in deformation (Tozer, 1956; Taylor *et al.*, 1964). Should the Porcupine Hills Formation be younger than the Foothills Paskapoo, one could fix the formation of the easternmost Foothills as an intra-Paleocene event, as suggested by Bossort (1957). Such speculations, however, can be substantiated only by detailed paleontologic and palynologic correlations. In any event, the Paskapoo marks the end of the foredeep phase.

Deposition of the Mesozoic clastic wedge of the Rocky Mountains reflects orogenic, metamorphic and igneous events in interior British Columbia. Figure 12 shows a plot of age determinations from southeast British Columbia by Gabrielse and Reesor (1964) and another plot of the same data by Ross (1966). Schematically sketched are the major sandstone-

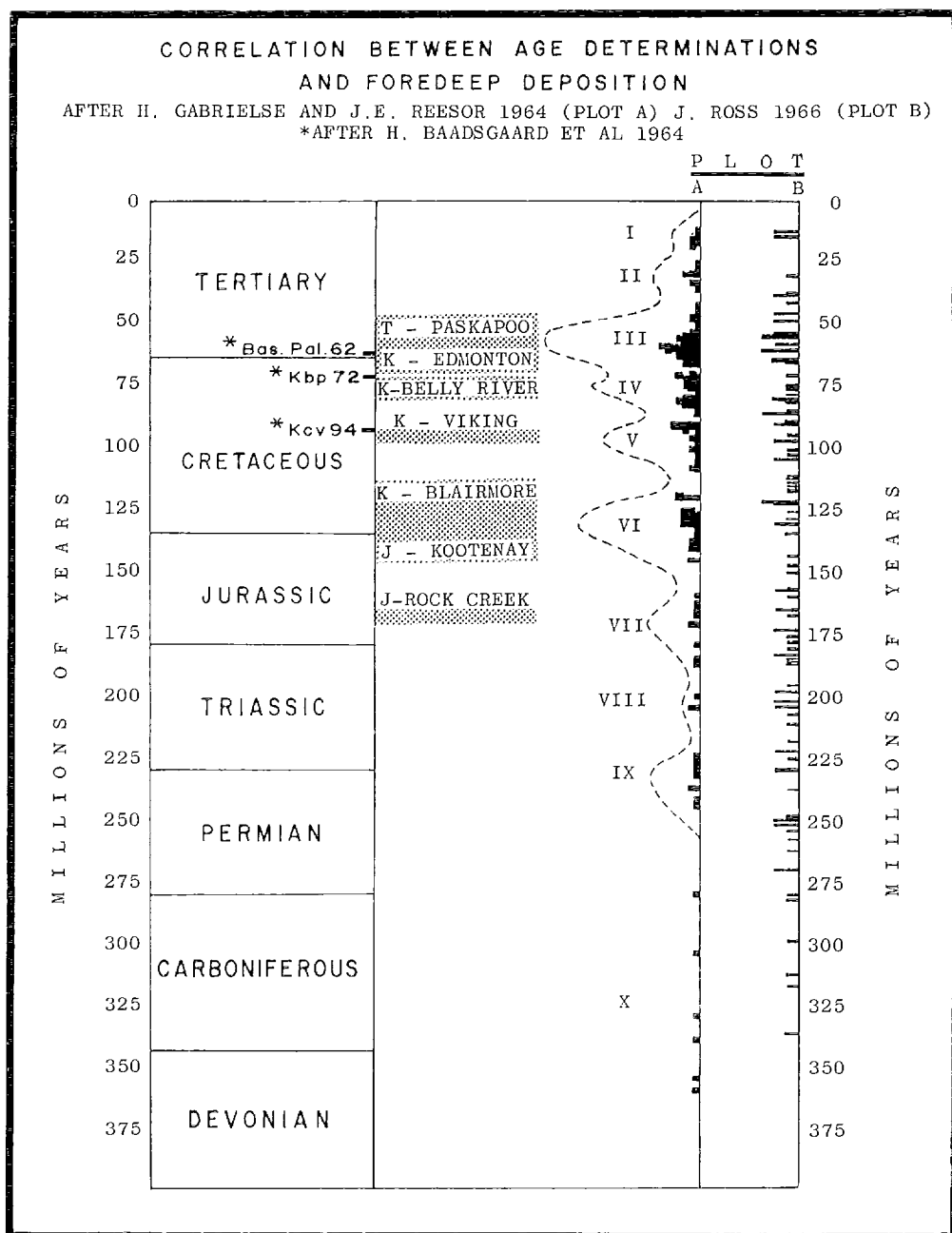


FIG. 12.—Correlation between age determinations and foredeep deposition.

conglomerate accumulations of the Foothills and Plains and their calibration by the age determinations of Baadsgaard *et al.* (1964). We are aware of the pitfalls in the use of radiometric dates, but are nevertheless intrigued by the apparent correlation of metamorphic-igneous events in British Columbia with the occurrence of coarse clastic rocks in the adjacent foredeep.

The specific nature of our correlation may be obscure and debatable. We feel, however, that clastics of the foredeep were derived largely from highlands in the west formed as a consequence of granitic intrusion and metamorphism (Nelson uplift of Rudkin, 1964; see also Wheeler, 1965). Whether this "high" remained autochthonous or moved eastward with the deformation of the Rockies has been discussed previously. The occurrence of igneous pebbles yielding K-Ar whole rock ages from 113 to 174 m.y. from the Lower Cretaceous (Albian) McDougall-Segur conglomerate further supports this concept (Norris *et al.*, 1965).

On a palinspastic base, the main depocentres of the coarse clastic rocks appear to have migrated eastward, i.e. the main axis of the foredeep migrated eastward. Thick, coarse clastic material of the Kootenay Formation occurs in the Front Ranges, whereas in the more easterly Foothills, coarse clastic rocks of the Lower Cretaceous overlie the thin distal end of the underlying Kootenay Formation. Similarly thick sandstone sequences of the Upper Cretaceous Belly River and Edmonton Formations overlie the thin distal end of the Lower Cretaceous foredeep.

On Figure 11, the westward side of the younger foredeep is shown unconformably onlapping its deformed predecessor. There is no positive support for this but we prefer this view because it avoids the extreme postulate, that the Rocky Mountains all were formed during one short phase bracketed between the end of the Paleocene and early Oligocene. We believe the Foothills were deformed during Eocene time and, because they are linked with a common sole fault to the Front Ranges and Main Ranges, that deformation also affected these units. It appears more reasonable to assume that deformation of the Front Ranges followed deposition of the Upper Cretaceous, and that the Main Ranges were conceivably deformed much earlier, perhaps after deposition of the Lower Cretaceous.

In summation, a foredeep sequence developed in the Rocky Mountains during most of Mesozoic time. The clastic rocks were derived from Paleozoic and metamorphic rocks outcropping in highlands in central British Columbia. As deformation progressed, some of these clastic rocks were reworked into new and younger foredeeps. The axis of the asymmetrical basins migrated eastward. The underlying basement of the Rocky Mountains kept subsiding during this period.

Our interpretation of the sequence of structural events is similar to that proposed by Armstrong and Oriel (1965) for the Idaho-Wyoming thrust belt, a province quite analogous to, and on regional strike with, the Alberta fold belt. These authors interpret onlap relations of specific Mesozoic foredeep sequences on faults, and a progression of deformation from west to east.

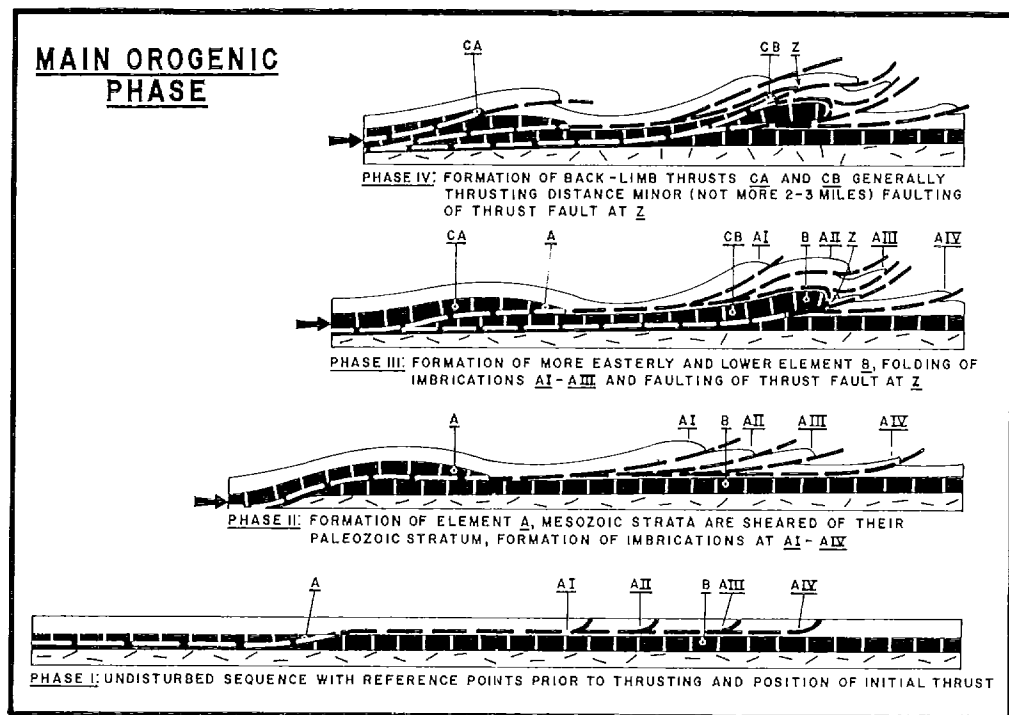
E. MAIN OROGENIC PHASE (FIGURE 13)

We suggested that during Mesozoic time deformation proceeded from west to east, concomitantly with the formation and migration of a fore-deep. It may then seem to be contradictory to speak of any "main" phase of deformation. Inspection of section B'-B'' (Pl. 12) shows that about 25 miles of shortening occurred in the Foothills after Paleocene time. To the west, and at depth, this amount is carried by the same group of sole faults that carried the earlier displacements of the Front and Main Ranges. These 25 miles represent approximately 25 per cent of the total amount of shortening of the Rocky Mountains that occurred between Paleocene and Late Eocene-Oligocene time. The remaining 75 per cent all could have occurred during the same time, but we prefer to assume that it occurred during Mesozoic time. The main orogenic phase is thus taken to mean the formation of the Foothills.

Within this phase, the sequence of deformation can be unraveled only by structural deductions. We prefer the following sequence (Fig. 13):

Preliminary Phase: Gentle folding. This has been demonstrated in a few cases (Henderson and Dahlstrom, 1959; Mountjoy, 1960), but we believe that folding does not necessarily precede the formation of thrust faults and therefore suggest that this phenomenon is of minor significance.

Phase 1: Step-like faulting as illustrated by Douglas (1950) and shown on Figure 13, or straight low-angle faulting. All transitions



C. G. D.

FIG. 13.—Main orogenic phase.

between the two types are conceivable. The regional distribution of the original fault traces can be seen on the restoration (Pl. 12).

Phase 2: Overthrusting and, in the case of step-like faulting, simultaneous warping and some drag folding at the leading edge of the thrust sheet. In the Foothills this process frequently caused the Mesozoic formation underlying the thrust sheet to be sheared off its Paleozoic base.

Phase 3: Folding of thrust sheets and imbrications formed during Phase 2, by an underlying element formed later, and in the same manner as the previously formed overlying sheet. The displacement of the more easterly lower sheet is generally less than that of the upper sheet. This phase leads to the formation of folded faults (e.g., Scott, 1951; Douglas, 1950, and others). The same phase also leads to the formation of faulted listric thrusts as illustrated on Figure 6.

Phase 4: Back-limb thrusting as suggested by Douglas (1950). These thrusts, which are associated with underlying highs, are in our opinion of a minor magnitude, and have minor displacements.

In conclusion, we interpret that deformation of the Eastern Cordillera proceeded from west to east, that is, that the higher and more westerly thrust sheets were formed prior to the lower and more easterly elements. As in the case of back-limb thrusting, we can conceive of minor exceptions. In many cases, where a reversal of this overall sequence of events is indicated, we believe that we are dealing with listric thrusts that have been faulted by deeper, more easterly and younger faults (Fig. 6).

F. MORPHOGENIC UPLIFT (FIGURE 14)

This last phase of deformation lead to formation of the present-day mountains (Fig. 14). It involved a large regional uplift of the whole of western Canada, with intensive uplifting in the Rockies and simultaneous formation of intramontane basins by downfaulting along listric normal faults. In the Plains, uplift decreased in an easterly direction as indicated by the position of young terrace systems. During all preceding phases of deformation the basement underlying the Rockies was subsiding and tilted more and more to the west. The morphogenic uplift thus was a readjustment movement which, however, was not nearly sufficient to flatten the westerly dip of the basement. Alden (1932), Russell (1951, 1954), Pardee (1950) and Cook (1960) have described phenomena related to this phase. Most supporting observations have been made in Montana and farther south.

Cook (1960) rightly points out that mountains formed during and before the main orogenic phase (Laramide Revolution) usually had their bases at elevations little higher than sea level. It appears that both mountains and plains were nearly base-levelled after deposition of the Upper Eocene and Oligocene gravels (Swift Current, Cypress Hills of Saskatchewan). These gravels contain components of Beltian sediments which probably originated from northwestern Montana (Vanhof, 1965).

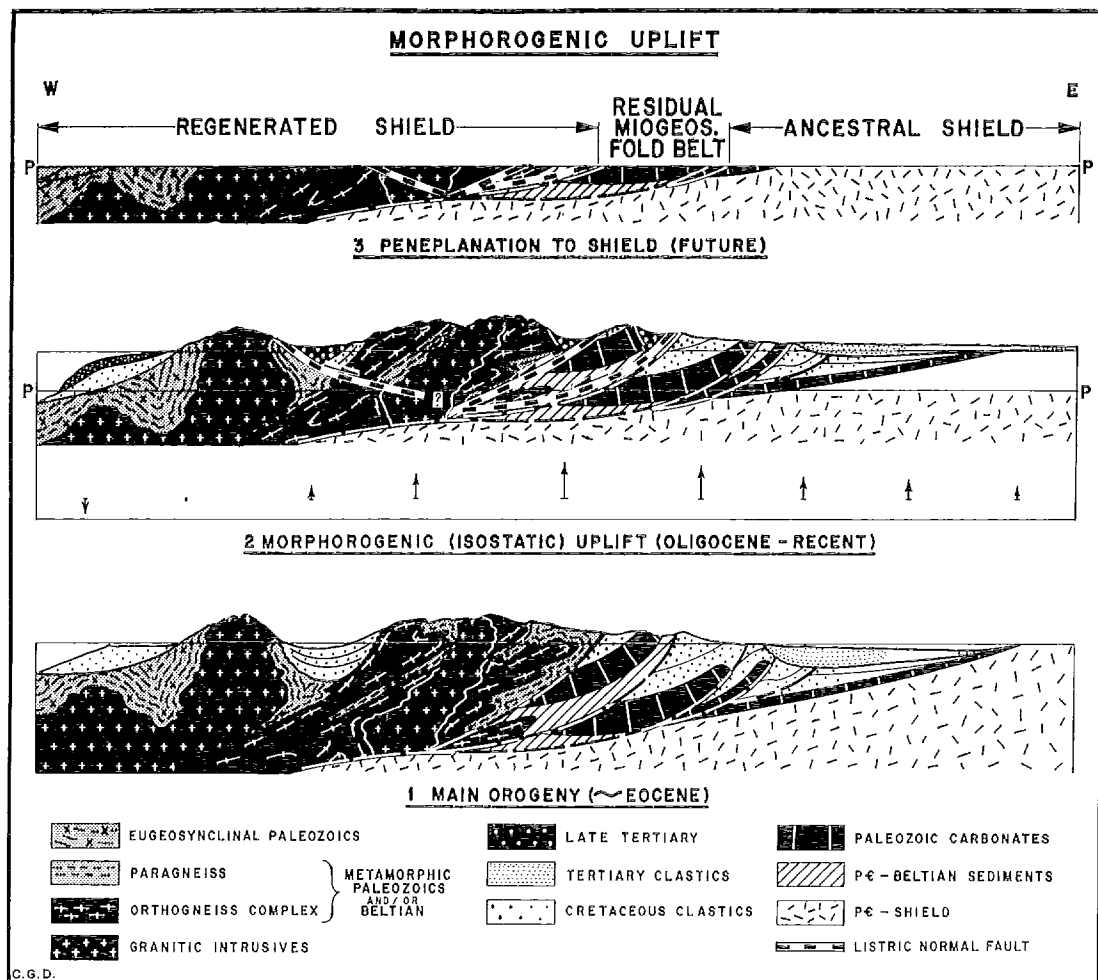


FIG. 14.—Morphorogenic uplift.

Alden (1932, p. 6) projects the Cypress Plain into the mountains of Glacier National Park, assuming a gradient similar to the one exhibited by underlying, better-preserved terraces. "Such a gradient rising in a westerly direction from the head of the Cypress Hills at about 4,850 feet above sea level would reach the mountains at about 8,300 feet—that is, about 750 feet below the crest of the Chief Mountain—and, if continued westward at 100 feet to the mile, would overtop all but the highest peaks east of and along the Continental Divide in Glacier National Park." With reference to the later physiographic history, the same author states: "The development of the Cypress Plain was followed by differential uplift and dissection to depths ranging from 700 to 1,500 feet on the plains and possibly 2,000 to 3,000 feet in the mountains."; and with respect to recent and late Pleistocene uplift, "Certain phenomena [described in detail in Alden's publication] suggest that the regional uplifts continued through Pleistocene into Recent time. The depths of Recent stream erosion range from 50 to 200 feet, and in general the streams appear to be still actively cutting downward."

All this means that since Oligocene time the mountains have been uplifted more than the Plains and that the total amount of differential uplift is considerable. Seismic data show that during this uplift the Rocky Mountains and Plains were linked by a common westward dipping basement that remained intact. The formation of the Rocky Mountain Trench and possibly other valleys and intramontane basins (e.g. Flat-head basin) are related to the same deformation, being related to rotational movement along essentially post-Oligocene, listric normal faults.

The timing and morphologic expression of the process is best summarized by quoting from Pardee's (1950) abstract which reports on the formation of basins in northwestern Montana:

"By Oligocene time the region had been generally reduced to a surface of moderate to slight relief. During the Oligocene and Miocene the drainage became sluggish or ponded . . . and in these [areas] accumulated the Tertiary 'lake beds' . . . In the late Miocene or early Pliocene the surface comprised areas of older rocks that . . . had been eroded to slight or moderate relief; and areas of the 'lake beds' that formed gently sloping or level plains . . . this surface is called . . . the Late Tertiary peneplain."

"Further leveling . . . was interrupted by a general re-elevation of the region accompanied by greatly accelerated local crustal movements that relatively elevated the present mountains. These movements continued intermittently and with decreasing intensity through the Pliocene and, except for small displacements on some of the faults as late as the Recent epoch, ceased in early or middle Pleistocene. They are thought to constitute a distinct late stage of the Cenozoic mountain building."

"During the halt in the uplift of the mountains, wide stream valleys as much as 1500 feet deep were eroded in the elevated and deformed peneplain. In the basins during this pause, called the Old Valley cycle, the 'lake beds' were reduced to gently sloping plains collectively referred to as No. 1 Bench. With renewed uplift the more vigorous streams deepened their channels across the mountain blocks as fast as the surface rose and thus excavated narrow inner valleys or gorges. In this, the Present cycle of erosion, No. 1 Bench of the 'lake bed' areas was, in most of the basins, dissected to a series of terraces."

We believe that this description applies also to the Southern Canadian Rockies, where the morphology and Tertiary-Pleistocene stratigraphy have not yet been studied in detail. The effect of this last phase on the morphology and drainage history of the Cordillera must have been profound. Our restoration shows that during Mesozoic and early Tertiary time, the drainage pattern of the Central Cordillera of interior British Columbia was oriented eastward toward the foredeep, a hypothesis that might be supported by a regional morphologic study finding remnants of late Cretaceous and Tertiary stream systems with drainage direction towards the Plains. The present drainage to the Pacific Ocean and the extensive longitudinally oriented valleys probably originated during the late morphogenetic uplift with its associated systems of listric normal faults.

Figure 14 also shows a speculative interpretation that assumes the present Rockies will eventually be peneplained to a much deeper level

(marked P-P). We then would see an ancestral shield, a regenerated portion of the shield, and a remnant fold belt in juxtaposition. This concept may aid in understanding tectonic maps of the Canadian Shield (e.g. Stockwell, 1965), where we observe the juxtaposition of metamorphic provinces of different age, which in places are separated by remnants of fold belts of relatively more miogeosynclinal aspect (e.g. Scheferville area or Belcher Islands).

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C. *Subject Index of Selected References* (in approximate chronologic order)

REGIONAL SECTION A-A'

MacKay (1943); Erdman (1946, 1950); Link (1949); Douglas (1956); A.S.P.G. (1958a); Shaw (1963).

REGIONAL SECTION B-B'

McConnell (1887); Hume (1932, 1936, 1941a); Evans (1930); Beach (1943); Clark (1948); A.S.P.G. (1954, 1956, 1959, 1960); North and Henderson (1954a); Fox (1959); Wright-Broughton (1960); Fitzgerald (1962).

REGIONAL SECTION B'-B'' WESTERN ROCKY MOUNTAINS AND BRITISH COLUMBIA ONLY

Daly (1915); Walker (1926); Evans (1933); Cairnes (1934); Henderson (1954a); North and Henderson (1954b); A.S.P.G. (1954, 1956, 1960, 1962b); Jones (1959); Reesor (1957b, 1965); Little (1960); Wheeler (1961, 1965).

REGIONAL SECTION C-C'

Hume (1931, 1938, 1941b); Hage (1942, 1943b, 1946); Gallup (1954); A.S.P.G. (1953, 1959, 1961); Link (1953); Penner (1957); Douglas (1958); Keating (1966).

REGIONAL SECTIONS E-E' AND F-F'

Dawson (1875, 1886); Willis (1902); Daly (1912); Clapp (1932); Hume (1933); Billings (1938); Hage (1943a); Pardee (1950); Douglas (1951, 1952); A.S.P.G. (1953, 1957, 1962a, 1964a); Erdman *et al.* (1953); Clark (1954, 1964); Gallup (1955); Ross (1959); Price (1958, 1962, 1965); Fox (1959); Robertson (1963); Jones (1964); Oswald (1964); Russell (1964); Keating (1966).

ROCKY MOUNTAIN TRENCH AND SECTION G-G'

Rice (1937); North and Henderson (1954b); Holland (1959); Leech (1959, 1960, 1962, 1965); Thompson (1962); A.S.P.G. (1962a); Lamb and Smith (1962); Crickmay (1964).

STRUCTURAL EVOLUTION MAINLY BASED ON STRUCTURAL CONSIDERATIONS

McConnell (1887); Willis (1902); Daly (1912); Hume (1933, 1941b, 1957); Hake *et al.* (1942); Hage (1942); Douglas (1950, 1958); Erdman (1950); Clark (1954); Gallup (1954, 1955); Link (1953); Scott (1953); Henderson and Dahlstrom (1959); Mountjoy (1960); Dahlstrom *et al.* (1962); Oswald (1964).

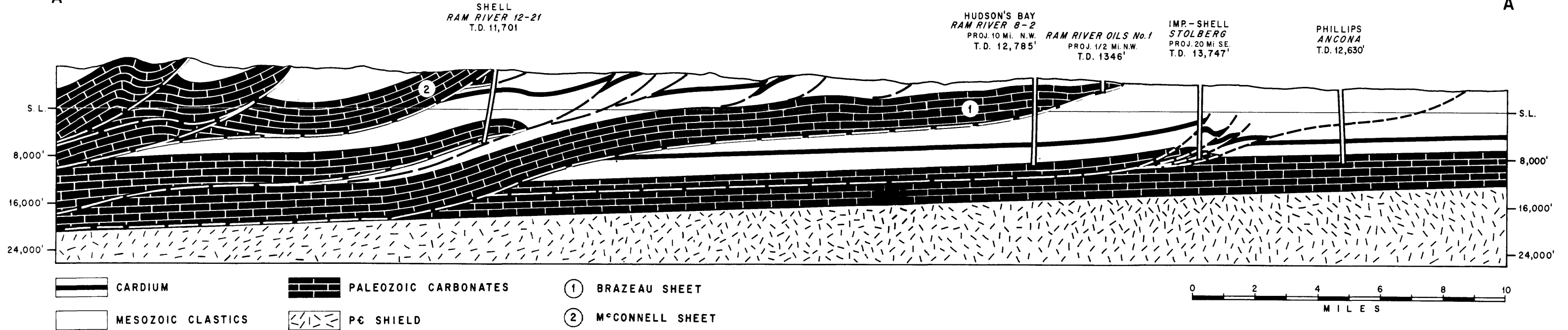
STRUCTURAL EVOLUTION BASED ON STRATIGRAPHIC AND MORPHOLOGIC CONSIDERATIONS

Daly (1912); Warren (1951); Pardee (1950); Russell (1951, 1954); Webb (1951, 1964); Alden (1932); Reesor (1957a); Warren and Stelck (1958); White (1959); Patterson and Storey (1960); Gussow (1960); A.S.P.G. (1964b); Wheeler (1965).

RAM RIVER — STOLBERG

A

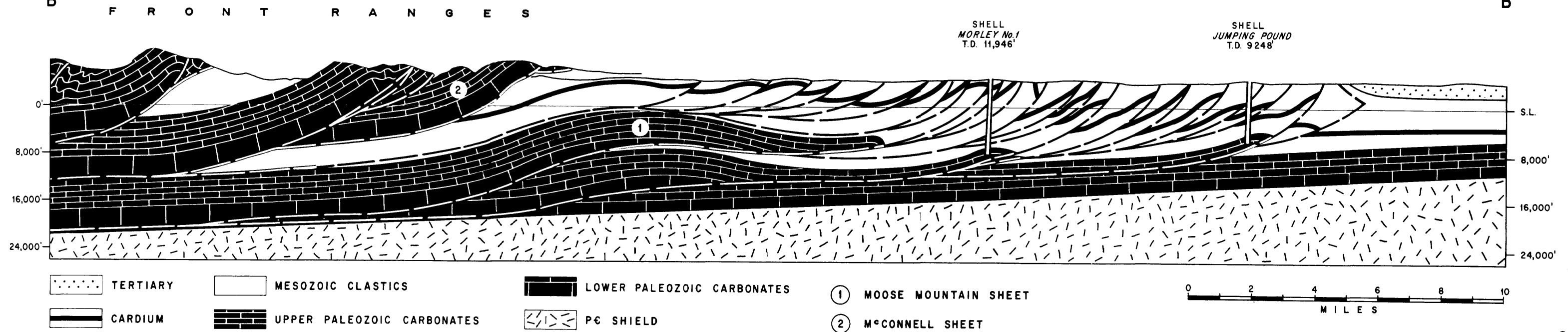
A'

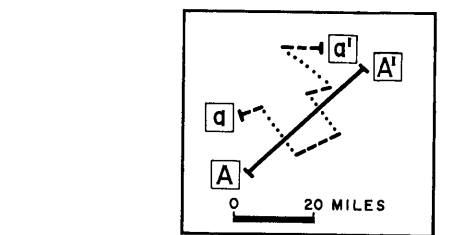
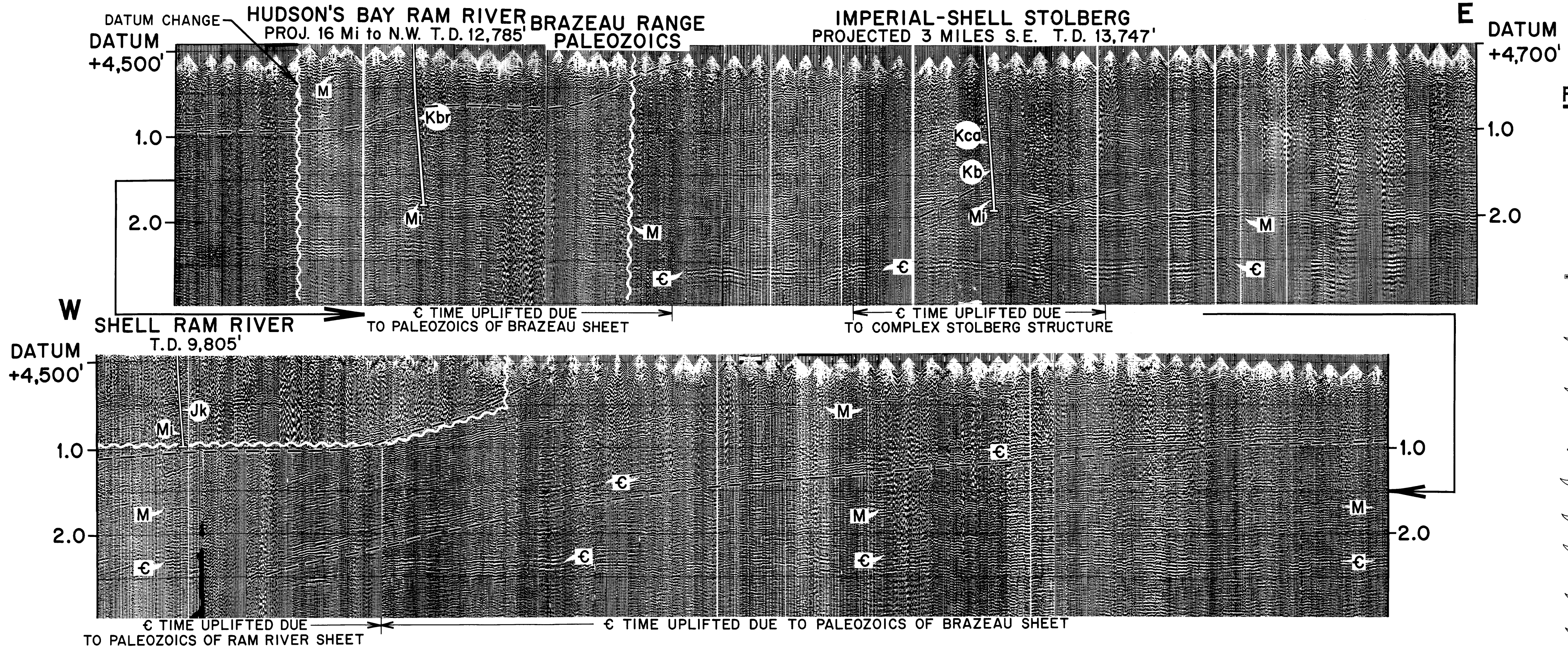


BOW VALLEY

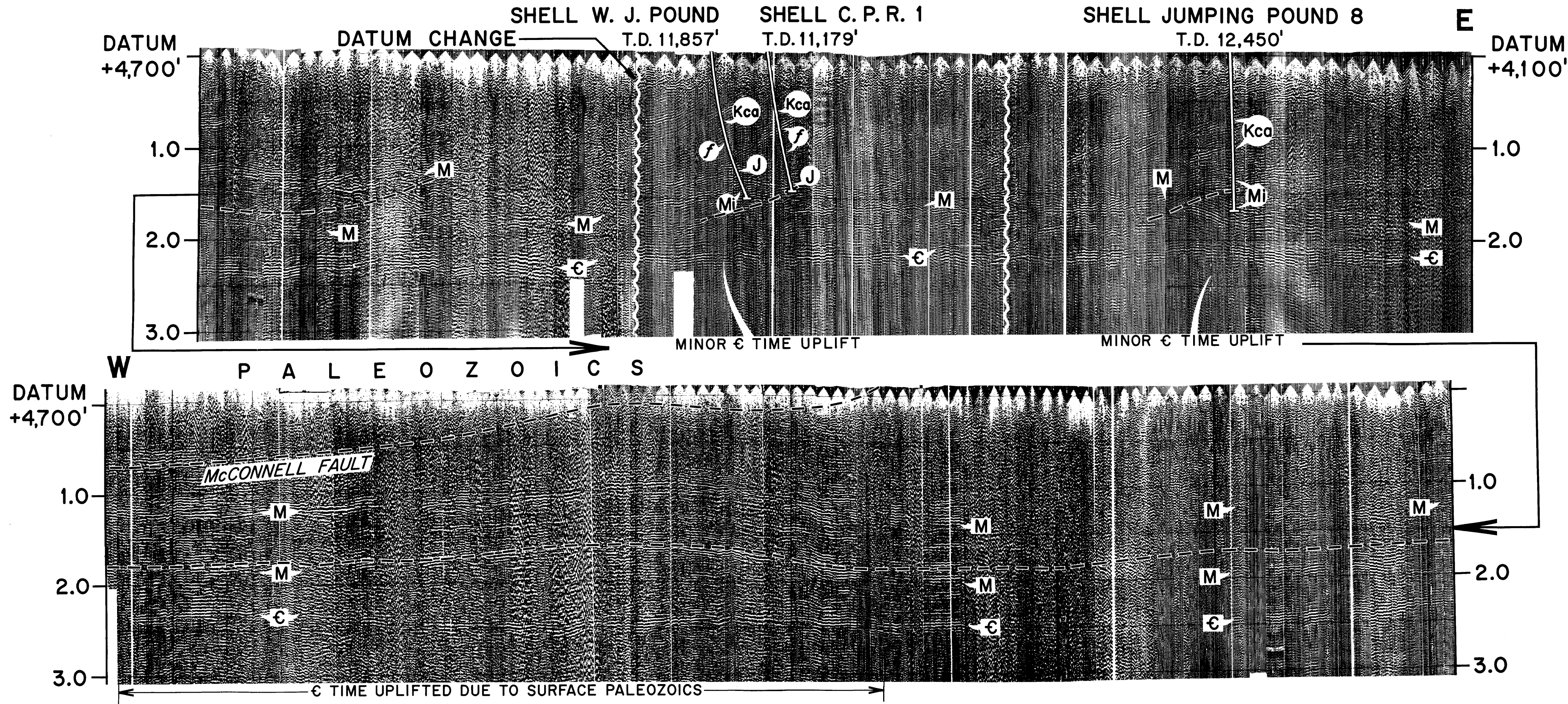
B

B'



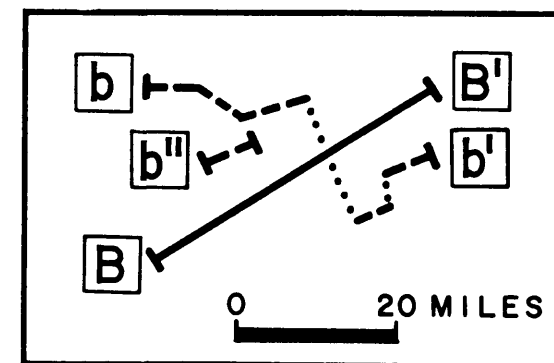
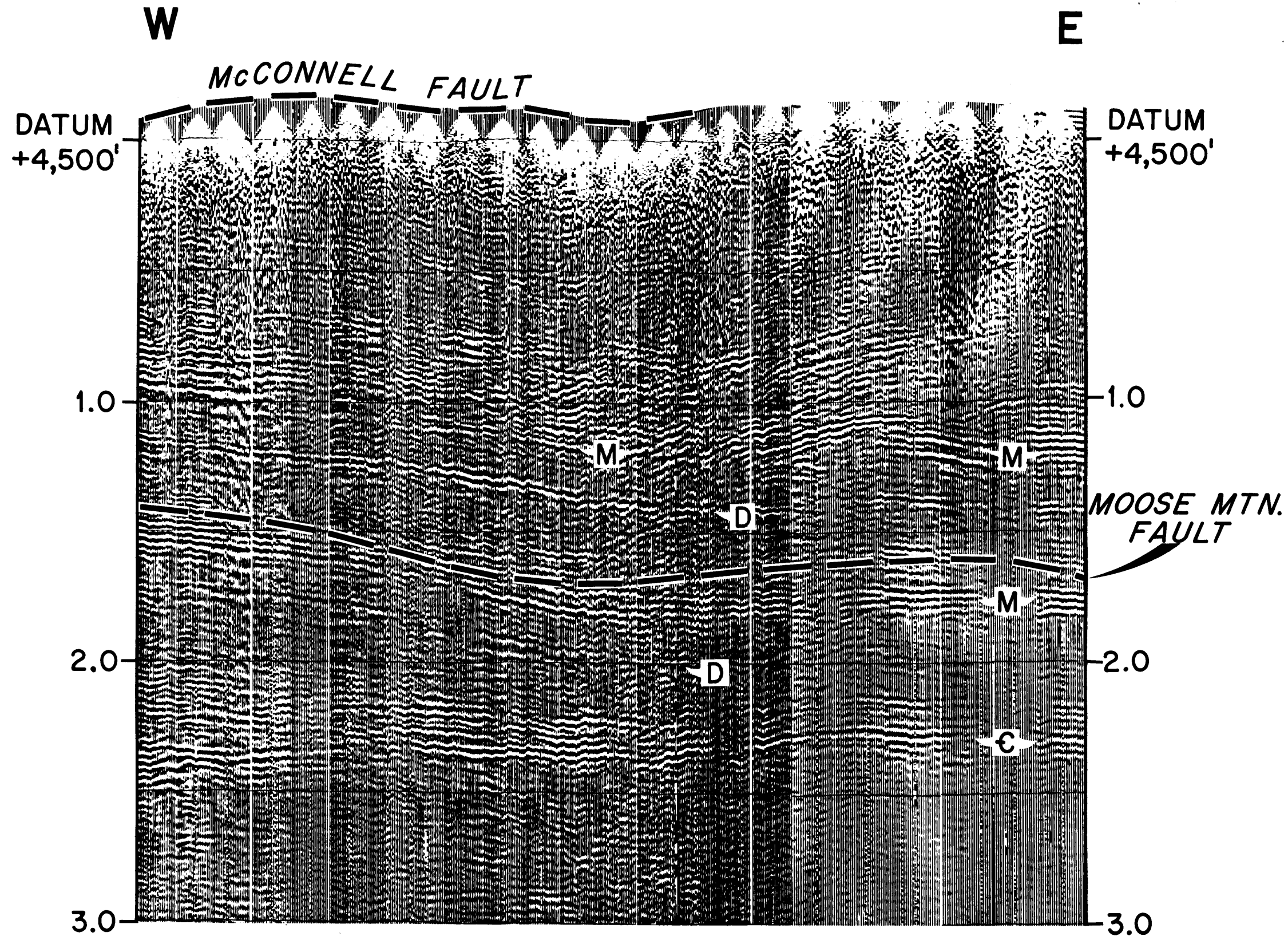


- SPICE LINE**
- TIME SCALE IN SECONDS**
- FAULT**
- REFLECTION EVENTS**
- BASAL MESOZOIC "NEAR MISSISSIPPIAN"**
 - CAMBRIAN "NEAR BASEMENT"**
- WELL TOPS**
- CRETACEOUS -CARDIUM**
 - BLAIRMORE**
 - BELLY RIVER**
 - JURASSIC -KOOTENAY**
 - MISSISSIPPIAN**



SECTION **b''**

SOUTH BRANCH GHOST RIVER

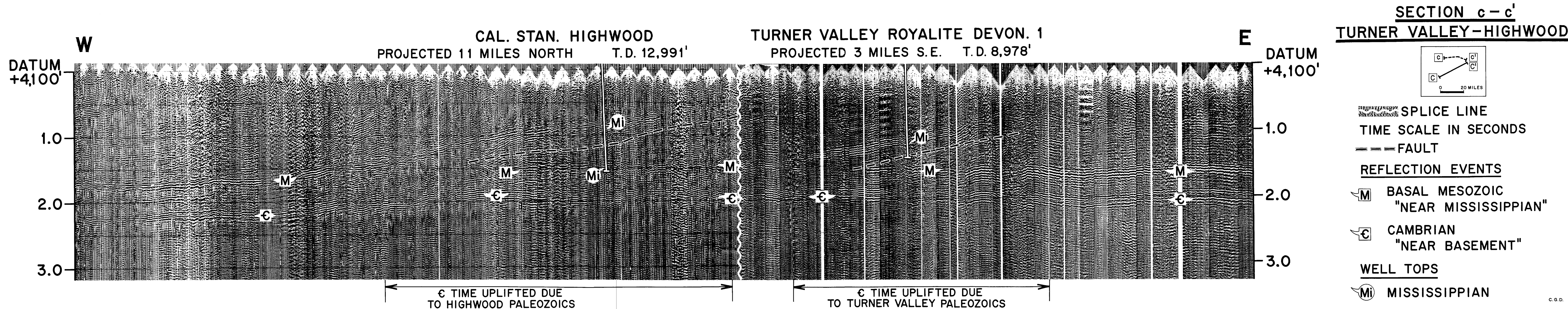


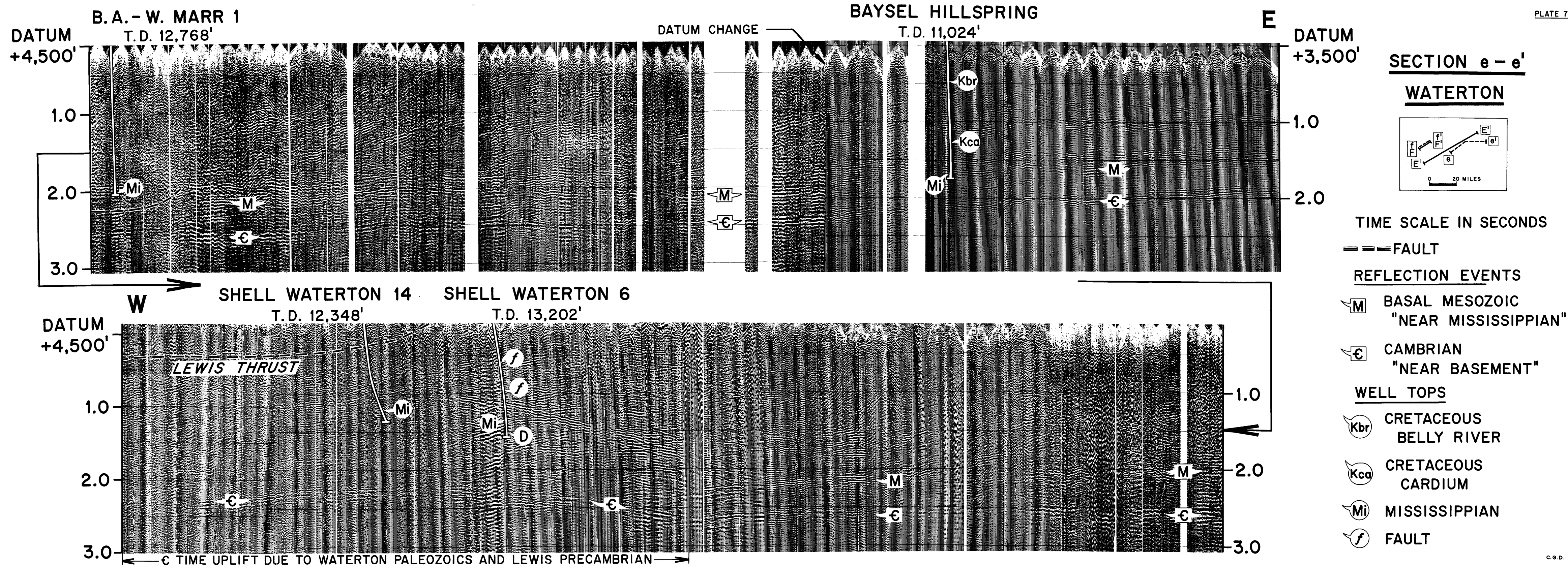
TIME SCALE IN SECONDS

REFLECTION EVENTS

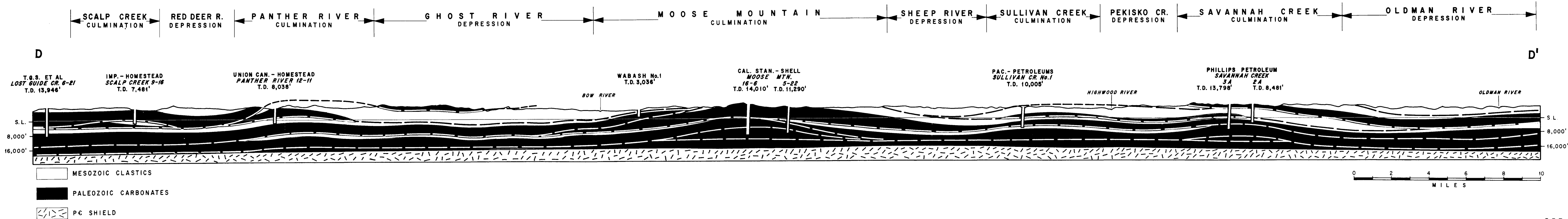
- ↖ **M** BASAL MESOZOIC
"NEAR MISSISSIPPIAN"
- ↖ **D** DEVONIAN
- ↖ **C** CAMBRIAN
"NEAR BASEMENT"







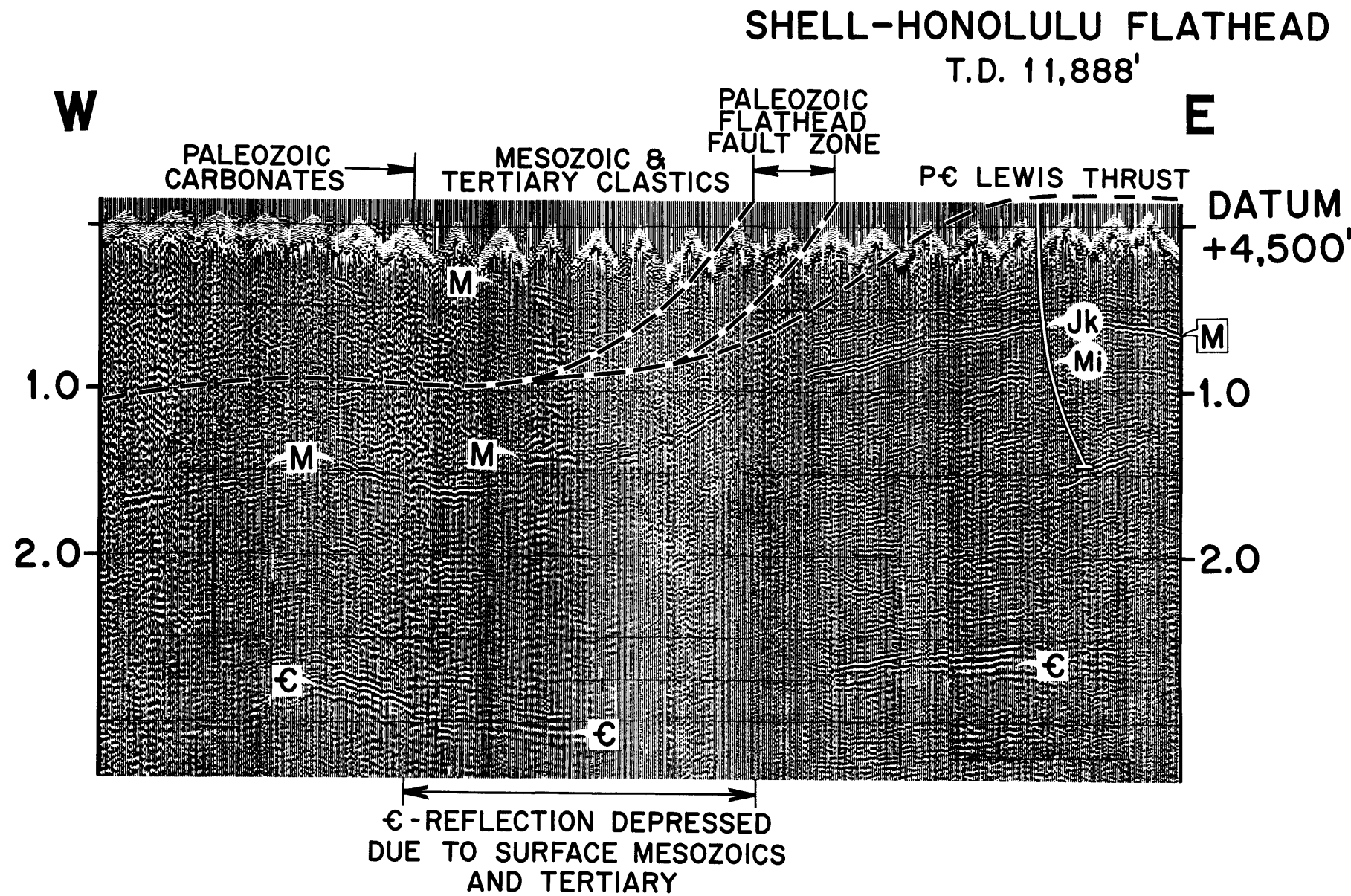
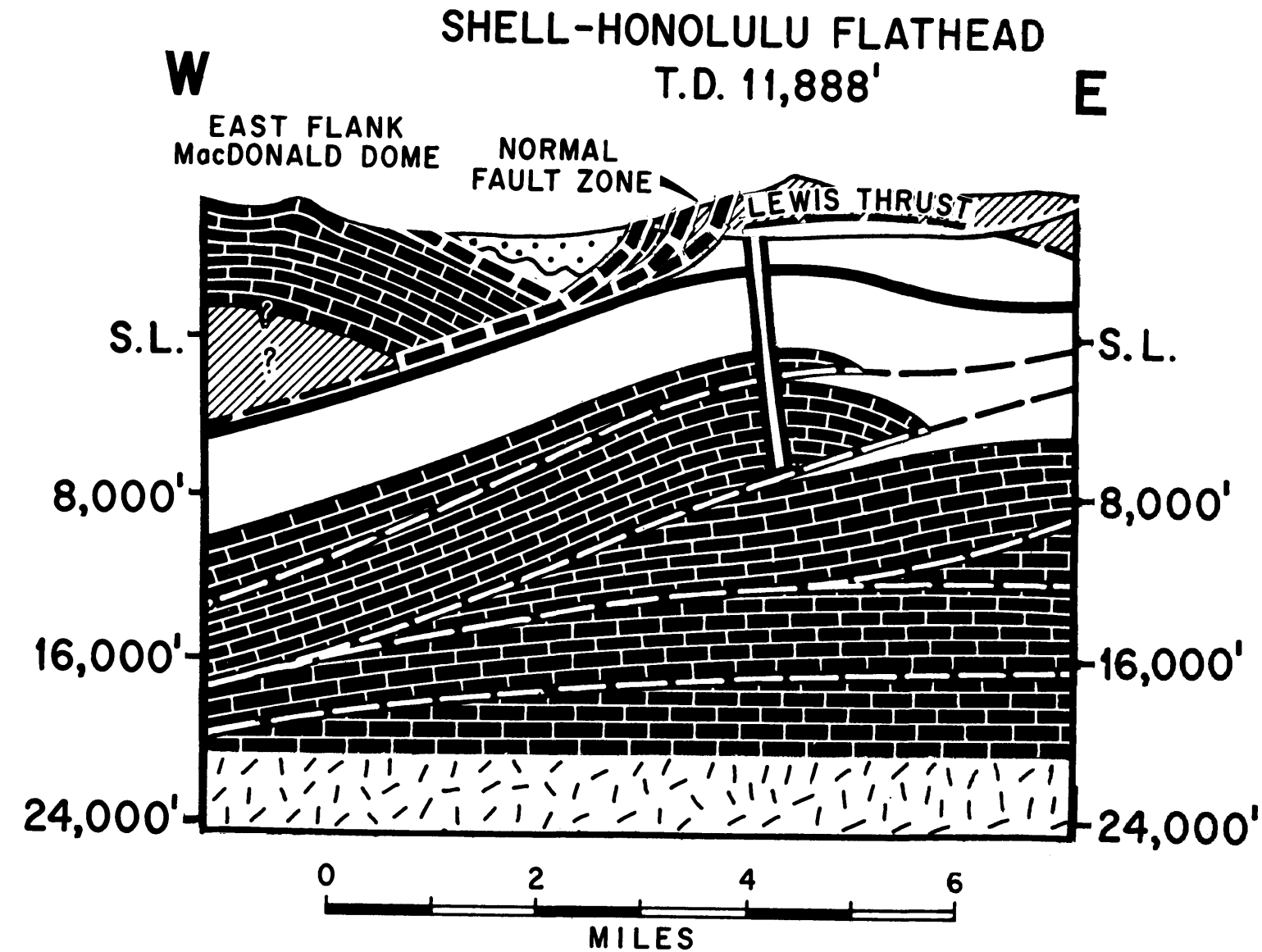
SCALP CREEK — OLDMAN RIVER



SECTION F-F'

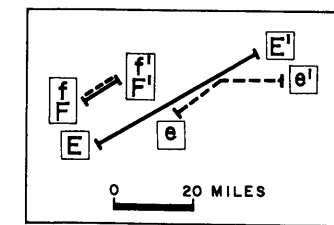
FLATHEAD

- TERTIARY
- CARDIUM
- MESOZOIC CLASTICS
- PALEOZOIC CARBONATES
- PRECAMBRIAN-BELTIAN SED.
- PRECAMBRIAN SHIELD
- LISTRIC THRUST FAULT
- LISTRIC NORMAL FAULT



SECTION f-f'

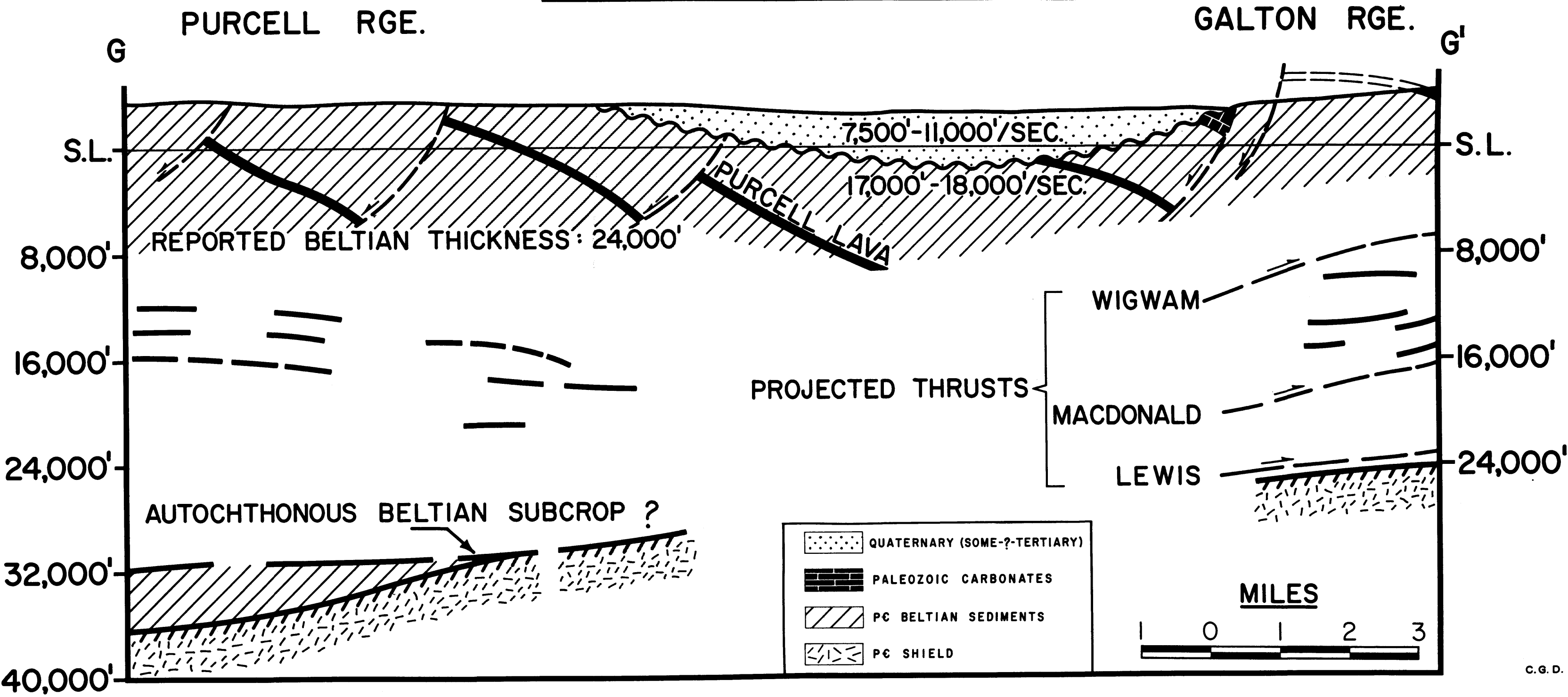
FLATHEAD



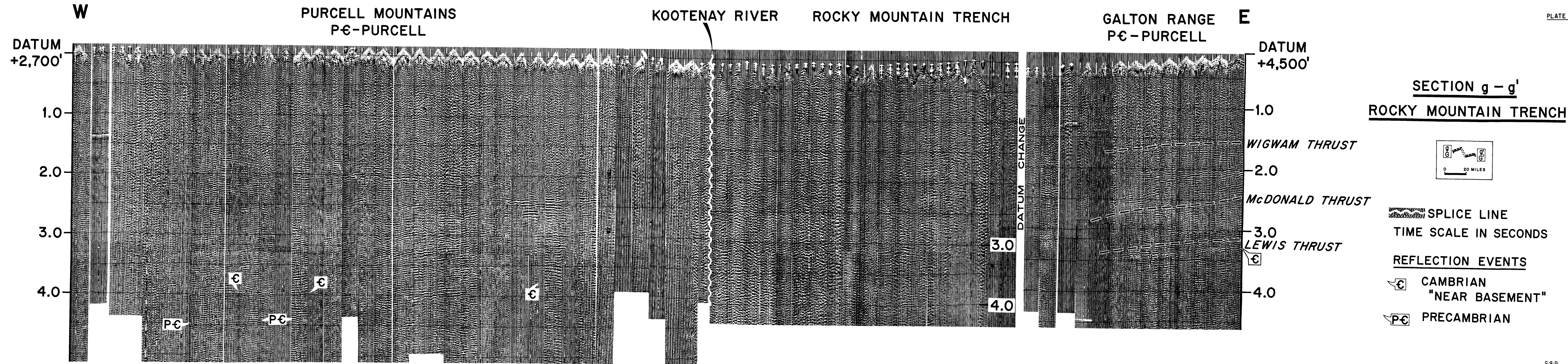
- TIME SCALE IN SECONDS
- FAULT
- REFLECTION EVENTS
- M BASAL MESOZOIC "NEAR MISSISSIPPIAN"
- C CAMBRIAN "NEAR BASEMENT"
- WELL TOPS
- Jk JURASSIC KOOTENAY
- Mi MISSISSIPPIAN

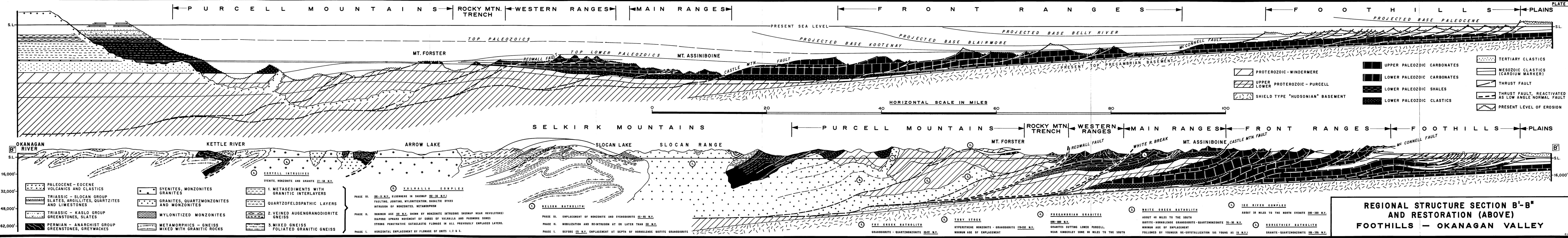
ROCKY MTN. TRENCH

PLATE 10



C.G.D.





W

ROCKY MOUNTAIN GEOSYNCLINE

E

