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TRIASSIC ROCKS OF THE ROCKY MOUNTAIN FOOTHILLS AND FRONT RANGES OF NORTHEASTERN BRITISH COLUMBIA AND WEST-CENTRAL ALBERTA

D.W. Gibson

1975

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PREFACE

In this bulletin, the third of three final reports, the author briefly summarizes the stratigraphy and nomenclature of the Triassic rocks of the Rocky Mountain Foothills and Front Ranges of west–central Alberta and northeastern British Columbia, and describes and interprets the sedimentary petrography, the paleoenvironment and the history of deposition of these rocks. Used in conjunction with earlier reports, this information provides data necessary for an economic evaluation of Triassic strata as potential source rocks and reservoirs for oil and gas and other mineral deposits.

D. J. McLaren,
Director-General,
Geological Survey of Canada

Ottawa, July 14, 1975

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TRIASSIC ROCKS OF THE ROCKY MOUNTAIN FOOTHILLS AND FRONT RANGES OF NORTHEASTERN BRITISH COLUMBIA AND WEST-CENTRAL ALBERTA

Abstract

Triassic rocks in the Foothills and Front Ranges of the Rocky Mountains of northeastern British Columbia and west-central Alberta comprise a thick and variable sequence of marine siltstone, shale, sandstone, limestone, and dolostone. In the north half of the report-area, between Pine Pass and Sikanni Chief River, the Triassic rock succession is subdivided into eight formations which are, in ascending order: Grayling, Toad, Liard, Charlie Lake, Ludington, Baldonnel, Pardonet, and Bocock; south of Peace River the Baldonnel Formation is divided into two lithofacies, the lower of which is distinguished as the Ducette Member. In the south half of the report-area, the rocks are subdivided into two lithologically contrasting units: the Sulphur Mountain Formation and the overlying Whitehorse Formation. Each of these formations is made up of several members; in ascending order they are: Vega-Phroso, Whistler, and Llama of the Sulphur Mountain Formation; Starlight Evaporite, Brewster Limestone, and Winnifred of the Whitehorse Formation. All formations and members are correlated with their subsurface counterparts in the important oil and gas producing region of the Peace River Plains to the east, and the successions in the Jasper-Banff-Crowsnest Pass regions of west-central and southern Alberta.

A detailed description and an analysis of the detrital and chemical components of the Triassic rock succession are included; these suggest that the allochthonous mineral suite was derived mainly from a source area of low relief, consisting of sedimentary rocks. X-ray diffraction, chemical, and mineralogical analyses were completed on selected samples of the Sulphur Mountain and Toad Formations as a means of identifying clay, opaque minerals, and submicroscopic minerals, and checking semiquantitative mineral estimates made from thin section studies. Insoluble residue analyses of samples of the Sulphur Mountain and Toad Formations suggest a general decrease in carbonate concentration towards the east and northeast.

It is postulated that sediments of the Grayling Formation, lower part of the Toad Formation and of the Vega-Phroso and Whistler Members of the Sulphur Mountain Formation were deposited in an easterly to southeasterly transgressing sea, along the western margin of a relatively deep water, marine, open-shelf environment. In contrast, sediments of the overlying formations and members were deposited during major regressive and transgressive cycles, under more restricted and, at times, much shallower depositional conditions.

Résumé

Les roches triasiques qui se trouvent dans les Foothills et les chaînons Frontaliers des Rocheuses dans le nord-est de la Colombie-Britannique et le centre ouest de l'Alberta sont formées d'une succession épaisse et variable de siltstone, de chiste, de grès, de calcaire et de dolostone marins. Dans la partie nord de la région en question, entre Pine Pass et la rivière Sikanni Chief, la succession de roches triasiques se subdivise en huit formations qui sont, par ordre ascendant: Grayling, Toad, Liard, Charlie Lake, Ludington, Baldonnel, Pardonet et Bocock. Au sud de la rivière de la Paix, la formation de Baldonnel se divise en deux lithofaciès; le lithofaciès inférieur est connu sous le nom de niveau de Ducette. Dans la partie sud de la région en question, les roches se subdivisent en deux unités lithologiques contrastantes qui sont la formation de Sulphur Mountain et la formation susjacente de Whitehorse. Chacune de ces formations est composée de plusieurs niveaux qui sont, par ordre ascendant: Vega-Phroso, Whistler et Llama de la formation de Sulphur Mountain; et Starlight Evaporite, Brewster Limestone, et Winnifred de la formation de Whitehorse. Toutes les formations et les niveaux de la région sont en corrélation avec l'infra-structure analogue qui se trouve à l'est, dans la région productrice de pétrole et de gaz des plaines de la rivière de la Paix et avec les successions des régions de Jasper, Banff et Crowsnest Pass dans le centre ouest et le sud de l'Alberta.

L'auteur fait une description et une analyse détaillées des éléments détritiques et chimiques de toute la succession triasique et est d'avis que la série minérale allochtone provient principalement d'une zone à faible relief formée de roches sédimentaires. Des études par diffraction des rayons X et des analyses chimiques et minéralogiques ont été faites sur des échantillons choisis des formations de Sulphur Mountain et de Toad, dans le but d'identifier l'argile, les minéraux opaques et les minéraux submicroscopiques, et de vérifier l'évaluation semi-quantitative des minéraux qui a été faite à la suite d'études de plaques minces. Des analyses de résidus insolubles provenant des échantillons des formations de Sulphur Mountain et de Toad suggèrent une diminution générale des concentrations de carbonate vers l'est et le nord-est.

L'auteur croit que les sédiments de la formation Grayling, de la partie inférieure de la formation de Toad ainsi que des niveaux de Vega-Phroso et de Whistler de la formation de Sulphur Mountain ont été déposés par le mouvement transgressif de la mer, de l'est vers le sud-est, le long de la marge continentale ouest dans un milieu à influences nettement océaniques. Par contraste, les sédiments des formations et des niveaux susjacents ont été déposés au cours de cycles majeurs de régression et de transgression et généralement de façon moins étendue et parfois en milieux à caractères plus continentaux.

INTRODUCTION

Triassic rocks in the Rocky Mountain Foothills and Front Ranges of northeastern British Columbia and west-central Alberta (Fig. 1) occupy part of an elongate belt of marine Triassic strata that extends from the United States border on the south to just beyond the 60th parallel on the north. The succession is thick, comprising a variable sequence of clastics, carbonates, and minor amounts of evaporites, ranging in age between Early Triassic Griesbachian to Late Triassic Norian.

In 1968, the writer began a study in the Rocky Mountain Foothills and Front Ranges between Sikanni Chief and Smoky Rivers (Fig. 2), as part of a major investigation of Triassic rocks in the Western Canada Sedimentary Basin (Gibson, 1968a, b, 1969, 1970, 1971a, b, and 1972). The objectives of the study were to: (1) study the field character, the megascopic and microscopic features of the sediments, and the fauna, and to use the results of these studies to solve some of the existing stratigraphic and nomenclatural problems; (2) correlate strata of this region with those of the Jasper–Banff areas of Alberta to the south and with subsurface rocks of the Peace River Plains area of British Columbia to the east; and (3) outline and interpret the environment and history of deposition. This report supplements the earlier work by mainly emphasizing the petrology of the succession.

Previous Work

Paleontologic and stratigraphic investigations in the Rocky Mountain Foothills of northeastern British Columbia by McLearn (1921, 1930, 1940, 1941a, b, 1945, 1946, 1947a, b, 1960, 1969), Kindle (1944, 1946), and McLearn and Kindle (1950) provided a basic Triassic stratigraphic framework that has been used and modified by many geologists and paleontologists. Most of the later investigations were of a more specialized nature, attempting to obtain detailed information on the stratigraphy, sedimentology, and paleontology of the Triassic rocks in the area. Many of the investigators were involved in assessing the petroleum potential, following the discovery of large oil and gas reserves in Triassic rocks of northeastern British Columbia in the early 1950s. The subsurface was investigated by Hunt and Ratcliffe (1959), Clark (1961), Armitage (1962), Jansonius (1962), Hughes (1967), Fitzgerald and Peterson (1967), Mothersill (1968), Sharma (1969), and Matwe and Bos (1970). Surface studies of varying detail were undertaken by Laudon *et al.* (1949), Irish (1954, 1963, 1965, 1970), Muller (1961), Govett (1961), Westermann (1962), Pelletier (1963, 1964), Gibson (1968a, 1970, 1971b,

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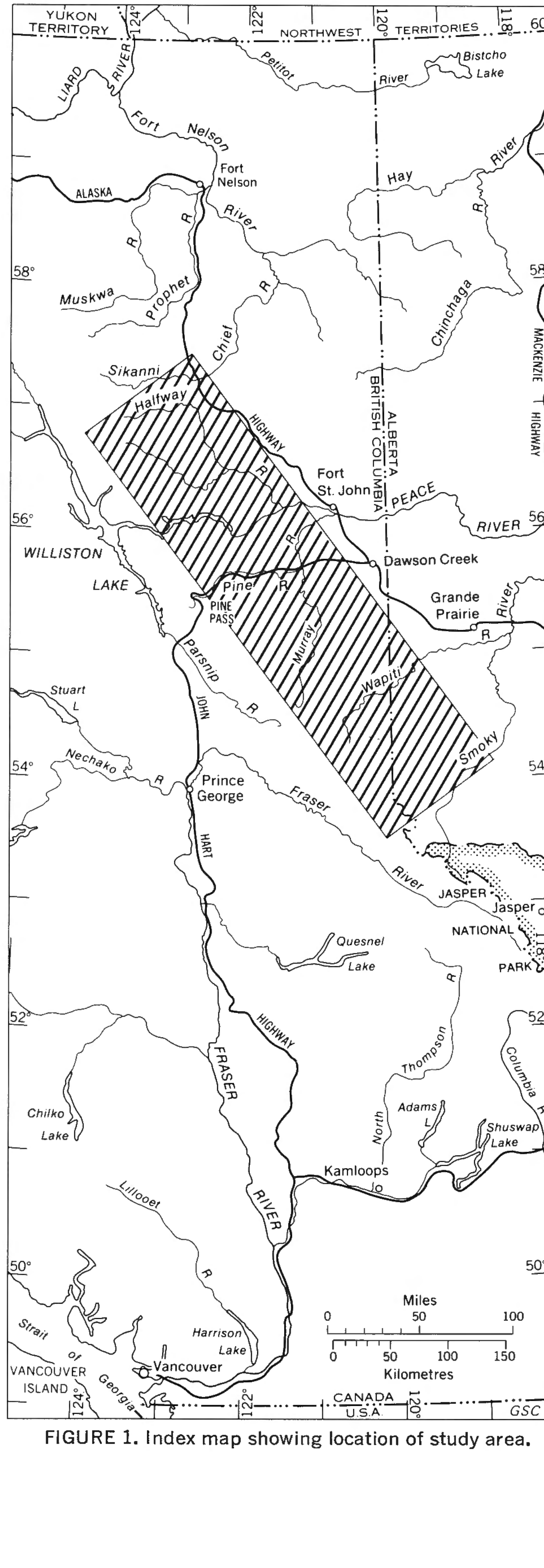

FIGURE 1. Index map showing location of study area.

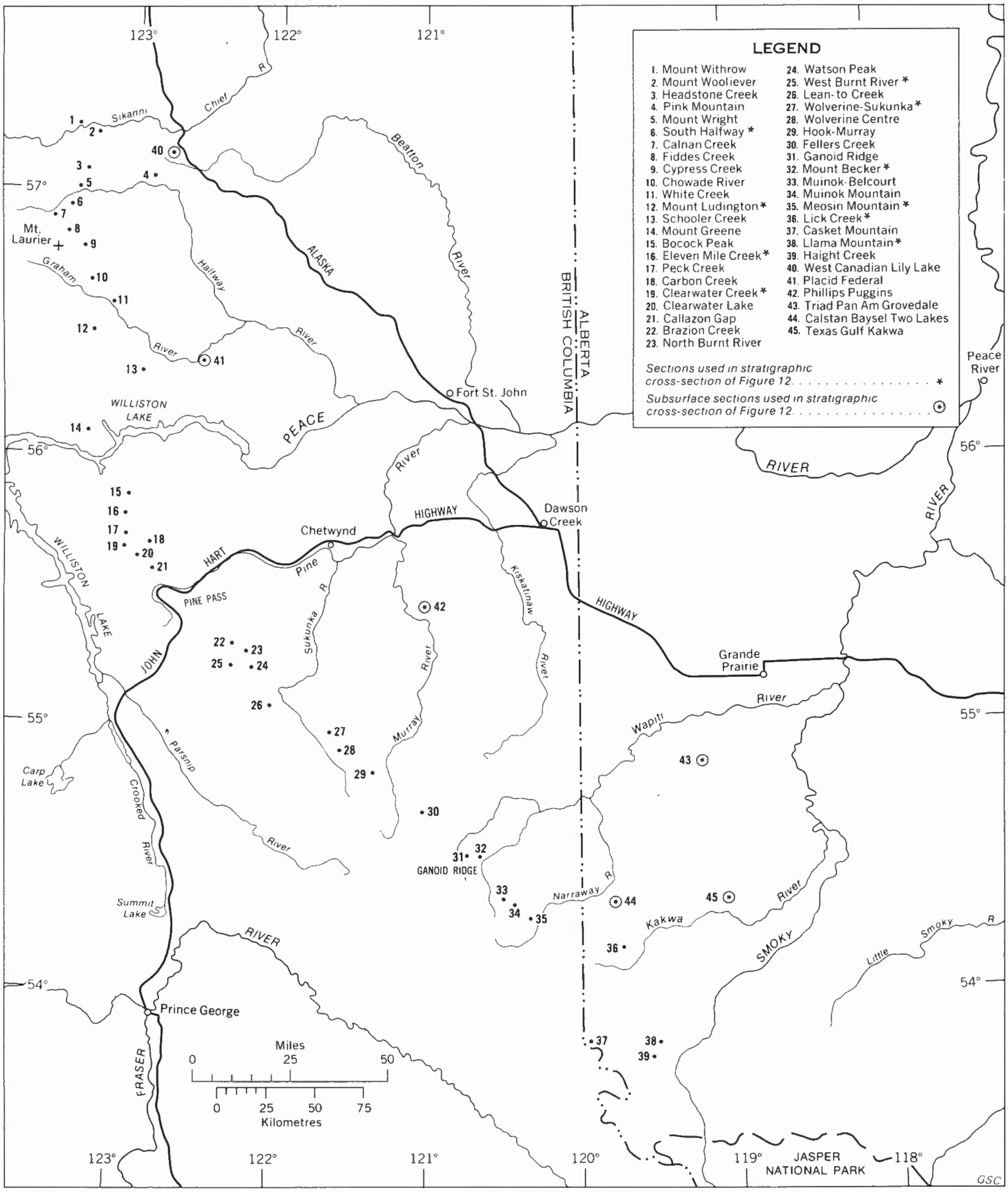

FIGURE 2. Locations and names of Triassic sections.

1972), and Tozer (1961, 1963, 1967). A synthesis of all published Triassic surface and subsurface information in Western Canada was made by Barss *et al.* (1964); this summary includes subsurface information to the end of 1961 and surface information gathered to the end of 1962.

Acknowledgments

Field and logistic support were provided by Operation Smoky, a regional geological mapping and stratigraphic investigation co-ordinated by G. C. Taylor of the Geological Survey of Canada. Able field assistance was given in 1968 by D. Dutton, J. Irish, R. Patterson, and E. Thorsteinsson; in 1969 by G. Belik, J. Craig, J. Irish, and P. Lord; and in 1970 by J. Irish, D. Jamieson, and P. Latour.

X-ray and chemical analyses on selected samples of the Grayling, Toad, Liard, Pardonet, Sulphur Mountain, and Whitehorse Formations were done by A. E. Foscolos, A. G. Heinrich, and R. R. Barefoot of the Geological Survey. Other laboratory support was given by Miss A. Renn, Mr. J.

Rees (insoluble residues), and Mr. O. McEwan (thin sections), also of the Geological Survey.

All fossils collected in the field were identified, dated, and placed into appropriate zones by E. T. Tozer of the Geological Survey of Canada.

STRATIGRAPHY

Triassic stratigraphy of the Sikanni Chief–Smoky River area has been presented in two earlier Geological Survey reports (Gibson, 1971b, 1972); these describe in detail the lithology, facies relationships and changes, distribution, faunal content, and age of the formations and members. Preliminary discussions and conclusions on correlation, economic potential, and depositional history included in previous reports have been modified and/or amplified because of additional information obtained during the petrological phase of the investigation.

Nomenclature and major lithofacies characteristic of Triassic rocks in the region are summarized, and isopach maps, plates, and a major stratigraphic cross-section illustrating thickness trends and facies distribution are included. The isopach maps contain subsurface data obtained from Alberta and British Columbia well records and, consequently, some thickness values may be subject to minor modifications owing to inconsistent or different placement of member and formation contacts by individual well operators and government workers.

The nomenclature used in the Sikanni Chief – Smoky River area is summarized in Figures 3 and 13. Field studies north of Pine Pass (Gibson, 1971b) indicated that the Triassic nomenclature adopted for that region could not be extended reliably into the area between Pine Pass and Smoky River because of physical and compositional differences between the Early and Middle Triassic rocks of the Pine Pass area and those of the Smoky River region. As Triassic nomenclature is well established for the southern Rocky Mountains of the Jasper–Banff area (Fig. 13), a transitional geographical region had to be designated where the Sikanni Chief River – Pine Pass nomenclature would be discontinued and replaced by the existing Jasper–Banff Triassic nomenclature. The Pine Pass – Sukunka River area (Fig. 2; Gibson, 1972) was selected as it contains lithofacies and stratigraphic boundaries common, in part, to both the northern and southern Rocky Mountain regions.

Sikanni Chief River – Pine Pass Area

Grayling Formation

This formation is best exposed in the extreme western Foothills of the Sikanni Chief River – Pine Pass area, where it comprises a dark grey to brownish grey, recessive, shaly to

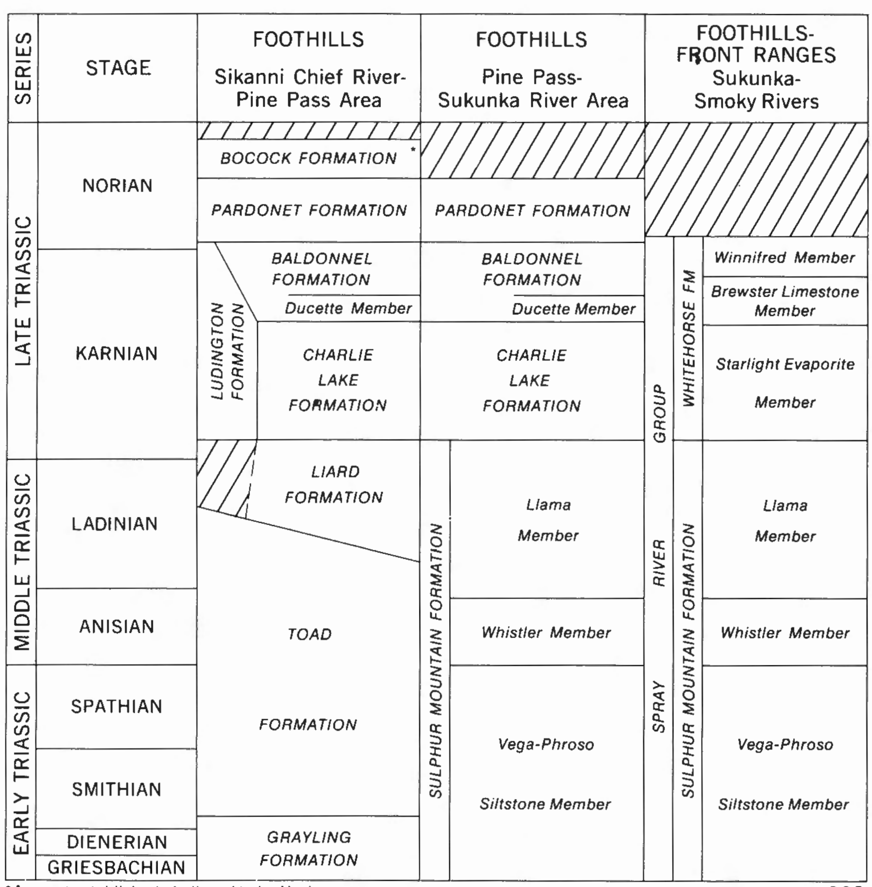

FIGURE 3. Nomenclature and correlation chart.

flaggy weathering sequence of dolomitic siltstone, silty shale, and minor amounts of calcareous siltstone, silty limestone, dolostone, and very fine grained sandstone. The continuance of the formation into the eastern Foothills and adjacent subsurface of the Plains is uncertain. The recessive nature of the formation results in poorly exposed intervals in many of the eastern field sections (Pl. 1A). Hunt and Ratcliffe (1959) noted the occurrence of strata similar to the Grayling Formation in the subsurface of the Peace River district, and combined these strata with the overlying Toad Formation, naming the interval the Toad–Grayling Formations. The Grayling contains a fauna ranging in age from Early Triassic Dienerian to Smithian.

Measured thickness of the Grayling Formation ranges from a maximum of 335 feet east of Clearwater Lake, to a minimum thickness of 118 feet near Calnan Creek (Sec. 7, Fig. 2). Lack of exposed sections and reliable thickness values in the eastern Foothills and subsurface of the Plains area prevented the preparation of a reliable and meaningful isopach map of the formation.

The Grayling Formation unconformably overlies chert and siliceous mudstone of the Permian Fantasque Formation. The upper contact with the Toad Formation is gradational, and is designated mainly on the basis of a change in carbonate composition, and to a lesser degree on bedding thickness and resistance to weathering. The contact is placed where the cement of the Grayling siltstone changes upward from a predominance of dolomite to a predominance of calcite; calcite is a characteristic mineral of the siltstone of the Toad Formation. This change occurs throughout a thick interval (25 to 50 feet) of strata at some sections. The Grayling is commonly more thinly bedded and more recessive than the Toad, thereby facilitating contact placement between the two formations.

Toad Formation

The Toad Formation consists of a thick succession of dark grey, shaly to flaggy weathering, very calcareous siltstone, silty limestone, silty shale, and minor amounts of silty dolostone and calcareous sandstone, generally characterized by a distinctive alternation of resistant and recessive bedding, a feature probably related to variations in the carbonate content of the strata (Pl. 1A, B, E). The formation is fossiliferous at many localities, containing well-preserved ammonites, pelecypods, and brachiopods ranging in age from Early Triassic Smithian to Middle Triassic Ladinian.

Measured thickness of the formation ranges from 520 feet at Mount Greene (Sec. 14, Fig. 2), to more than 2,700 feet at South Halfway (Sec. 6, Fig. 2). Complete sections of the formation throughout much of the area are difficult to find because of its recessive nature and resulting partial talus and forest cover, again preventing the preparation of an accurate isopach map. In the Peace River – Pine Pass area, thickness values between measured sections are variable, possibly due either to an uneven surface upon which the Triassic sediments were deposited, or to the gradational and interfingering nature of the contact between the underlying and overlying formations at some localities.

The contact with the overlying Liard and Ludington Formations ranges from gradational, to sharp and conformable, to probably unconformable depending on location in the report-area. Between Pine Pass and Peace River, the contact is gradational and is placed where the dark weathering siltstone, limestone, and silty shale of the Toad grade vertically into Liard Formation rocks, a succession of generally paler grey weathering, coarser grained siltstone, very fine grained sandstone, and very finely crystalline limestone characterized by a subconchoidal fracture. A sharp, conformable contact between the two formations occurs in the eastern Foothills region north of Peace River. There, the grey weathering siltstone, limestone, and silty shale change abruptly into paler coloured, grey to brown weathering, resistant, very fine to fine grained sandstone of the Liard Formation. In the extreme western Foothills north of Peace River, the Toad Formation is overlain, probably unconformably at most localities, by medium grey weathering, very fine grained sandstone, siltstone, and silty to sandy bioclastic limestone of the Ludington Formation (Pl. 1E). At Calnan Creek (Sec. 7, Fig. 2), the base of the Ludington Formation is characterized by a 5-foot-thick unit containing subangular to well-rounded pebbles, cobbles, and boulders of siltstone up to 1 foot in diameter (Pl. 1F). At Mount Ludington (Sec. 12, Fig. 2), a similar abrupt lithologic break was noted, although at that location conglomerate was not observed (Pl. 1E). The magnitude of the unconformity is unknown as fossils are lacking in the lower strata of the Ludington Formation.

Liard Formation

The Liard Formation (Pl. 1C) consists mainly of resistant, dolomitic to calcareous sandstone, calcareous and dolomitic siltstone, and lesser amounts of dolostone. At many sections, thin to medium beds of buff to grey weathering sandy to silty to bioclastic limestone are sporadically interbedded within the succession. South of Peace River, this limestone is very finely crystalline, less sandy and silty, and commonly cherty, and is characterized by a distinct subconchoidal fracture. The rocks of the Liard Formation are pale to medium grey to yellowish grey, except in the region south of Peace River. There, they are much darker reflecting a greater carbonaceous–argillaceous concentration, such that, at some localities, they resemble strata of the Toad Formation. The formation contains few fossils compared with the underlying Toad Formation. In the Pine Pass – Peace River region, however, good index fossils of Late Ladinian and Early Karnian age were collected (Gibson, 1971b).

Figure 4, which includes Halfway Formation thicknesses obtained from British Columbia and Alberta well records, illustrates variable formation thickness values and trends in the region. These features may be due, in part, to the difficulty in placing the contact with the overlying Charlie Lake Formation and, at some localities, with the underlying Toad Formation. Furthermore, the effect of tectonic deformation in the western part of the report-area has not been taken into consideration in preparing the isopach map. G. C. Taylor (pers. com.) estimates crustal shortening in the report-area to have been approximately 15 to 20 per cent. Thickness anomalies and unusual patterns shown on Figure 4 may be

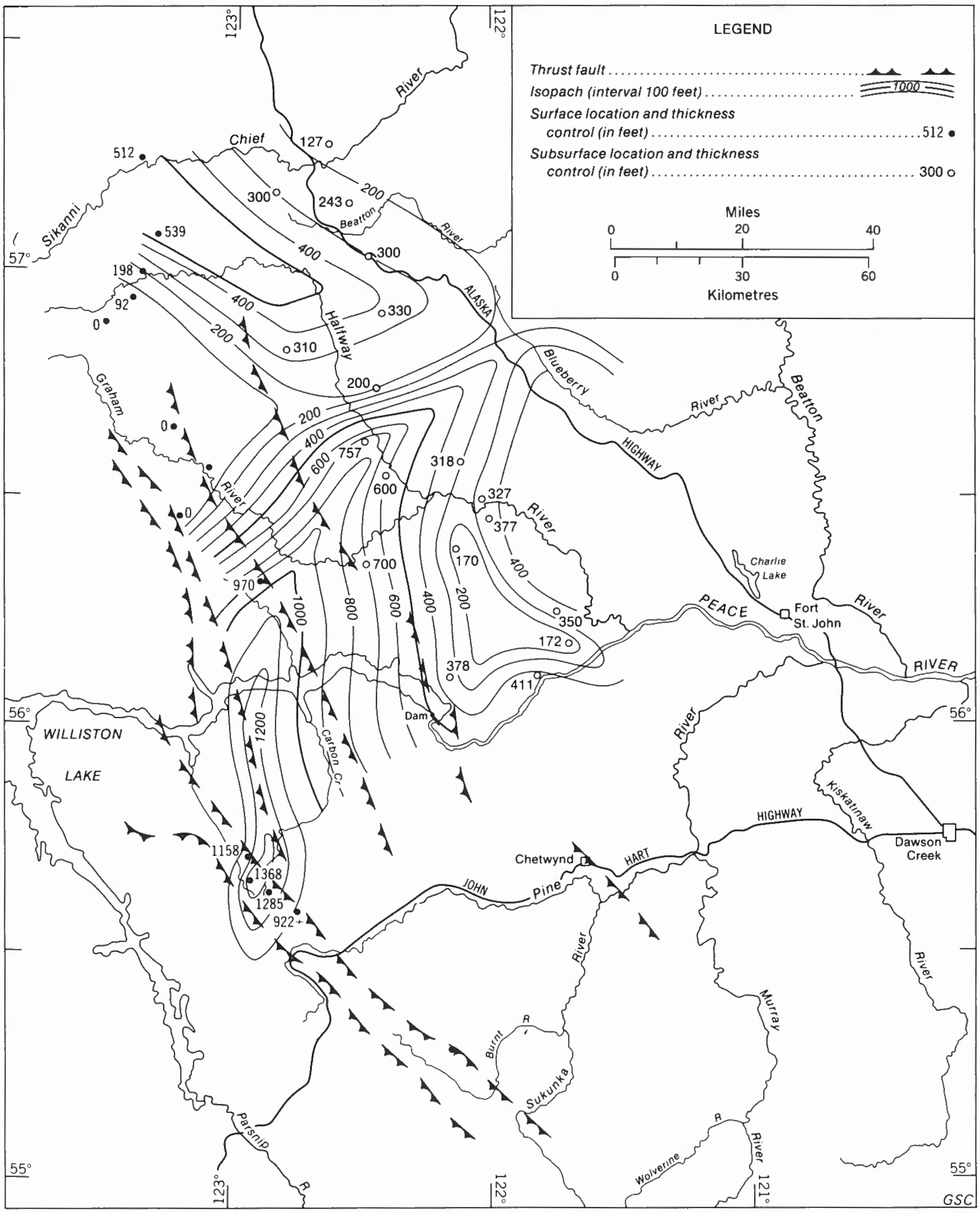

FIGURE 4. Isopach map of Liard–Halfway Formations.

partly the result of tectonic compression and distortion, rather than of sedimentation. For the distribution of folds and other faults, the reader is referred to geologic maps by Irish (1968), Mountjoy (in preparation), and Taylor (in preparation). In general, the Liard Formation shows a thickness increase toward the southwest, where a value of 1,370 feet was recorded at Clearwater Creek (Sec. 19, Fig. 2). In the northwestern part of the region, the formation becomes progressively thinner and finally disappears as a consequence of uplift and erosion of Liard strata, as shown by the occurrence of an unconformity between the Ludington and Toad Formations (Figs. 3 and 12).

The contact of the Liard with the overlying Charlie Lake Formation is gradational. In the Sikanni Chief – Halfway River area it is placed at the level where the sandstone and siltstone of the Liard Formation grade into or contain a high percentage of pale weathering silty to sandy dolostone. In the Halfway – Peace River region to the south the Charlie Lake Formation is resistant and contains very few dolostone interbeds in the basal part of the formation. At this locality the contact is placed where the carbonate cement changes from a predominance of calcite below to mainly dolomite above in the Charlie Lake Formation, and where the generally darker grey to brown-weathering strata of the Liard

Formation change or grade into yellowish brown and yellow weathering, commonly coarser grained sandstones of the Charlie Lake. South of Peace River, the contact also is gradational and is placed where the dark grey-brown weathering sandstone and siltstone of the Liard Formation grade into pale grey to yellowish brown weathering dolostone and dolomitic sandstone of the Charlie Lake Formation.

Charlie Lake Formation

The Charlie Lake Formation (Pl. 1D) comprises a variable sequence of yellowish brown to yellow, pale grey to orange-brown weathering, dolomitic to calcareous sandstone, siltstone, sandy limestone, dolostone, and minor amounts of intraformational and/or solution breccia. In the Plains area to the east, it also contains thick intervals and interbeds of anhydrite, which have not been observed in outcrop north of Sukunka River. Few fossils occur, probably because of the shallow water, evaporitic conditions prevailing during deposition of the sediments. The laterally equivalent deeper water facies to the west, the Ludington Formation, does, however, contain a fauna of probably Karnian age.

Measured thickness ranges from a maximum of 1,330 feet near the headwaters of Schooler Creek (Sec. 13, Fig. 2) to a minimum of 600 feet at Mount Withrow (Sec. 1, Fig. 2).

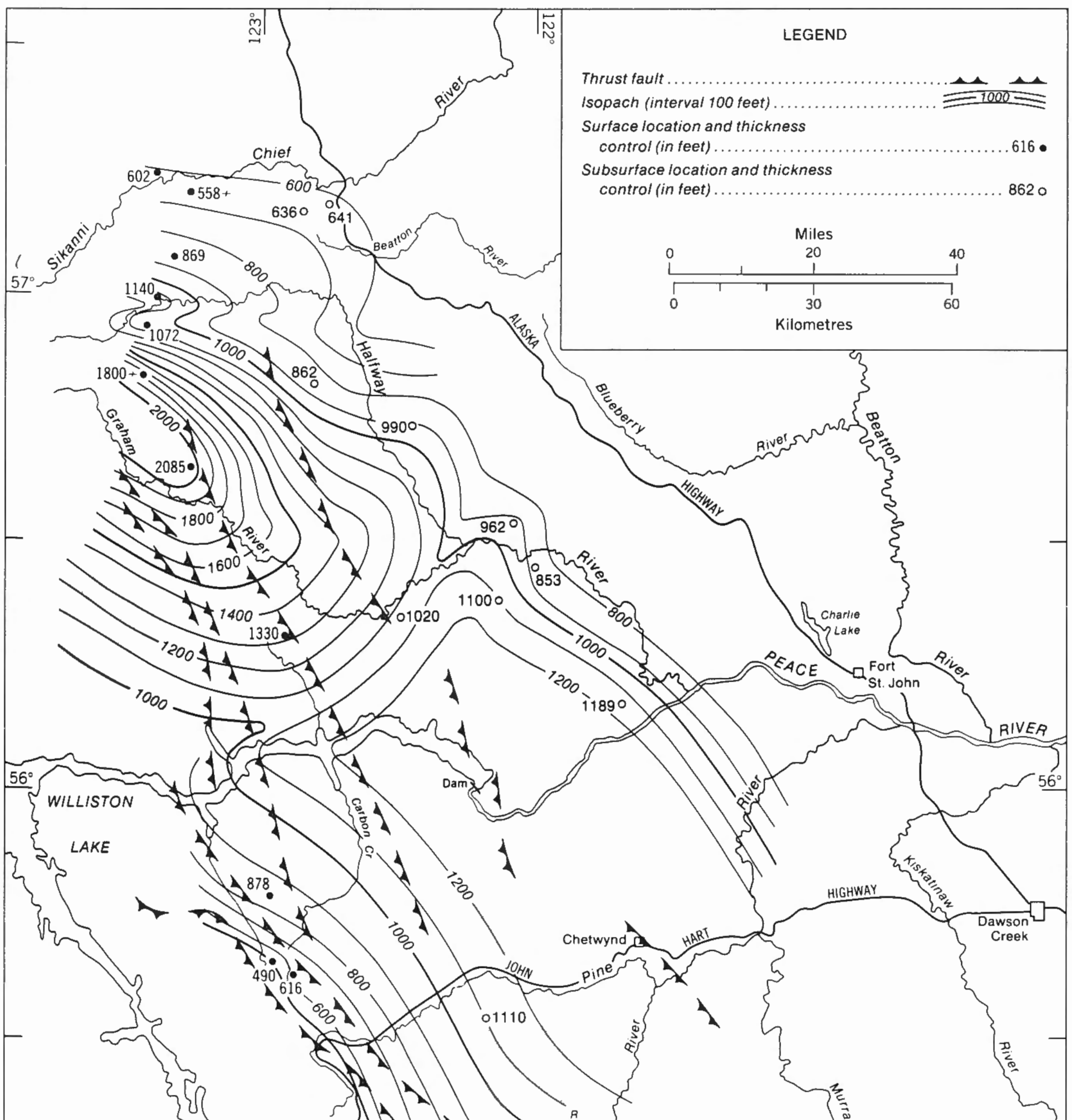

FIGURE 5. Isopach map of Charlie Lake – Ludington Formations.

Figure 5 illustrates a lenticular sequence of strata thinning toward the east and west and thickening toward the northwest in the vicinity of the headwaters of Halfway River. To present a more meaningful interpretation of Charlie Lake thickness trends in the region, thickness values of the laterally equivalent Ludington Formation and the subsurface Charlie Lake Formation were included in the analysis.

North of Peace River, the contact with the overlying Baldonnel Formation is placed where medium grey dolostone, siltstone, and limestone of the Charlie Lake Formation grade into pale grey weathering, cliff-forming limestone and calcareous dolostone of the Baldonnel Formation. In the southern Peace River and Sukunka River region, the contact is abrupt and distinct, and placed where the yellowish brown to pale grey weathering rocks of the Charlie Lake Formation contrast sharply with the overlying dark greyish brown weathering limestone and dolomitic siltstone of the Ducette Member of the Baldonnel Formation (Pl. 1D).

Ludington Formation

The Ludington Formation (Pl. 1E), a recently named unit of upper Triassic rocks in the extreme western Foothills north of Peace River (Gibson, 1971b), consists of a thick sequence of medium to pale grey weathering, dolomitic to calcareous siltstone, sandstone, and silty to sandy bioclastic limestone. Near Mount Laurier in the northwestern part of the report-area (Fig. 2), a large shell accumulation or "bank" of recrystallized and fragmented pelecypod shells (Pl. 9F) was observed. The "bank" consists of a porous accumulation of shells ranging in thickness from zero to an estimated 150 feet along its western margin. The Ludington Formation ranges in age from probable Ladinian to Late Karnian, and passes laterally eastward into the Charlie Lake Formation. This distinctive lithofacies has been recognized by the writer as far north as Liard River in the vicinity of the Alaska Highway.

Complete and well-exposed stratigraphic sections are difficult to find, partly because the strata are covered by detritus due to weathering and partly because of their removal by post-Laramide erosion. At Mount Ludington, the type locality of the formation, 1,640 feet of strata was measured; however, a fault contact with the Pardonet Formation (Gibson, 1971b, p. 19) suggests that part of the section is missing. At Fiddes Creek (Sec. 8, Fig. 2), where the upper beds of the formation have been eroded, 1,720 feet of strata was measured. Maximum thickness appears to occur in the vicinity of Mount Laurier (Fig. 2), where Pelletier (1964) recorded 3,150 feet of Triassic strata above his Liard Formation. The writer considers that most of these strata belong to the Ludington Formation.

Contact relationships with overlying formations are uncertain. At Mount Laurier (Fig. 2), an area examined briefly but not measured, strata typical of the Ludington Formation pass abruptly upward into dense, well-indurated, light grey weathering limestone typical of the Baldonnel Formation. At Mount Ludington (Sec. 12, Fig. 2), however, the Baldonnel Formation was not observed, and the Ludington was overlain by grey to brown weathering limestone and siltstone of the Pardonet Formation. The absence of Baldonnel strata at this locality may be the result of fault truncation as previously noted, or of a facies change into strata similar to the Ludington Formation. The Baldonnel Formation at Mount Laurier was estimated to be 50 feet thick. Therefore, if the Baldonnel was originally present at Mount Ludington, at least 50 feet of strata is missing because of the fault. The alternative explanation of a possible facies change to account for the absence of Baldonnel strata at Mount Ludington is favoured (*see* Fig. 12). Proof is lacking, however, as stratigraphic sections in the immediate vicinity that show the relationships between the Ludington, Baldonnel, and Pardonet Formations are absent. In the extreme western part of the Foothills of the report-area, the Ludington Formation generally forms the youngest Triassic exposures observed. Contact of the Ludington Formation with the Liard Formation was not observed.

Baldonnel Formation

In the Foothills between Sikanni Chief and Sukunka Rivers, the Baldonnel Formation is divided into two distinct lithofacies (Pl. 2A, B). The main unit is recognized throughout the region and overlies a localized lower unit, the Ducette Member, which is restricted to the area immediately adjacent to and between Peace and Sukunka Rivers.

The main facies of the Baldonnel Formation comprises a pale grey to brownish grey weathering, resistant, cliff-forming sequence of limestone and dolostone, with lesser siltstone and very fine grained sandstone. In the Plains to the east, the formation consists mainly of dolostone, commonly with a well-developed porosity and permeability, forming a productive gas reservoir. The formation is sparsely fossiliferous. In the Foothills, however, the few pelecypods and brachiopods collected indicate a Late Triassic Karnian age (Gibson, 1971b).

The Baldonnel Formation, including the Ducette Member, ranges in measured thickness from a minimum of 83 feet near the headwaters of the main fork of Burnt River (Sec. 25, Fig. 2) to a maximum of 480 feet at the headwaters of Eleven Mile Creek south of Peace River (Sec. 16, Fig. 2). Figure 6, an isopach map of the Baldonnel Formation, includes thickness values from wells in the western Plains area. The map illustrates a number of stratigraphic "highs" and "lows." However, as noted for the Liard Formation, some of the thickness distribution patterns and trends may be the result of structural deformation and not contemporaneous sedimentation.

The contact of the Baldonnel with the overlying Pardonet Formation is generally sharp and distinct. It is placed where resistant, cliff-forming, pale to medium grey weathering carbonates of the Baldonnel Formation change to finely laminated, thinly bedded, very dark grey weathering limestone and siltstone of the Pardonet Formation. At some localities south of Peace River, however, the contact is gradational, and is placed below the level at which the finely laminated, thinly bedded strata typical of the Pardonet Formation form the predominant lithology.

Ducette Member

The Ducette Member is a distinctive dark grey-brown weathering sequence of carbonaceous-argillaceous siltstone, very fine grained sandstone, limestone, and minor amounts of

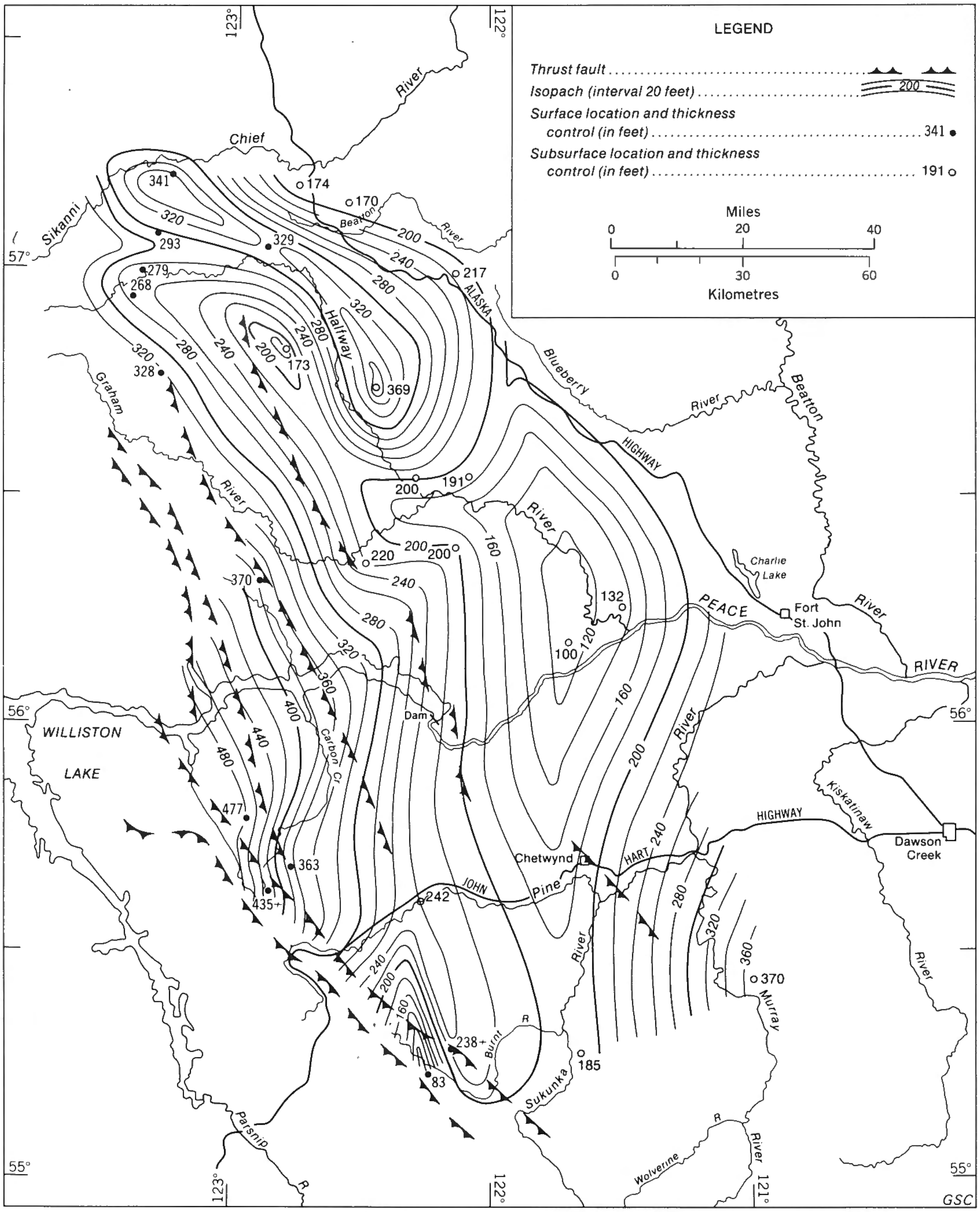

FIGURE 6. Isopach map of Baldonnel Formation.

dolostone, confined to the lower half of the Baldonnel Formation in the Peace River – Sukunka River area (Pl. 2A). Measured thickness ranges from a minimum of 43 feet in the Burnt River area (Secs. 23 and 25, Fig. 2) to a maximum of 390 feet near Clearwater Lake (Sec. 20, Fig. 2). The member has not been generally recognized north of Peace River, possibly because of a change in facies into strata characteristic of either the upper Charlie Lake or the lower Baldonnel Formation. At Schooler Creek (Sec. 13, Fig. 2), however, a thin unit of dark grey-brown weathering siltstone similar to that of the Ducette Member was observed in a partly talus-covered interval below strata typical of the main Baldonnel Formation, which suggests that the member may extend as far north as this locality. On the basis of stratigraphic position, the Ducette Member is considered to be of Late Triassic Karnian age. It contains indeterminate rhynchonellid brachiopods.

The contact of the Ducette Member with the typical facies of the Baldonnel Formation is gradational. It is placed at the top of a small interval in which the dark grey-brown weathering siltstone, and silty limestone grade into more resistant and lighter grey weathering carbonates of the main Baldonnel lithofacies.

Pardonet Formation

The Pardonet Formation comprises a dark grey to dark brownish grey weathering sequence of very carbonaceous-argillaceous limestone, silty limestone, calcareous and dolomitic siltstone, and minor shale (Pl. 2B, C). The predominant limestone is commonly bioclastic, consisting of, or containing, whole and fragmented pelecypod shells generally forming dense coquinas which resemble wavy to crenulated laminations (Pl. 3E). The formation is one of the most fossiliferous units of the Triassic succession, containing well-preserved ammonites and pelecypods ranging in age from Early to Late Norian (Gibson, 1971b, p. 23).

Thickness of the formation ranges from a maximum of 450 feet near the headwaters of Eleven Mile Creek (Sec. 16, Fig. 2) to a minimum value of 126 feet at Pink Mountain (Sec. 4, Fig. 2). The formation does not, however, extend far eastward into the Plains area, or south of Sukunka River, because of pre-Jurassic erosion and, possibly, to a lesser

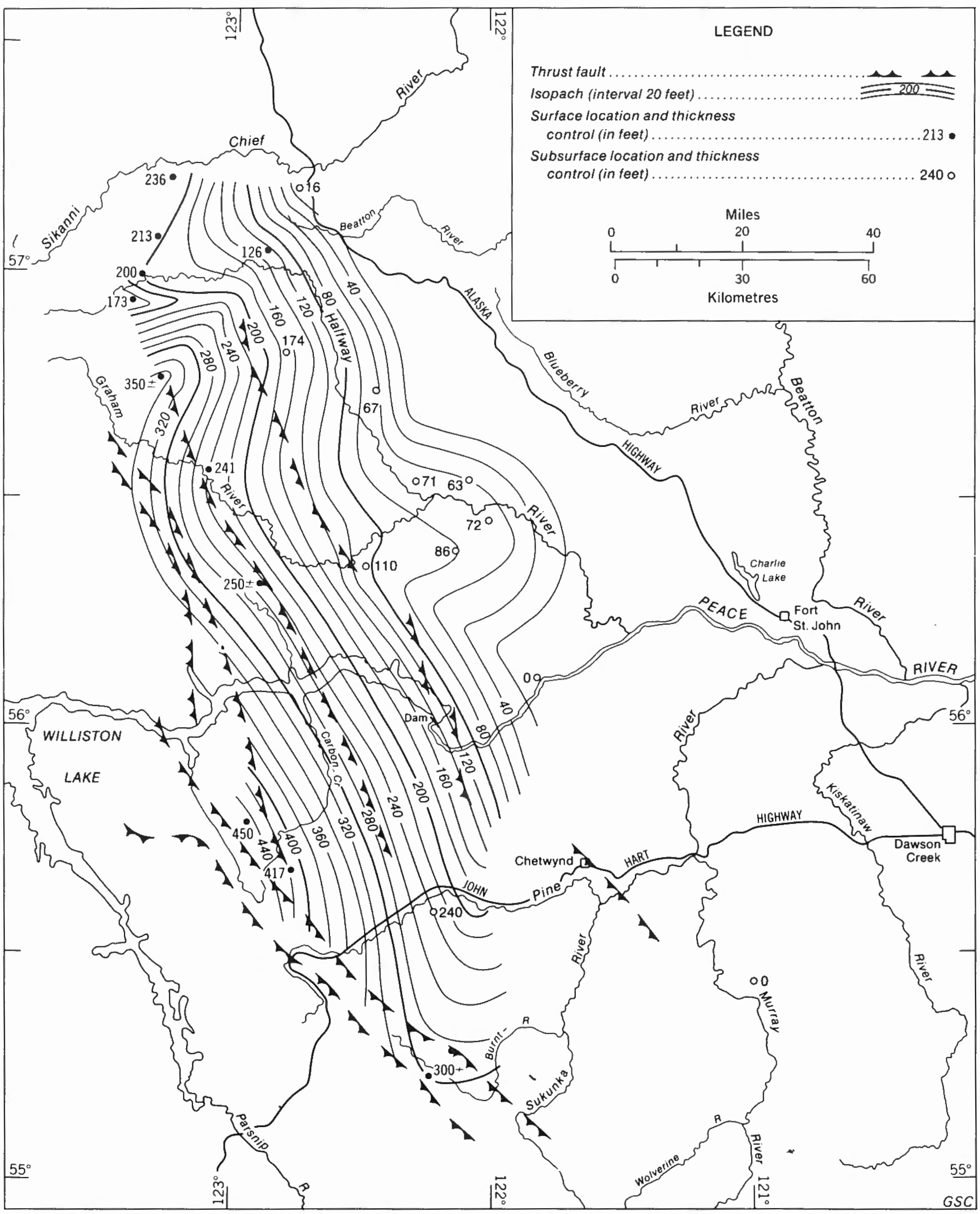

FIGURE 7. Isopach map of Pardonet Formation.

degree, due to thinning along the eastern edge of the depositional basin. Figure 7 illustrates a general thickening trend toward the west.

Throughout most of the report-area, the Pardonet is unconformably overlain by dark grey, recessive shale, shaly siltstone, and limestone of the Jurassic Fernie Formation. Between Pine Pass and Peace River (Fig. 2), however, the formation is overlain, probably disconformably, by very pale grey weathering limestone of the Bocock Formation (Pl. 2C). The base of the Bocock at Bocock Peak (Sec. 15, Fig. 2) has a relief of 2 inches or less, and contains phosphatic, rust-coated, angular clasts of Pardonet-type rocks up to 1 inch long.

Bocock Formation

This formation comprises a distinctive resistant sequence of light grey to yellowish brown weathering, medium to thick bedded limestone, exposed only in the Pine Pass – Peace River area (Pl. 2C). The limestone is medium to medium light grey, and ranges in texture from aphanitic to coarsely crystalline to bioclastic. The limestone contains well-rounded, fragmented pelecypod shells, crinoid columnal and other fossil fragments, and well-rounded carbonate grains. Fibrous calcite (Pl. 7E) was observed at Bocock Peak. At Carbon Creek (Sec. 18, Fig. 2) large stromatolitic or algal-like mounds were found at the top of the formation. Thin section and binocular microscope examination of samples, however, revealed no obvious internal structure.

As complete and identifiable fossils have not been collected from the Bocock, its age is uncertain. Lithologic similarity to carbonates of the Baldonnel Formation and the marked contrast in lithology with the overlying Jurassic strata suggest, however, that the Bocock Formation is probably part of the Triassic rock assemblage, and possibly Late Norian or younger.

Measured thickness ranges from 65 feet near Bocock Peak (Sec. 15, Fig. 2) to a maximum of 208 feet on the east fork of Carbon Creek (Sec. 18, Fig. 2). The formation has not been observed in exposures north of Peace River; strata of similar appearance to the Bocock have been observed in well samples from the Placid–Federal C-29-E well in the Peace River Plains north of Peace River (Fig. 12). Bocock Formation lithologies have not been observed in either outcrop or subsurface samples south of the John Hart Highway and Pine Pass (Figs. 1 and 2). At Pine River bridge crossing (near Sec. 21, Fig. 2), it is absent and the Pardonet Formation is overlain by the Fernie Formation.

The contact with the overlying Jurassic Fernie Formation is distinct and probably unconformable; it is placed where the cliff-forming, pale grey weathering limestone of the Bocock is abruptly overlain by dark grey to black siltstone, shale, and limestone of the Fernie Formation (Pl. 2C). Near Eleven Mile Creek (Sec. 16, Fig. 2), the contact with the Fernie Formation was observed to have an estimated relief of 25 feet in a lateral distance of 150 to 200 feet.

Pine Pass – Smoky River Area

Triassic rocks throughout most of the region south of Pine Pass comprise the Spray River Group and are divided into two contrasting lithofacies, a lower Sulphur Mountain Formation, and an upper Whitehorse Formation. Each formation is characterized by distinctive rock-units that facilitate further subdivision into members (Fig. 3). In the Pine Pass – Sukunka River area (Fig. 2), the same nomenclature is retained for Upper Triassic rocks as in the Sikanni Chief River – Pine Pass area, because of a similarity in physical and compositional properties of the strata in the two areas. The lower part of the succession in the Pine Pass – Sukunka River area is more amenable to subdivision into lithologic units of the Sulphur Mountain Formation as recognized in the Jasper–Banff area of west-central Alberta (Fig. 13).

Sulphur Mountain Formation

In the Pine Pass – Smoky River area, the Sulphur Mountain Formation is divided into three members (Pl. 2D) in ascending order: Vega–Phroso Siltstone Member, Whistler Member, and Llama Member (Fig. 3). The formation weathers to a characteristic dark grey to orange-brown, and comprises a sequence of siltstone, silty limestone, minor shale, dolostone, and very fine grained sandstone. Figure 8 illustrates a thickening trend toward the west and southwest, with a maximum measured thickness of 1,827 feet at West Burnt River (Sec. 25, Fig. 2). It must be noted, however, that this map and those of some members of the Sulphur Mountain Formation are prepared on a non-palinspastic base and, therefore, any unusual patterns or thickness anomalies depicted on Figures 8 to 11 may result from tectonic compression and displacement, or possibly in part from inconsistent contact placement by geologists and drilling operators in wells to the east. They are not necessarily a result of contemporaneous sedimentation.

Vega–Phroso Siltstone Member

The name Vega–Phroso Siltstone Member is a combination of two names for distinctive lithofacies found in the Jasper–Banff area (Gibson, 1972, p. 6). The Vega Siltstone Member comprises a sequence of well-indurated, cyclical alternations of medium grey, carbonaceous, pyritiferous, dolomitic siltstone to silty dolomite and shale, whereas the Phroso Siltstone Member comprises a monotonous assemblage of thin-bedded to massive, shaly to flaggy weathering, grey brown to dark grey, carbonaceous, pyritiferous siltstone, and silty shale. In the Pine Pass – Smoky River area subdivision into separate members is not practicable because of the lack of a well-defined contact between the two units. Throughout most of the Pine Pass – Smoky River region, lithofacies of the Vega and Phroso Siltstone Members interdigitate throughout several hundred feet of strata. The Vega–Phroso Member (Pl. 2F) comprises a dark brownish grey to rusty brown, shaly to flaggy weathering sequence of dolomitic to calcareous siltstone, finely crystalline to bioclastic limestone, silty shale, and minor amounts of very fine grained sandstone. Ammonites and pelecypods collected from the member indicate an age ranging from Early Triassic Griesbachian to Spathian.

The Vega–Phroso Member ranges in thickness from 266 feet near Hook Lake (Sec. 29, Fig. 2) to 894 feet at Casket Mountain (Sec. 37, Fig. 2). The configuration shown on

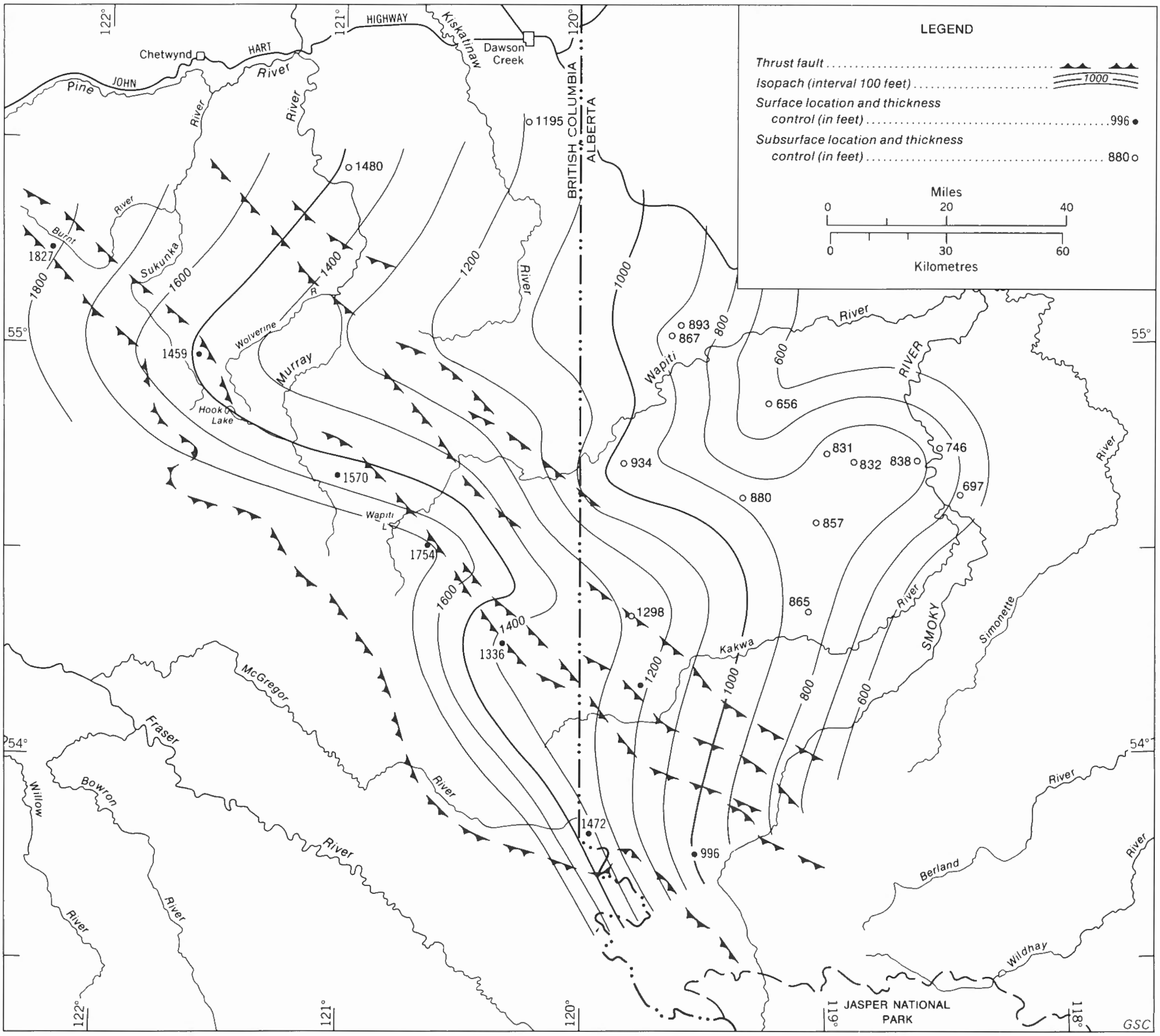

FIGURE 8. Isopach map of Sulphur Mountain Formation.

Figure 9 is due probably in part to deposition on an uneven Mississippian–Permian erosion surface. Once again, the thickness anomalies recorded in part of the region, especially the southwest corner of the map, may be the result of tectonic distortion through thrust faulting and folding, and not entirely the result of contemporaneous sedimentation.

Between Pine Pass and Sukunka River (Pl. 2E, F), the Vega–Phroso Member disconformably overlies chert and siliceous mudstone of the Permian Fantasque Formation, and cherty limestone of the Mississippian Prophet Formation. Between Sukunka River and Wapiti Lake, the member overlies cherty sandstone and conglomeratic limestone of the Permian Belcourt Formation, whereas, in the region south of Wapiti Lake, it disconformably overlies sandstone of the Permian Mowitch Formation. The contact with the overlying Whistler Member is generally sharp and abrupt, and is placed where the resistant brownish grey to rusty brown weathering siltstone of the Vega–Phroso Siltstone Member is overlain by recessive, dark grey weathering siltstone and limestone of the Whistler Member. At many localities, this contact is marked by a bed of phosphatic pebble conglomerate and phosphatic sandstone at the base of the Whistler Member (Pl. 5D). Between Wapiti and Hook Lakes (Fig. 9), the contact of the Vega–Phroso with the Whistler Member is gradational, and is placed at the stratigraphic level where the cement and matrix of the Vega–Phroso siltstone changes

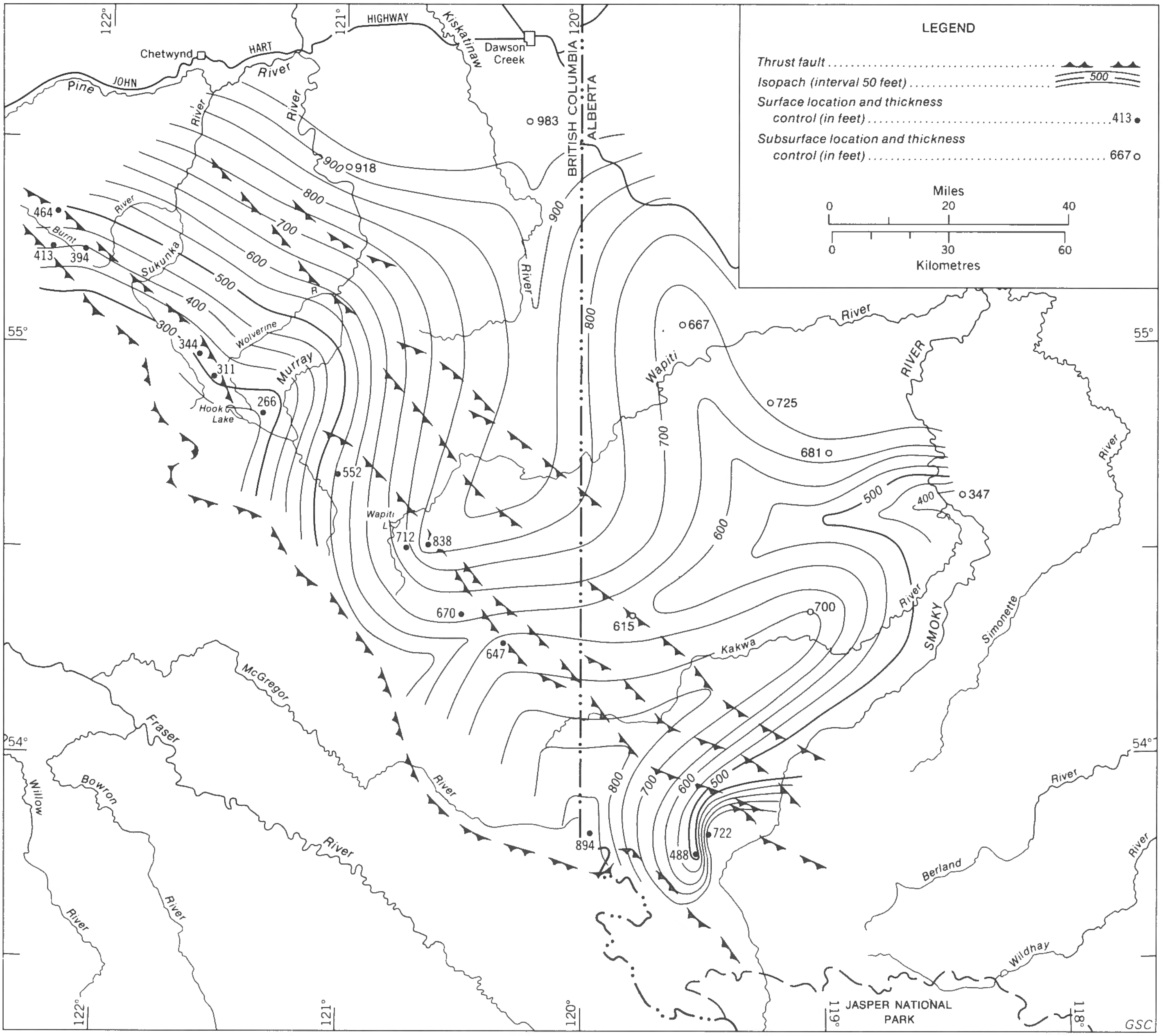

FIGURE 9. Isopach map of Vega–Phroso Siltstone Member.

from a predominance of dolomite below to a predominance of calcite above. In addition, lamination of the two members differs. Vega–Phroso rocks are generally regularly to lenticularly laminated (Pl. 3F) whereas those of the Whistler commonly show very wavy or crenulated lamination in which whole and fragmented pelecypod shells are prominent (Pl. 7C).

Whistler Member

The Whistler Member consists of dark grey to black weathering siltstone, silty and fossiliferous limestone with minor interbeds of silty shale, and dolostone, phosphatic and quartz sandstone, and phosphatic pebble conglomerate. Throughout most of the area, the member serves as a distinctive marker in the Sulphur Mountain Formation because of its dark grey and recessive nature (Pl. 2D). Most sections are poorly exposed and difficult to sample. The Whistler Member contains ammonites, pelecypods, and scattered brachiopods that have been dated as Middle Triassic Anisian.

Thickness ranges between 280 feet at Watson Peak near Sukunka River (Sec. 24, Fig. 2) and 60 feet at Lick Creek and Casket Mountain (Secs. 36, 37, Fig. 2). Figure 10 indicates a general thickening trend from east to west throughout most of the region. In the vicinity of Wapiti Lake and north, however, the isopachs indicate small basin and shelf areas aligned perpendicular to the general thickness trend of the member in the region.

Outcrop sections containing good phosphatic sandstone

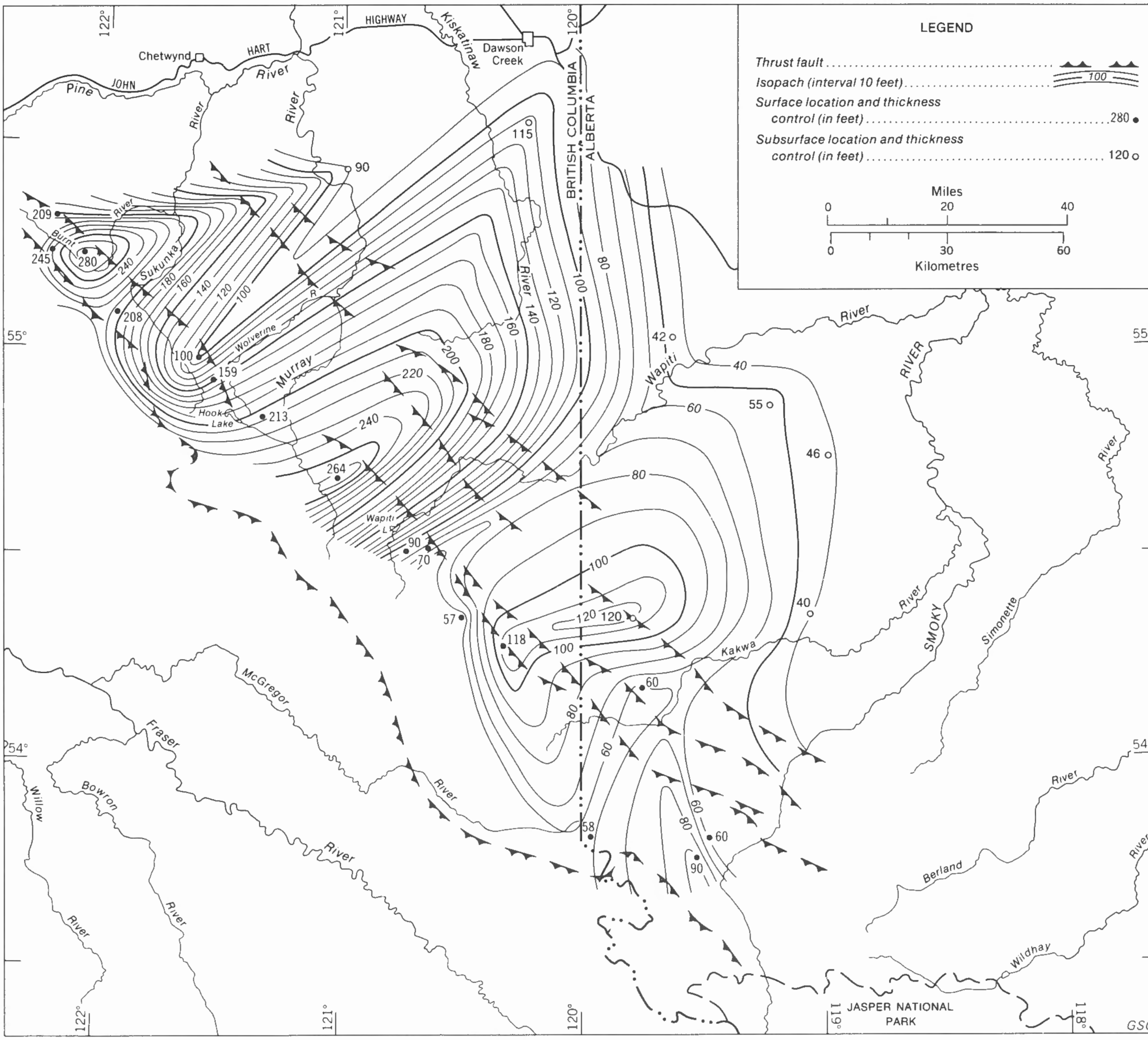

FIGURE 10. Isopach map of Whistler Member.

and conglomerate interbeds at the base of the member are associated generally with the "shelf" or thinning trends designated on the map. Conversely, those lacking phosphatic sandstone and conglomerate and characterized by gradational contacts above and below the Whistler Member are associated with the basin or thickening trends outlined on Figure 10. The isopach configuration shown on Figure 10 appears, therefore, to be in part the result of contemporaneous sedimentation on a surface with minor local relief. At some localities, particularly in the Front Ranges near Smoky River, isopach trends may be a result of structural deformation by folding and thrust faulting.

The contact of the Whistler with the overlying Llama Member is sharp at some localities and gradational at others. Where sharp, the contact is placed where the recessive, thin to medium bedded siltstone and silty limestone of the Whistler Member are overlain by thicker bedded, cliff-forming siltstone of the Llama Member. The gradational contact at sections near Hook Lake and between Sukunka River and Pine Pass is placed at the base of an interval where more resistant, paler grey weathering, and thicker bedded siltstone characteristic of the Llama Member forms the predominant lithology.

Llama Member

The Llama Member comprises a resistant sequence of thin to thick bedded dolomitic quartz siltstone, silty and bioclastic limestone, and lesser amounts of dolomitic quartz sandstone and dolostone (Pl. 2D), ranging from Middle Triassic Late Anisian to Late Ladinian age.

Measured thickness ranges from 1,170 feet at West Burnt River (Sec. 25, Fig. 2) to 210 feet near Lick Creek (Sec. 36, Fig. 2). Figure 11 indicates a general stratigraphic thickening from east to west across the topographic and structural grain of the region.

The contact with the overlying Charlie Lake and Whitehorse Formations may be gradational or sharp and distinct, according to location. In the Pine Pass – Sukunka River area, the Llama Member is overlain gradationally by the Charlie Lake Formation. The contact is placed at the level where the orange to greyish brown weathering sandstone and siltstone of the Llama Member grade upward into yellow weathering sandstone, dolostone, and intraformational and/or solution breccia of the Charlie Lake Formation. A similar contact relationship exists between the Llama Member and Starlight Evaporite Member of the Whitehorse Formation between Sukunka and Smoky Rivers. At some localities south of Sukunka River, however, the contact is sharp and distinct and is placed where the orange-brown weathering siltstone and sandstone of the Llama are overlain by pale grey to yellow weathering sandstone, silty dolostone, siltstone, and pelecypod coquinas of the Starlight Evaporite Member (Pl. 3C). In the Plains area to the east, the Llama Member is overlain in the subsurface by pale grey quartz sandstone of the Halfway Formation, a subsurface facies equivalent to the Liard Formation north of Pine Pass. The

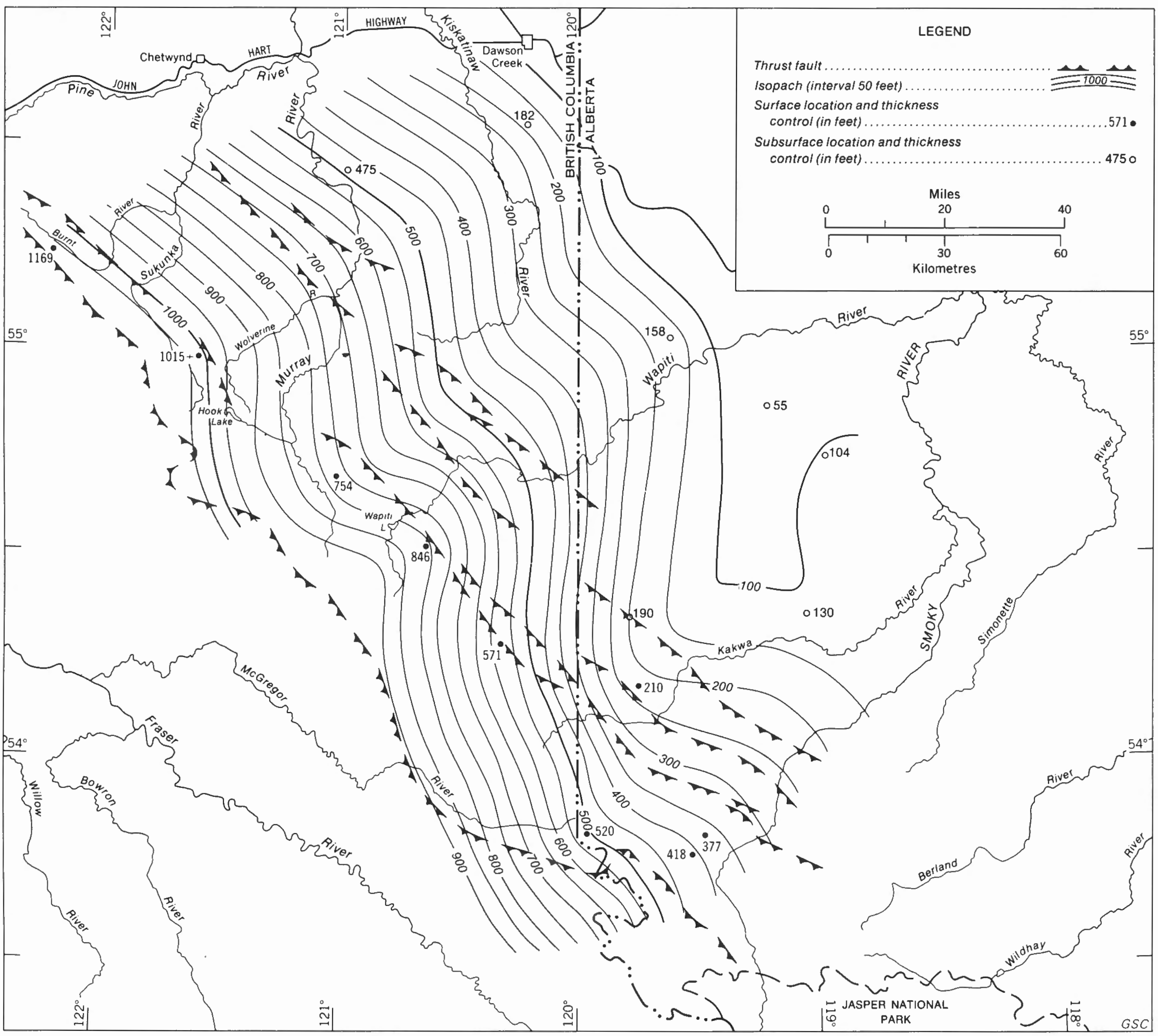

FIGURE 11. Isopach map of Llama Member.

Halfway Formation is, however, not recognizable as a map-unit in exposures within the Foothills and Front Ranges south of Pine Pass.

At Lick Creek (Sec. 36, Fig. 2), small, elongate, calcareous conical tubes of probable annelid origin were observed in some samples of the Llama Member (Pl. 9D). These organisms may have been responsible partly for much of the bioturbate mottling characteristic of the upper Llama Member at many localities of the report-area. In addition, the upper Llama Member is characterized at many sections by black to dark grey carbonaceous films, up to 8 inches long and ½ to 1 inch wide, which the writer interprets to be mainly aquatic plant stems and stem fragments (Pl. 9E). A few field samples and thin sections reveal a circular cross-section for some fragments, with an internal sediment texture and composition similar to that of the surrounding rock. This feature suggests that some and perhaps all the films were originally hollow and later compressed by the weight of the overlying sediment.

Whitehorse Formation

The name Whitehorse Formation is used for strata overlying the Sulphur Mountain Formation in the Sukunka–Smoky River area. Contiguous strata in the remainder of the area between Sukunka River and Pine Pass are given a different nomenclature, and were included in foregoing descriptions of Upper Triassic rocks of the Sikanni Chief River – Pine Pass area. Complete and undeformed sections of the Whitehorse Formation are scarce in the region, because of talus cover, post-Laramide erosion and structural complexities. The Whitehorse Formation is divided into three members, in ascending order: Starlight Evaporite, Brewster Limestone, and Winnifred (Fig. 3). Because of the lack of good exposures and adequate thickness control, isopach maps were not prepared. The Whitehorse Formation is overlain disconformably by the Jurassic Fernie Formation (Pl. 3B).

Starlight Evaporite Member

This member consists of a variegated sequence of recessive, yellowish brown to grey weathering dolostone, sandstone, siltstone, limestone, and intraformational and/or solution breccia, and ranges in thickness from a maximum of 700 feet at Meosin Mountain (2 miles southwest of Sec. 35, Fig. 2) to a minimum of 230 feet near Lick Creek (Sec. 36, Fig. 2). Near Casket Mountain (5 miles southeast of Sec. 37, Fig. 2), the Starlight Evaporite Member contains beds of folded and contorted white gypsum. A description of the stratigraphy and of the gypsum at this locality is given by Govett (1961). The member contains a few poorly preserved and fragmented indeterminate pelecypod shells. Based on relative stratigraphic position with the Charlie Lake Formation to the north, however, the age of the Starlight is considered to be Karnian (Fig. 13).

The Starlight Evaporite Member is overlain conformably but abruptly by the Brewster Limestone Member at most localities (Pl. 3B). The contact is placed where the yellow to grey, calcareous and dolomitic sandstone and siltstone of the Starlight are abruptly overlain by pale to medium grey weathering, cliff-forming limestone of the Brewster. At Meosin Mountain, however, the contact is gradational with the Brewster, and is placed at the base of an interval in which pale grey limestone predominates.

Brewster Limestone Member

The Brewster Limestone Member (Pl. 3B), in its limited exposure, forms a distinctive pale grey, resistant, cliff-forming, medium to thick bedded sequence of limestone, with minor amounts of dolostone and intraformational breccia. The limestone is very finely crystalline to bioclastic. It commonly contains pale grey lenses of chert up to 6 inches long. Fossils are mostly fragmented and detailed identification is not possible. The member is considered, however, to be of Karnian age (Gibson, 1968a, p. 25). Measured thickness ranges from 65 feet at Lick Creek (Sec. 36, Fig. 2) to a maximum of 105 feet at Meosin Mountain to the west (Fig. 2).

The contact between the Brewster Limestone Member and the overlying Winnifred Member is sharp and conformable, and is placed at a prominent lithological break where the cliff-forming, pale grey weathering limestone of the Brewster changes to more recessive, darker weathering dolostone and siltstone of the Winnifred Member.

Winnifred Member

The upper member of the Whitehorse Formation is absent throughout most of the Sukunka–Smoky River area. Where exposed, however, it consists of a slightly recessive, yellowish grey weathering, medium-bedded sequence of dolostone and limestone, with minor intercalated beds of sandstone, siltstone, and intraformational breccia; dolostone forms the predominant lithology. The dolostone is commonly quartzose, slightly calcareous, very fine to medium crystalline, and breaks with a subconchoidal fracture. Dark grey chert lenses and nodules as much as 6 inches long are found in the upper beds of the member. No fossils were collected; however, the equivalent facies south of Smoky River contains a sparse fauna of probable Middle or Late Triassic age (Gibson, 1965, p. 12).

The Winnifred Member is overlain disconformably by the Jurassic Fernie Formation (Pl. 3B), which consists of dark grey to black shale with, at some localities, a basal, phosphatic, quartzose pebble conglomerate up to 3 inches thick (Pl. 3B). The dark grey to black weathering shale of the Fernie Formation contrasts sharply with the paler grey weathering carbonates of the Triassic Winnifred Member.

Correlation

The correlation of Triassic rocks in the Sikanni Chief – Smoky River area has been documented and discussed by McLearn and Kindle (1950), Hunt and Ratcliffe (1959), Colquhoun (1960, 1962), Armitage (1962), Barss *et al.* (1964), Tozer (1967), and Gibson (1968a, 1971b, 1972). Figure 12 is a stratigraphic cross-section illustrating the lithology, lithologic relationships and stratigraphic equivalence of surface and subsurface rock-units in the Sikanni Chief – Smoky River area. Figure 13 is a nomenclature and correlation chart illustrating the equivalence or correlation of rock-units in the report-area, and their relationship and time equivalence to

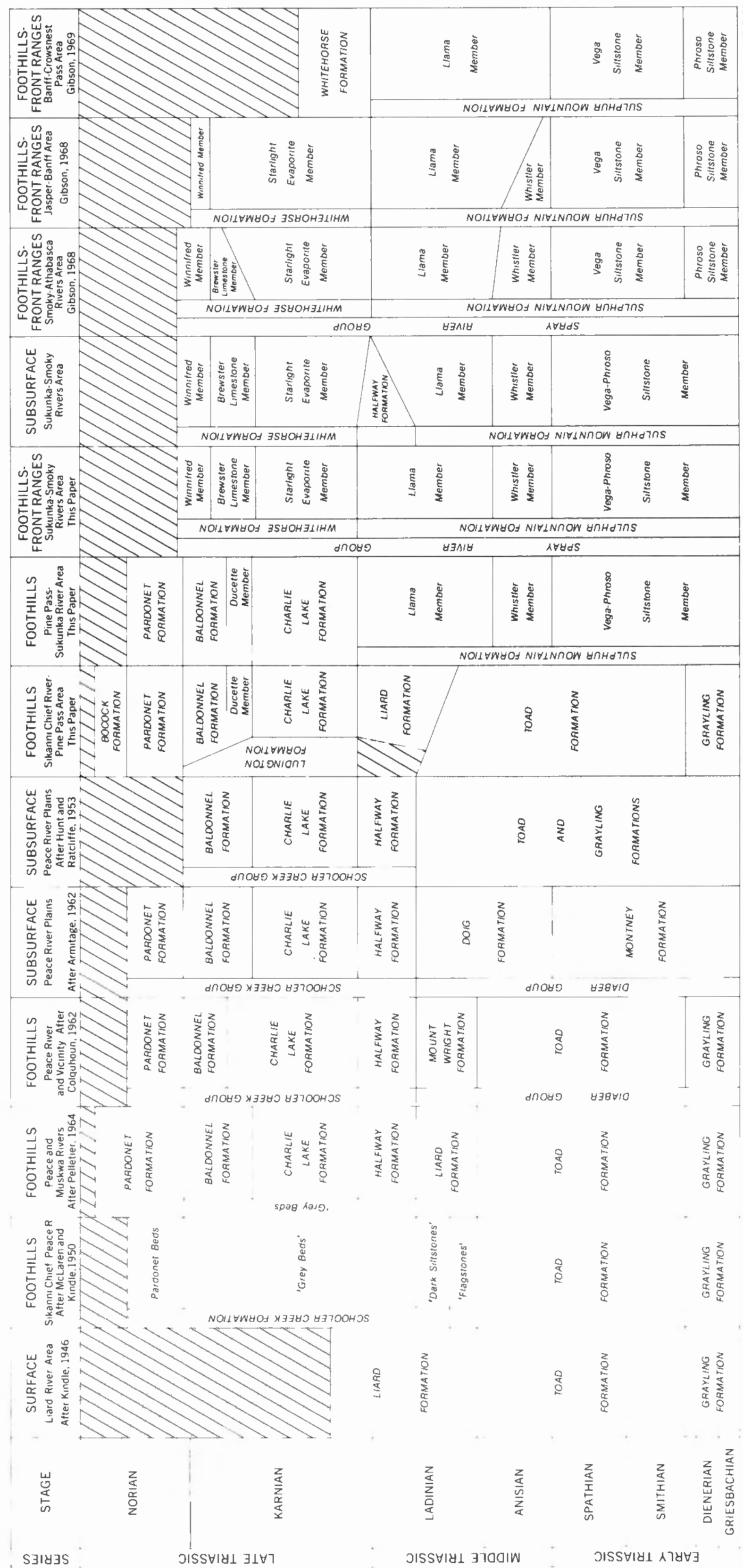

FIGURE 13. Correlation chart illustrating suggested equivalence between Triassic formations and members of this report and those of adjacent surface and subsurface areas of British Columbia and Alberta.

other Triassic rock-units in other areas of the Western Canada Sedimentary Basin of Alberta and British Columbia. A brief outline follows of the correlation of stratigraphic units within the report-area, and their equivalence and relationship to the Triassic members and formations, including the subsurface, recognized in other areas of British Columbia and Alberta. Emphasis is placed, however, on modifying or amending the writer's preliminary correlations made before all phases of the investigation were complete. Correlation with some subsurface units must remain speculative because of the absence of fossil control, and because all available well samples and cores from the adjacent Triassic of the Plains area have not been examined systematically.

Triassic nomenclature and subdivisions between Pine Pass and Smoky River are used as a reference. The Sulphur Mountain Formation is shown as a correlative of the Grayling, Toad, and Liard Formations in the Foothills of the Sikanni Chief River – Pine Pass area; the Grayling, Toad and part of the Liard Formation in the Liard River area; and the Montney, Doig, and Halfway Formations in the Peace River Plains (Fig. 13). South of Smoky River, the Sulphur Mountain Formation contains all major lithofacies recognized in the Pine Pass – Smoky River area. In this region, however, the Vega–Phroso Member can be subdivided and mapped as two separate stratigraphic units. The prominent lithological break between the Whistler and Vega–Phroso Members is not apparent in exposures of the Toad Formation north of Pine Pass. Correlation between the Whistler and equivalent lithofacies of the Toad can, however, be confirmed readily by fossils. In the Peace River Plains, the contact recognized between the Whistler and Vega–Phroso Members at the surface is evident at most localities in the subsurface and provides the basis for subdividing the Daiber Group into the Montney and Doig Formations. In well cuttings from the subsurface of the Alberta Foothills to the south between Sukunka and Smoky Rivers, this lithologic break generally is very subtle and difficult to observe. Nevertheless, the Whistler contacts and lithofacies generally correspond to a marked increase or reflection trace on Gamma Ray–Neutron log records. In the subsurface of the same area, the Sulphur Mountain Formation is overlain by a pale grey to yellowish brown quartz sandstone unit referred to by most subsurface geologists as the Halfway Formation. Examination by the writer of samples from wells containing the Halfway sandstones indicates that the formation, in this region, grades westward and southward into strata characteristic of both the Llama and Starlight Evaporite Members of the Sulphur Mountain and Whitehorse Formations. Therefore, on the basis of stratigraphic position and lithologic similarity, and in the absence of diagnostic fossils, the subsurface Halfway Formation is considered to be correlative mainly with the Llama Member of the Sulphur Mountain Formation, but partly with the basal Starlight Evaporite Member of the Whitehorse Formation, as shown in Figures 12 and 13.

The Whitehorse Formation, comprising the Starlight Evaporite, Brewster Limestone, and Winnifred Members, is correlated with the Charlie Lake, Baldonnel, and possibly part of the Pardonet Formation. The Starlight Member, in the Sukunka–Smoky River area, is equivalent to the Starlight lithofacies recognized throughout the Jasper–Banff region of Alberta. In the Foothills north of Sukunka River, the Starlight Member can be correlated with the Charlie Lake Formation and with most of the Ludington Formation in the extreme western Foothills north of Peace River (Fig. 13). In the area between Sukunka and Smoky Rivers, the Brewster Limestone Member is poorly exposed. This distinctive limestone unit can be recognized easily and extended into some eastern subsurface locations as shown on Figure 12, and correlated with equivalent beds in the type area south of Smoky River. South of Athabasca River, the Brewster Limestone Member interdigitates and grades laterally into strata typical of the Starlight Evaporite Member. North of Sukunka River, the Brewster Member is correlated with the Baldonnel Formation, to a stratigraphic level above the Ducette Member. The Brewster Limestone Member probably may be correlated with part of the upper Ludington Formation, as shown on Figures 12 and 13. This suggested correlation is based on lithologic similarity between the Baldonnel limestones and upper Ludington lithofacies. The correlation between the Baldonnel Formation and Brewster Limestone Member is based partly on lithologic similarity and relative stratigraphic position, but mainly on the occurrence of *Lima poyana*.

The Winnifred Member is equivalent to the remainder of the Baldonnel Formation north and east of Sukunka River and to the upper part of the Ludington Formation and possibly the lower part of the Pardonet Formation in the Sikanni Chief River – Pine Pass area (Fig. 3). The equivalence to basal Pardonet strata is based on the occurrence of a dark brownish grey weathering dolomitic siltstone unit commonly found at the top of the Winnifred Member at some localities near Smoky River, and at the base of the Pardonet Formation near Pine Pass.

The Pardonet Formation is recognizable throughout the Foothills area of northeastern British Columbia; however, it does not extend any great distance to the east into the subsurface Foothills area, nor south of Burnt River. Most of the Pardonet Formation appears to have been removed by pre-Jurassic erosion.

The youngest Triassic rocks exposed in the Sikanni Chief – Smoky River area are represented by the Bocock Formation, a distinctive pale grey weathering limestone lithofacies found in the Foothills of the Pine Pass – Peace River area. A lithologically similar limestone facies occurs above the Pardonet Formation in the Placid Federal C-29-E well (No. 4, Fig. 12) north of Peace River. This limestone unit is correlated with the Bocock Formation.

PETROLOGY

Petrological studies of Triassic rocks in the Foothills and Front Ranges of the Sikanni Chief – Smoky River area have been limited largely to strata of the subsurface Schooler Creek Group north of Peace River and to the Whitehorse Formation between Sukunka and Smoky Rivers, because of their economic potential as possible hydrocarbon reservoirs and evaporite mineral deposits. In the Peace River Plains, the Halfway and Baldonnel Formations and the Coplin and Inga Members of the Charlie Lake Formation contain large reserves of oil and natural gas whereas, in the Front Ranges near Casket Mountain (Sec. 37, Fig. 2), the Whitehorse Formation contains gypsum in the Starlight Evaporite Member.

The following discussion includes a detailed description and analysis of the detrital and chemical mineralogy of the total Triassic rock succession, and a discussion of insoluble residue analyses and trends in the Sulphur Mountain and Toad Formations. X-ray, chemical and mineralogical analyses were undertaken on many selected samples of the Sulphur Mountain and Toad Formations as a means of identifying clay, opaque minerals, and submicroscopic minerals, and to check semiquantitative mineral estimates made during the petrographic studies. These analyses were performed by A. E. Foscolos, R. R. Barefoot, and A. G. Heinrich of the Geological Survey of Canada, and the results are included in the Appendix. Paleocurrent observations were recorded wherever possible in the report-area; directional current structures were not as numerous as had been anticipated. Preservation was generally poor, so that reliable field azimuth values were difficult to obtain and interpret. Because of these facts the writer's recorded random observations are of limited value for a detailed discussion of paleocurrents; they are incorporated into the paleoenvironmental analysis at the end of this report. Pelletier (1965) discussed Triassic paleocurrents in northeastern British Columbia, which includes part of the Sikanni Chief – Smoky River area of the present report.

To facilitate comparisons between the Triassic rocks of the Sikanni Chief – Smoky River area and those studied earlier in the Front Ranges of the Rocky Mountains of southern Alberta and southeastern British Columbia, the petrographic discussion follows a format used previously (Gibson, 1971a; 1974).

Descriptive Mineralogy

Quartz–chalcedony

Detrital quartz is commonly the most abundant non-carbonate component of the Triassic rock assemblage in the report-area. Most grains are angular to subangular, although subrounded to well-rounded ones are common in the sandstone and sandy limestone and dolostone of the Whitehorse and Charlie Lake Formations. The size of quartz ranges from medium and coarse silt (0.03 to 0.065 mm) to medium grained sand (up to 0.55 mm); the former size range predominates in strata of the Grayling, Toad, Liard, and Sulphur Mountain Formations.

Near Smoky River, quartz forms a characteristic "welded" or quartzitic texture in many samples of the Sulphur Mountain Formation similar to that shown in Plate 4 (A, B), a feature previously noted in Sulphur Mountain strata of the Jasper–Banff region to the south (Gibson, 1971a). In the Sikanni Chief River – Pine Pass area to the north, however, the quartzitic texture is uncommon, and most detrital quartz, as well as feldspar, occurs as "floating" or carbonate-supported grains in a cement and matrix of calcite and/or dolomite (Pl. 4C, D). Many of the samples of the Sulphur Mountain Formation characterized by quartzitic textures display evidence of silica solution or replacement by calcite or dolomite (Pl. 4E), a diagenetic feature common in strata of the Sulphur Mountain Formation south of Smoky River (Gibson, 1971a). This diagenetic replacement is not as common in the report-area as it is in the southern area. The general nature, geochemistry, and evidence of carbonate replacement of quartz grains have been discussed and illustrated by Carozzi (1960), Walker (1957, 1960), Siever (1962), Glover (1964), Peterson and von der Borch (1965), Sharma (1965), and Gibson (1971a). The silica dissolved from the detrital grains is considered to serve as a silica source for overgrowths and cement in some of the siltstone displaying quartzitic textures. The general absence of well-developed quartzitic textures in strata north of Smoky River suggests a low degree of silica replacement by carbonate minerals in this area. The apparent degree of corrosion or etching of quartz grains as seen in thin sections appears to be related to the size of carbonate crystals in contact with the quartz. The coarser the crystallinity of the carbonate in contact with the detrital quartz, the more apparent is the etching or corrosion of the detrital grain. In some observations, this size relationship in part may be the result of an optical illusion effect (Folk, 1964, p. 67). The illusion of etching is created by the overlapping of the crystalline carbonate onto the smooth edges of the detrital quartz.

Some quartz in the upper half of the succession displays well-developed euhedral overgrowths, which are outlined by a rim of reddish brown iron staining or by clear, small bubble-like inclusions or vacuoles between the parent grain and the overgrowth. In some samples of the Charlie Lake Formation, quartz also occurs as well-rounded grains surrounded by a thin rim of quartz of variable thickness that has the appearance of an overgrowth. These grains, however, probably represent recycled grains derived from a sedimentary quartzite or quartz sandstone with the quartz rim representing part of the original quartz cement of the quartzite or quartz sandstone terrain.

Many quartz grains observed in this study contain scattered authigenic inclusions of either apatite, and/or pyrite, carbonate, and acicular crystals of rutile, and are commonly characterized by straight to slightly undulose extinction. Characteristics similar to these grains have been observed in other sedimentary quartz grains, some of a different age, by Anderson and Picard (1971) and Gibson (1971a), and it has been suggested that they are related to the detrital grain size. For example, in many observations, the coarser grained quartz contains a relatively larger percentage of authigenic inclusions and a slightly higher degree of undulose extinction than in quartz of silt or very fine sand grain size. This feature is particularly evident in samples of quartzose rocks from the Whitehorse and Charlie Lake Formations. However, these observations may be related also in part to microscope optics and ease of observation. The coarser grains are generally more prominent, with the inclusions and type of extinction easier to observe. The rutilated quartz grains were observed only in the Liard and Charlie Lake Formations suggesting, perhaps, a different source area for these grains. Blatt *et al.* (1972, p. 276) suggest that acicular inclusions of rutile are common in granitic quartz.

Associated with the detrital monocrystalline quartz described above are angular to subangular grains of microcrystalline quartz (composite crystals less than 0.02 mm in diameter) that are most common in the siltstone of the lower Sulphur Mountain and Toad and Grayling Formations (Pl. 4E, F). The source rocks for these silt-sized polycrystalline grains were most likely the sandstones and cherts of the Permian Fantasque, Debolt, and Mowitch Formations, or possibly chert-bearing carbonates of the Lower Carboniferous. Chalcedony occurs as a secondary or diagenetic replacement of carbonate shells and shell fragments in samples of the Liard, Charlie Lake, and Baldonnel Formations. Folk and Pittman (1971) reported that chalcedony with length-slow optical properties was associated with sediment deposition under evaporitic conditions. On testing this hypothesis on a few of the above-mentioned samples, it was found that the chert displayed only length-fast optical properties despite the known occurrence of interbedded evaporites in the subsurface Charlie Lake Formation and the Starlight Evaporite Member of the Whitehorse Formation.

The nature, composition, and relative concentration of the quartz–chalcedony in relation to other detrital minerals of the rock succession suggest a derivation mainly from a preexisting sedimentary rock source area. The few grains of rutilated quartz, however, may have been derived from a granitic terrain.

Feldspars

Feldspar grains, comprising, in order of decreasing concentration, orthoclase, plagioclase and microcline, occur throughout all siltstone, sandstone, silty limestone, and dolostone of the report-area. They occur with detrital quartz, and together constitute a large proportion of the total non-carbonate mineral components. In selected samples of the Sulphur Mountain and Toad Formations, concentration values between 20 and 30 per cent by weight were common (Table 7, Appendix). The feldspars display many of the textural and diagenetic features common to quartz.

Orthoclase, the most common variety of feldspar, represents approximately 60 per cent by weight of the total feldspars in the rock samples analyzed. It occurs as angular silt-sized grains in part displaying corroded grain boundaries, the probable result of carbonate replacement. Most grains "float" or, less commonly, are welded into clumps with the detrital quartz and other feldspars, forming a quartzitic texture, a feature of some siltstone of the Sulphur Mountain, Grayling, and Toad Formations. Most of the orthoclase is anhedral, although subhedral to euhedral crystal faces and overgrowths are common in some samples from the Sulphur Mountain, Whitehorse, and Charlie Lake Formations. Euhedral orthoclase overgrowths were observed on a few samples with the overgrowth rim developed on a well-rounded grain, although the overgrowth was not in optical continuity with the host orthoclase grain. Semiquantitative estimates of the orthoclase concentration in many thin sections, using the AGI Visual Estimation of Percentage Composition Chart (Terry and Chilingar, 1956), suggest a relatively small amount of orthoclase feldspar in comparison to quartz. However, chemical and X-ray analyses of samples first studied microscopically reveal a significantly greater orthoclase concentration in the analyzed samples. These larger values suggest that some of the orthoclase occurs as very small to submicroscopic grains in the cement and matrix of the siltstone and sandstone. In addition, most carbonate and non-carbonate textural relationships in strata of the Sulphur Mountain, Grayling, and Toad Formations are masked by opaque to semi-opaque carbonaceous-ferruginous matter. Consequently, much of the very fine to submicroscopic orthoclase may not be either readily apparent or even visible using a standard petrographic microscope. It is possible that much of the very fine grained feldspar represents an authigenic replacement; however, no evidence in the form of overgrowths or feldspar replacements has yet been observed in the Triassic siltstone and shale to justify this interpretation.

Chemical and X-ray analyses indicate that plagioclase, the second most abundant feldspar, constitutes up to 12 per cent by weight of the total mineral components or approximately 35 to 40 per cent by weight of the total feldspar minerals in the rock succession. Again, utilizing numerous thin sections and a standard petrographic microscope, semiquantitative estimates of the plagioclase indicate very low volumetric concentrations. These concentration estimates were based mainly on the recognition of the albite or polysynthetic twinning in the detrital grains. The relatively high plagioclase concentration recorded by chemical analyses suggests, therefore, that much of the plagioclase, like the orthoclase, is very fine grained and not readily apparent, or may occur as untwinned grains which easily can be mistaken for quartz or orthoclase feldspar. Recently, Middleton (1972) described an occurrence of untwinned plagioclase from Cambrian sandstone of the Charney Formation near Quebec City. These grains were interpreted, however, as a diagenetic alteration of perthite or potash feldspar. Some of the plagioclase in the Triassic succession of the report-area may have a similar origin but, if so, it does not display any of the textural or cleavage patterns characteristic of the original potash feldspar. Furthermore, the untwinned plagioclase described from the Charney Formation is different in optical appearance from the associated quartz (Middleton, 1972). Plagioclase grains in the Triassic samples which display good polysynthetic and albite twinning, when coupled with good 010 cleavage, indicate a composition in the albite-oligoclase range. The textural parameters of plagioclase are similar to those for orthoclase, except that euhedral crystals and authigenic overgrowths were not observed in plagioclase.

Microcline, the least abundant of the feldspar varieties observed in the succession, forms a ubiquitous but quantitatively insignificant mineral of the non-carbonate detrital components. All grains are distinguished readily by their unique cross-hatched or grid-twinning.

Many of the feldspars have undergone minor diagenetic alteration, chiefly in the form of replacement by carbonate minerals, a process also common to quartz. In addition, some feldspars show incipient alteration to clay minerals in some siltstone and sandstone of the Sulphur Mountain, Toad, and Liard Formations.

Collophane

Collophane (carbonate fluorapatite), a cryptocrystalline mineral of the apatite group of minerals, occurs throughout most strata of the report-area, although generally in quantitatively insignificant concentrations, rarely exceeding 1 per cent of the total mineral components. Within certain stratigraphic intervals of the Vega–Phroso and Whistler Members of the Sulphur Mountain Formation and the Toad Formation, phosphate occurs in concentrations up to 71 per cent by weight of the mineralogy with a P_2O_5 concentration up to 30 per cent by weight (Tables 4 and 6, Appendix). The phosphate in these formations occurs as thin conglomerate and sandstone beds up to 6 inches thick (Pl. 5A, D), and as thin lenses and nodules randomly dispersed in the lower Toad Formation over several tens of feet of strata. In most chemically analyzed samples, phosphate was recorded in relatively minor concentrations (Table 6, Appendix). The collophane in these analyzed samples was not apparent in thin sections of the same sample because of the staining and masking effect of brown opaque to semi-opaque carbonaceous-ferruginous matter.

The collophane occurs most commonly as well-rounded grains, pellets, and ooliths with the detrital quartz and feldspar in many of the siltstone and sandstone of the Sulphur Mountain, Toad, and Liard Formations, or less commonly as well-indurated, fine to medium grained phosphatic sandstone strata at the base of the Whistler Member at some localities (Pl. 5A, B, C). Furthermore, these three textural types combine to form the subangular to well-rounded phosphate clasts of the conglomerate beds found also at the base of the Whistler Member. Many ooliths are characterized by well-developed concentric banding, commonly encompassing nuclei or cores (Pl. 5C) of either detrital quartz, feldspar, shell fragments, calcite, dolomite, or rarely pyrite, although in some oolites no nucleus or core is apparent (Pl. 5A, B). Textural relationships suggest that some of these coreless ooliths represent a replacement or phosphatization of well-rounded carbonate grains, which subsequently developed the oolitic banding now preserved around the grains. Most ooliths range in size between 0.10 and 0.40 mm, although ooliths up to 1 mm in diameter are not uncommon. Many of the well-rounded grains and pellets of collophane which are commonly associated with the oolitic sandstone and conglomerate contain minute inclusions of opaque to semi-opaque carbonaceous-ferruginous matter.

Collophane also occurs as irregularly shaped replacement patches in some of the limestone, dolostone, and siltstone of all formations, and as replaced bioclasts in some limestone of the Baldonnel and Charlie Lake Formations. In many samples of siltstone from the Llama Member of the Sulphur Mountain Formation, blue-black to black phosphate occurs as distinct laminated "shreds" or shell fragments, derived from lingulid and/or orbiculid inarticulate brachiopods.

As with most other minerals of the Triassic rock succession, phosphate has been diagenetically altered, in part by carbonate minerals in some samples, and by chert or silica in other samples.

The origin and nature of deposition of sedimentary phosphate, whether deposition took place under deep or shallow water conditions, have long been contentious issues. Many workers, including Bushinski (1964), Bromley (1967), Russell and Trueman (1971), and Oleinik (1972), are now of the opinion that much of the phosphate in the geological column had been formed and was deposited under relatively shallow water conditions, an origin favoured by the writer for the Triassic phosphate of the west-central area of Alberta (Gibson, 1971a, p. 15).

Layered Silicate Minerals
(Mica, chlorite–glauconite, clay minerals)

The layered silicates, consisting of mica, chlorite–glauconite, and the true clay minerals, occur in variable concentrations up to 17 per cent by weight of the total mineralogy in most Triassic strata in the region, although they appear to be most common in samples of siltstone and shale from the Sulphur Mountain, Grayling, Toad, and Liard Formations. The layered silicates were identified by means of a petrographic microscope where possible, and/or by X-ray diffractometer and chemical analyses (Appendix) where clay minerals were suspected but not apparent in thin section.

Mica occurs as angular grains or flakes of muscovite as much as 0.09 mm in longest apparent dimension, generally aligned parallel to the bedding and laminations in the carbonaceous-ferruginous siltstone of the Sulphur Mountain, Grayling, and Toad Formations, in concentrations ranging from zero to 5 per cent by volume of the detrital components. The muscovite concentration decreases from the base to the top of the rock succession, so that it was rarely observed in formations younger than the Whitehorse, Charlie Lake, or Ludington. The anhedral nature, relationship to surrounding minerals, and parallel alignment of most muscovite grains to laminations and bedding suggest that much of the muscovite is of detrital origin rather than an authigenic replacement of carbonate cement. Some thin sections of siltstone from the Toad, Grayling, and Sulphur Mountain Formations did not reveal any muscovite. Chemical and X-ray analyses of the same samples, however, indicated layered 2:1 silicates, in concentrations up to 5 per cent by weight. These values represent probable illite whose identification in thin sections was not possible by optical methods because of the masking or coating effect of the brown, opaque to semi-opaque carbonaceous-ferruginous matter as discussed below. Illite is considered to be a common mineral of the Triassic strata, in most analyses exceeding the concentration of muscovite.

Chlorite–glauconite, 2:2 and 2:1 ferruginous layered silicates, respectively, could not be identified as separate minerals during microscope work because of the small grain size, similar colour, and optical properties of the two minerals. Therefore, they were grouped and treated as a single mineral type. The green chlorite–glauconite occurs as traces (less than 1 per cent by volume) throughout the rock succession, but is relatively abundant in the siltstone samples of the Grayling, Toad, and Sulphur Mountain Formations.

Kaolinite, a 2:2 layered silicate, was identified mainly by chemical and X-ray diffraction methods (Table 6, Appendix). Clay minerals resulting from the alteration or decomposition of feldspars were noted, however, in thin sections of siltstone from the Liard and Vega–Phroso Members, and are considered to be kaolinite.

Opaque Minerals

The opaque minerals and other components comprise, in order of relative abundance, organic-carbonaceous matter, pyrite, and iron oxides. Although quantitatively insignificant, they form a diagnostic and conspicuous feature of some Triassic formations and members in the Sikanni Chief – Smoky River area, as well as in other areas of Western Canada. They are directly responsible for the dark grey to black colour of Lower, Middle, and some Upper Triassic strata.

The black to brown, opaque to semi-opaque organic-carbonaceous matter, identified by D.T.A. and X-ray diffraction techniques, is found throughout most rock-types of the Sulphur Mountain, Grayling, Toad, and Pardonet Formations, and part of the Liard and Baldonnel Formations depending on location in the report-area. The carbonaceous matter occurs as thin laminations, disseminated aggregates, and grain coatings in concentrations ranging mainly between 1 and 3 per cent by weight, and rarely up to 15 per cent of the total mineral components (Table 8, Appendix). The greatest concentrations and, consequently, the darkest strata occur in samples of the Vega–Phroso and Whistler Members of the Sulphur Mountain Formation, and in the Grayling and Pardonet Formations. Table 8 is a comparative chart illustrating the relationship between organic-carbonaceous concentration and degrees of darkness in some selected field samples. The results, compiled by R. R. Barefoot of the Geological Survey, illustrate that organic-carbonaceous matter largely is responsible for the dark colour of the siltstone and carbonate of the Triassic strata. Table 8 also shows a similar relationship for pyrite but not to the same degree as the organic-carbonaceous matter.

Pyrite, in concentrations up to 4 per cent by weight of the mineral components in some selected samples, occurs as small euhedral crystals and cubes, microaggregates, and as thin lenticular laminations up to ½ inch thick, and generally is found associated with the organic-carbonaceous matter. The association of pyrite and carbonaceous matter was such that differentiation using a petrographic microscope generally was not possible and, consequently, necessitated a chemical or X-ray analysis to differentiate the two constituents. Therefore, for convenience, and for ease of discussion and recognition, they were treated as a single component and indicated as carbonaceous-ferruginous matter. The presence of the pyrite and organic-carbonaceous matter together in samples of the Sulphur Mountain, Grayling, Toad, and Pardonet Formations suggests that these sediments were deposited in a restricted, possibly euxenic, environment, although some of the pyrite may have been introduced at a later time as a result of diagenesis.

Trace amounts (less than 1 per cent by weight or volume) of reddish brown ferric oxide or hematite were observed coating terrigenous grains and filling small pores or voids in some of the sandstone and intraformational breccia of the Charlie Lake and Whitehorse Formations. The ferric oxide probably formed as a result of post-depositional alteration of iron-bearing minerals.

Miscellaneous Minerals

Miscellaneous minerals form a ubiquitous but quantitatively insignificant rock component in the report-area, rarely exceeding 1 per cent by volume of the total mineral content. They include the common "heavy" minerals such as zircon, tourmaline, rutile, apatite, and gypsum.

Colourless, subrounded to well-rounded grains of zircon, up to 0.10 mm in diameter, were found as traces throughout most non-carbonate detrital rocks of the succession. Pleochroic brown to green tourmaline occurs as equidimensional to elongate grains, commonly displaying smooth parallel sides and well-rounded ends, with a detrital size range and distribution similar to that of zircon. Reddish brown to amber rutile occurs as well-rounded, silt-sized grains in many siltstones of the Sulphur Mountain, Grayling, and Toad Formations. In addition, acicular, euhedral crystals were observed as small authigenic inclusions in some quartz grains of the Liard and younger formations. Similarly, colourless, euhedral apatite crystals were noted as small inclusions in some detrital quartz and feldspar grains.

Near Casket Mountain (Sec. 37, Fig. 2) at Forget-me-not Pass, white gypsum was observed interbedded with dolostone, limestone, and intraformational and/or solution breccia of the Starlight Evaporite Member of the Whitehorse Formation. This gypsum is fibrous to prismatic, commonly forming a felted, interlocking mosaic. The gypsum is considered to be a product of a highly saline, evaporitic, shallow water environment. For a more detailed account of the Triassic gypsum deposit near Casket Mountain, the reader is referred to a report by Govett (1961).

Carbonate Minerals

Carbonate minerals volumetrically form one of the most conspicuous and abundant mineral assemblages in the Triassic rocks of the area. They comprise, in order of relative abundance, calcite, dolomite, and siderite, occurring mainly as cement and matrix in the siltstone and sandstone of the Sulphur Mountain, Grayling, Toad, and Liard Formations, and as detrital grains, ooliths, pellets, clasts, bioclasts, and calcispheres in the same and younger formations of the region forming, in places, distinct mud- or grain-supported carbonate rocks.

The carbonate minerals are recrystallized, a feature apparently common to all Triassic rocks in the Western Canada Sedimentary Basin, so that many original textures and structures are poorly preserved or are difficult to observe. Because of this feature and the presence of a generally high non-carbonate detrital rock component, specific textural or genetic carbonate classifications were not employed. An earlier classification, adopted by the writer for carbonate textures and strata in the Jasper area (Gibson, 1971a), was found to be impractical in classifying carbonate rocks of the Sikanni Chief – Smoky River area.

Throughout most of the report-area, dolomite occurs as a very fine to medium recrystallized mosaic, as individual "floating" or mud-supported subhedral to euhedral crystals, and as well-rounded silt- and sand-sized grains, pellets, and clasts (Pls. 5E, F, 6A–F). The dolomite is found mainly in strata of the Whitehorse and Charlie Lake Formations occurring as distinct beds or as series of beds intercalated with the other strata. In the vicinity of Smoky River, the dolomite is the main carbonate component of the Sulphur Mountain Formation, where it occurs as a fine to medium crystalline cement for much of the siltstone of the Vega–Phroso and Llama Members. This feature is characteristic of most Sulphur Mountain strata in the Jasper–Banff area to the south (Gibson, 1971a). The siltstone and silty limestone of the Sulphur Mountain, Grayling, and Liard Formations commonly contain isolated or "floating" euhedral to subhedral rhombic dolomite crystals (Pl. 6A), some of which display zoned overgrowths similar to those illustrated in Plate 6B. In places, these rhombic crystals form a cement and/or interlocking mosaic with the detrital quartz and feldspar, giving the rock a pseudogranular appearance. Euhedral overgrowths were observed on some well-rounded dolomite grains (Pl. 6B). The crystal outline and overgrowth stages are readily apparent in most thin sections because the grains and overgrowth crystal faces are coated or stained with opaque to semi-opaque carbonaceous-ferruginous matter. Textural relationships of the authigenic dolomite crystals and crystal mosaics with the host strata suggest that the euhedral crystals and some of the recrystallization or dolomite replacement took place after consolidation of the main sediment, probably at a stage when the host rock was porous and permeable, permitting the migration of dolomitizing solutions carrying carbonaceous and ferruginous material. Detrital dolomite, occurring as well-rounded grains, pseudo-ooliths, pellets, and intraclasts, is found as distinct grains and/or relict "ghost" outlines in the dolostone and dolomitic strata of the Whitehorse and Charlie Lake Formations (Pl. 7A).

X-ray and chemical analyses by A. E. Foscolos on selected samples from the Sulphur Mountain, Toad, and Grayling Formations reveal that much of the dolomite is iron rich, containing ferrous iron in solid solution with the carbonate. Consequently, some of the ferrous dolomite may be called ankerite depending on the concentration of the ferrous iron. In addition, most of the dolomite as well as the calcite contains opaque ferruginous inclusions, interpreted to be minute crystals of pyrite or iron oxide.

Most dolomite is thought to be of secondary origin, having replaced calcite or aragonite. The very fine crystallinity of the dolomite forming the individual beds, pellets, grains, and pseudo-ooliths suggests a penecontemporaneous replacement. Some of the granular dolomite, however, may be a product of a pre-existing carbonate rock and, consequently, may have been dolomitized before transport to the final site of deposition. No evidence has been found to indicate the composition of the original carbonate before replacement.

In comparison to dolomite, calcite occurs in relatively high concentrations throughout most members and formations in the report-area, with the exception of the Grayling and lower Sulphur Mountain Formations where dolomite and iron-rich dolomite generally comprise the main carbonate component.

Calcite (pseudospar of Folk, 1959), ranging in size from 0.03 to 0.15 mm in diameter, occurs mainly as an equicrystalline, recrystallized cement and matrix in most of the siltstone, sandstone, and bioclastic limestone throughout the region. Most of this calcite, particularly in the Sulphur Mountain, Liard, and Pardonet Formations, and the Ducette Member of the Baldonnel Formation, is stained or contains minute inclusions of organic carbonaceous-ferruginous matter, which commonly masks textural relationships. In contrast to dolomite, euhedral crystals and calcitic overgrowths were not observed.

Calcite bioclasts are conspicuous in much of the limestone, dolostone, siltstone, and sandstone of the rock succession, and in places form coquinas of compressed shells and shell fragments (Pl. 7B, C). These coquinas commonly form conspicuous and diagnostic beds in the strata of the Pardonet Formation and the Whistler Member of the Sulphur Mountain Formation. They also characterize parts of the Toad Formation in the vicinity of Peace River, but there, because of their random occurrence, they do not serve as a diagnostic lithofacies. The coquinas consist mainly of very thin, angular to well-rounded pelecypod shell fragments, which commonly have been subjected to recrystallization and pressure solution, leaving only remnant or ghost outlines of the original bioclast (Pl. 7A). The thin shells and their compacted crenulated wavy appearance in hand specimens resemble stromatolitic laminations in some samples of the Pardonet, Toad, and Sulphur Mountain Formations (Pl. 3E). Recrystallization has been such that, in some laminations, the shell fragments resemble fibrous calcite. Other notable bioclasts, although less common, include crinoid and echinoid fragments, thicker shelled pelecypod and/or brachiopod fragments which are the main bioclastic component of the Baldonnel and Bocock Formations, and rare ostracode, ammonite, gastropod, and bryozoan fragments (Pl. 6D, E, F). Crinoid ossicles at some levels of the Bocock Formation form dense, porous, encrinitic limestone. The rigid framework provided by the bioclasts in some of the limestones would necessitate classifying the rock as a packstone (Dunham, 1962), although most of the carbonate in the succession would have been classed originally as a wackestone before recrystallization. Some of the bioclasts, particularly in strata of the Baldonnel Formation, have been dolomitized partly and/or replaced by microcrystalline quartz or chalcedony.

In many of the limestone and calcareous siltstone beds of the Sulphur Mountain and Toad Formations of the more westerly sections, small well-rounded to spherical grains were observed as "floating" or carbonate-supported grains interspersed with detrital quartz and feldspars or, rarely, comprising a dense rigid packstone textural framework (Pl. 8A–D). Diameter of these spherical grains ranges from 0.06 to 0.25 mm, with most grains averaging 0.10 mm. The spheres are recrystallized, generally inclusion free, and mainly structureless; however, in some spheres where recrystallization has been less intense, thin concentric bands can be observed, with some of the bands separated by faint, randomly arranged pillars (Pl. 8B, C). Similar, although better preserved, pillars were noted on a much larger grain (1 inch in diameter) in a sample from the Pardonet Formation (Pl. 9C). The origin of most of the spheres is speculative, but the concentric banding and radial pillars preserved in some of the grains suggest that many or perhaps all of the spheres may be of algal origin and probable calcispheres. Alternatively, these grains could represent small, recrystallized ooliths. The predominant small size, presence of radiating pillars in a few banded grains, and general nature of the sediment, however, do not favour this interpretation. The fine, regular laminations and angular nature of the noncarbonate and carbonate detrital components suggest that the sediment has not undergone much shallow water wave or current agitation during deposition, a feature one might expect in the formation of ooliths. Similar spherical grains have been described in silty limestone and calcareous siltstone from the Sulphur Mountain Formation in the Rocky Mountain Front Ranges south of Banff, Alberta (Gibson, 1974), in a lithofacies similar to that of the Sulphur Mountain and Toad Formations of the Sikanni Chief – Smoky River area.

Some of the bioclastic limestone at the base of the Pardonet Formation contains well-preserved, concentrically banded ooliths and pisoliths up to 2.5 mm in diameter, but averaging approximately 1 mm (Pl. 8F, 9A, B). Many of the ooliths may have had a nucleus consisting of a different type of calcite than that now preserved such as a monocrystalline crinoid or echinoid fragment, or that the oolith had a hollow core. Some of the ooliths are characterized by solid cores with no evidence of a nucleus. The ooliths are commonly either clustered or "floating" in a detrital framework of angular, fragmented, thin pelecypod shells, generally cemented by pseudosparite (Folk, 1959). Plate 9A, B show ooliths with fine "hair-like" radiating calcite-filled fractures which do not extend into the cement and matrix of the host strata. These fine fractures may represent penecontemporaneous desiccation cracks resulting from a period of emergence and subaerial exposure. However, one may interpret the fine fractures to be the result of colloidal dehydration in a subaqueous environment.

The last variety of calcite observed in the study was fibrous calcite. It was found in limestone samples of the Bocock Formation, and in one sample of the Vega–Phroso Member of the Sulphur Mountain Formation (Pl. 7E, F). In the Bocock Formation, it consists of elongate, prismatic crystals up to 1½ inches long oriented perpendicular to the stratification. Cone-in-cone structures are common in some samples although generally poorly developed. The fibrous calcite forms lenses 6 to 12 inches long by 3 inches wide. The adjacent host strata and interstices of some of the fibrous calcite lenses contain fragmented crystals and, commonly, a crystal "mush." The fibrous calcite of the Bocock Formation occurs in a clean bioclastic limestone containing well-rounded bioclasts and carbonate grains but conspicuously lacking in detrital quartz and feldspar. The limestone of this formation is considered to be a product of shallow water sedimentation. The fibrous calcite in the Vega–Phroso Member occurs as a thin (¼ inch) lens in calcareous siltstone. The acicular crystals are stained and coated in part by carbonaceous-ferruginous matter and, like the calcite of the Bocock Formation, contain poorly preserved cone-in-cone structures. The fibrous calcite of the Vega–Phroso Siltstone Member, in contrast to that of the Bocock Formation, is associated with dark weathering, carbonaceous-ferruginous, calcareous and dolomitic siltstone and limestone, which are interpreted as products of a more restricted, relatively deeper water, marine environment below active wave base.

The origin of the fibrous calcite is uncertain. MacKenzie (1972) described fibrous calcite which he interprets to have developed at an undetermined depth in partly consolidated muds immediately below the water/sediment interface in response to undetermined changes in the physicochemical environment. The fibrous calcite of the Bocock Formation and of the Vega–Phroso Member possibly may represent diagenetic replacement of aragonite or, in the Bocock Formation, small cavity infillings after consolidation and cementation of the limestone.

Traces of siderite were identified by X-ray diffraction analysis in some siltstone samples of the Grayling and Toad Formations. Siderite was not observed, however, during the petrographic microscope phase of the study.

Insoluble Residue Analysis

Analyses of insoluble residue have long been used in the study of carbonate rocks as a means of ascertaining allogenic and authigenic clastic associations, current action, the sea bottom environment, and adjacent land conditions. It was hoped that similar information could be obtained from the very calcareous siltstone, silty limestone and dolostone of the Triassic sequence in the Sikanni Chief – Smoky River area, so that a comparison could be made with results from similar insoluble residue analyses on Lower and Middle Triassic rocks in the Rocky Mountain Front Ranges of the Jasper–Banff–Crowsnest Pass area of Alberta and southeastern British Columbia (Gibson, 1971a; 1974). Standard microscope point counting techniques proved unreliable in determining quantitatively the carbonate concentration in siltstone and silty limestone of the Sulphur Mountain, and laterally equivalent Grayling, Toad, and Liard Formations, because of the masking effect of carbonaceous-ferruginous matter in the strata, as discussed above.

Fourteen stratigraphic sections were selected for analysis, representing, as much as possible, all geographic localities of the region. Samples were selected from successive 25- to 50-foot stratigraphic intervals where possible; however,

TABLE 1. *Data chart illustrating mean and standard deviation values of the insoluble residue fraction for the total Sulphur Mountain Formation.*

SECTION	NO.	NO. SAMPLES	MEAN (%)	STANDARD DEVIATION (%)
Brazion Creek	22	30	63.6	16.7
Wolverine-Sukunka	27	35	59.3	14.2
Hook-Murray	29	31	57.0	13.1
Ganoid Ridge	31	39	66.8	16.2
Mount Becker	32	39	65.7	14.0
Muinok-Belcourt	33	30	61.3	18.8
Lick Creek	36	13	64.4	12.5
Casket Mountain	37	34	66.0	17.4
Haight Creek	39	18	62.6	17.9
Llama Mountain	38	48	61.0	?

Section localities (see Figure 2) ....38 GSC the Grayling Formation and lower Vega–Phroso and Whistler Members of the Sulphur Mountain Formation are characterized by numerous talus-covered intervals because of the recessive nature of the strata. Consequently, these stratigraphic units are represented by only a few analyses. Standard disaggregating techniques could not be applied to many samples because of quartzitic textures and secondary silicification commonly found in some of the siltstone. All samples were crushed, pulverized, and then treated with dilute HCl acid (10 per cent) and analyzed according to the techniques of Ireland (1958). Results were processed statistically to obtain the mean and standard deviation (Tables 1–3). The mean insoluble residue values for the total Sulphur Mountain Formation and its members, and for those of the Toad Formation, were plotted on base maps of the area and contoured to facilitate visual comparisons between the various section localities in the Sikanni Chief – Smoky River area (Figs. 14–18). In this format the data illustrate the variation in the average insoluble residue values between stratigraphic sections in the report-area for the total Sulphur Mountain and Toad Formations. Table 2 and Figures 15 to 17 illustrate the vertical variation in insoluble

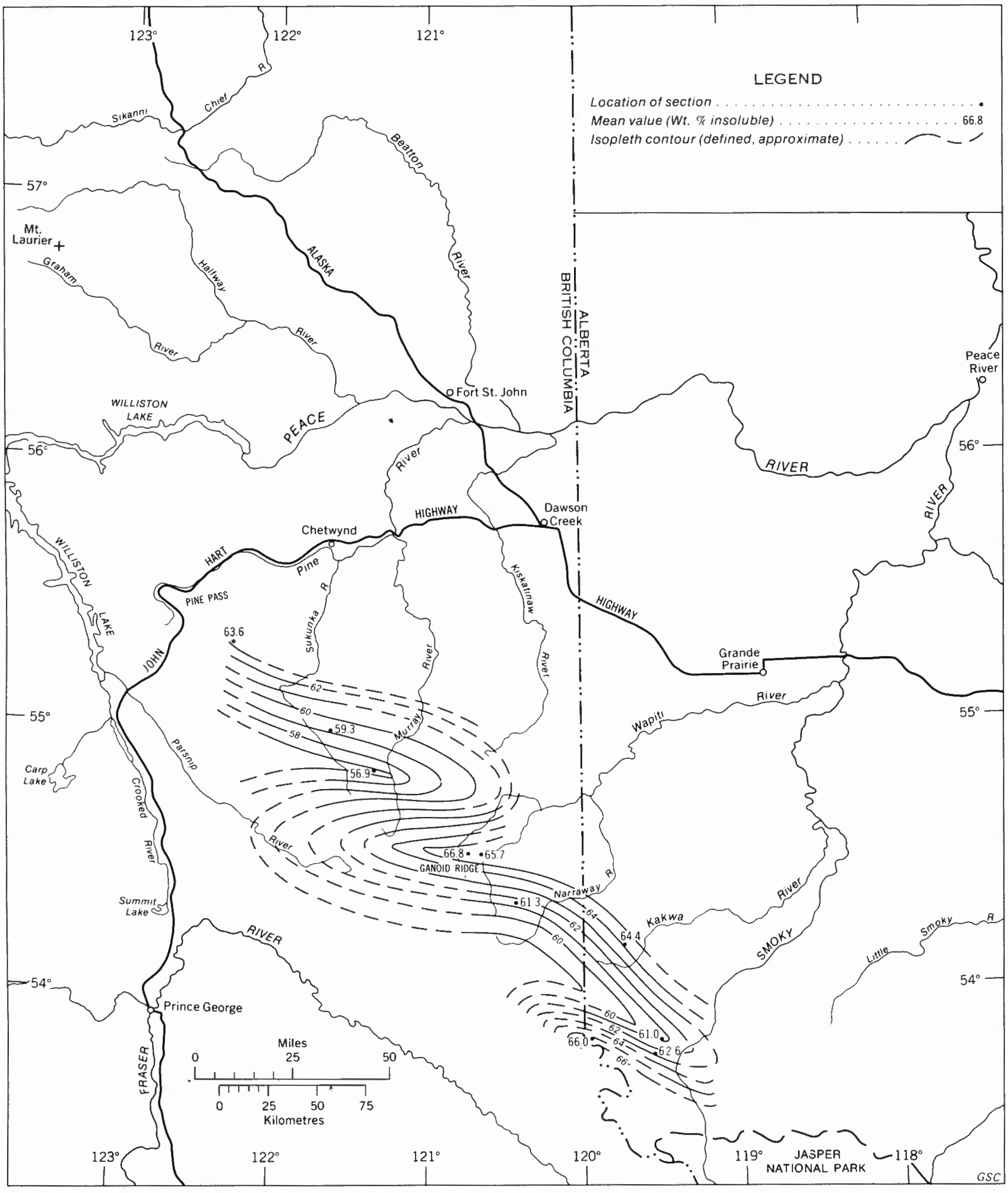

FIGURE 14. Isopleth map of the acid insoluble fraction in the Sulphur Mountain Formation.

residue values in the Sulphur Mountain Formation by subdividing the formation into its three component members. Lack of good Triassic exposures in some parts of the report-area, however, necessitates a subjective interpretation of some isopleth contour patterns between data control points.

The average insoluble residue concentration for the total Sulphur Mountain Formation ranges from a low of 57 per cent by weight near Hook Lake (Sec. 29, Fig. 2) to a maximum of 67 per cent on Ganoid Ridge (Sec. 31, Fig. 2). The mean insoluble residue concentration for the Sulphur Mountain Formation in the Pine Pass – Smoky River area is 63 per cent by weight, indicating a relatively high carbonate concentration for the siltstone of the Sulphur Mountain Formation. Similar high carbonate concentrations are found in equivalent strata to the south in the Jasper–Banff–Crowsnest Pass region of Alberta (Gibson, 1971a; 1974), and to the north in the Toad Formation of the Sikanni Chief River – Pine Pass area. Figure 14 illustrates insoluble residue concentration trends in the area; values, however, are plotted on a non-palinspastic base. Parts of the region are structurally complex, particularly near Smoky River. Therefore, the isopleth configurations and anomalous concentra-

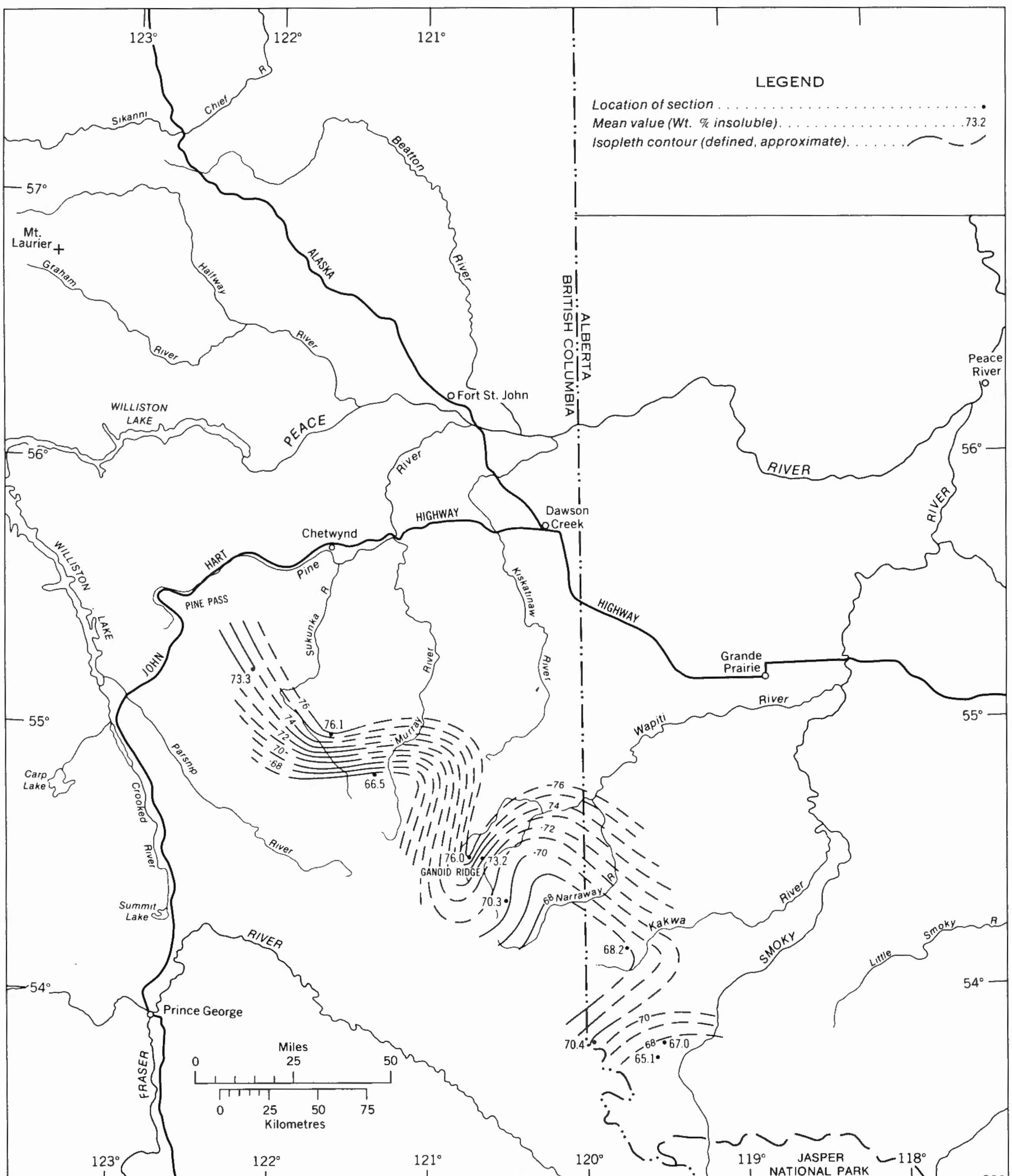

FIGURE 15. Isopleth map of the acid insoluble fraction in the Vega–Phroso Siltstone Member.

TABLE 2. *Data chart illustrating mean and standard deviation values of the insoluble residue fraction for each member of the Sulphur Mountain Formation.*

SECTION	NO.	MEMBER	NO. SAMPLES	MEAN (%)	STANDARD DEVIATION (%)
Brazion Creek	22	V-P	14	73.3	14.6
		W	7	60.4	11.7
		L	9	51.1	14.5
Wolverine-Sukunka	27	V-P	9	76.1	9.1
		W	3	42.3	16.7
		L	23	55.0	9.0
Hook-Murray	29	V-P	7	66.5	21.1
		W	5	44.5	9.1
		L	19	56.7	6.3
Ganoid Ridge	31	V-P	21	76.0	15.0
		W	1	34.6	
		L	17	57.4	8.2
Mount Becker	32	V-P	21	73.2	10.3
		W	2	45.8	6.0
		L	16	58.4	12.9
Muinok-Belcourt	33	V-P	17	70.3	17.7
		W	2	33.4	15.4
		L	11	52.5	11.0
Lick Creek	36	V-P	7	68.2	5.3
		W	1	39.3	
		L	5	64.0	15.7
Casket Mountain	37	V-P	22	70.4	20.2
		W	3	37.2	19.9
		L	9	55.6	8.3
Haight Creek	39	V-P	13	65.3	18.1
		W	2	51.7	25.8
		L	3	58.6	15.5
Llama Mountain	38	V-P	32	67.0	?
		W	2	38.5	
		L	14	50.9	15.6

GSC

Vega-Phroso Siltstone Member ..... V-P
Whistler Member .... W
Llama Member L
Section localities (see Figure 2) 12

TABLE 3. *Data chart illustrating mean and standard deviation values of the insoluble residue fraction for the Toad Formation.*

SECTION	NO.		NO. SAMPLES	MEAN (%)	STANDARD DEVIATION (%)
South Halfway	6	TOAD FORMATION	24	49.5	11.2
Calnan Creek	7		11	49.9	15.5
Mount Ludington	12		6	54.8	16.7
Mount Greene	14		13	49.9	16.9
Clearwater Lake	20		16	42.2	11.1

GSC

Section localities (see Figure 2) 20

tion values, and any conclusions drawn regarding trends and contemporaneous sedimentation patterns, must be interpreted with this possible tectonic modification in mind. A general residue concentration increase toward the east and northeast (*see* Fig. 14) suggests a probable detrital source area and shoreline in this direction. The two prominent isopleth anomalies in the vicinity of Wapiti and Hook Lakes may reflect in part a pre-Triassic erosional surface, characterized by shallow depressions and ridges, capable respectively of receiving or supplying clastic detritus. The isopleth anomaly near Smoky River is difficult to explain, but may result from tectonic distortion by folding and thrust faulting. The average insoluble residue values for the Sulphur Mountain Formation is noticeably higher in the Jasper–Banff–Crowsnest Pass area to the south (Gibson, 1971a; 1974), possibly reflecting either a shallower part of the basin with a greater chance of receiving a concentration of terrigenous detritus, or a closer proximity to the eastern margin of the Triassic shoreline. The textural relationships and relatively high carbonate concentration at many localities, in conjunction with other sedimentary characteristics, suggest that much of the Sulphur Mountain strata of the report-area was deposited under shallow water conditions, although generally below active wave base.

The mean insoluble residue values for the Vega–Phroso, Whistler, and Llama Members of the Sulphur Mountain Formation illustrate similar concentration trends in the region. Isopleth trends in the Whistler Member are, however, partly speculative owing to a lack of sufficient field samples for analysis. The isopleth anomaly near Smoky River shown for both the Vega–Phroso and Llama Members (Figs. 15, 17) again reflects a probable tectonic influence rather than a basinal configuration or contemporaneous sedimentation pattern. The irregular isopleth trends outlined for the Vega–Phroso Member (Fig. 15) probably are due in part to pre-Triassic erosion of Permian sediments, as suggested for similar irregular configurations in the total Sulphur Mountain Formation (*see* Fig. 14). Pre-Triassic erosion and the resultant increase in detrital sediments [i.e., Mowitch Formation (McGugan and Rapson, 1973)] may account for the increase in average insoluble residue concentrations in the Vega–Phroso Siltstone Member over those in the other two members of the Sulphur Mountain Formation (Table 2).

In the Pine Pass – Sikanni Chief River area, only samples from the Toad Formation were subjected to an insoluble residue analysis. Insoluble residue concentrations range from a minimum of 42 per cent to a maximum of 55 per cent by weight, with the average concentration of the formation being 49 per cent by weight throughout the area (Table 3). The average insoluble values is considerably lower than that for equivalent strata in the southern part of the report-area. An isopleth map of the acid insoluble fraction of the Toad Formation shows an average concentration increase toward the northeast (Fig. 18), again implying a probable shoreline and detrital source area in this direction.

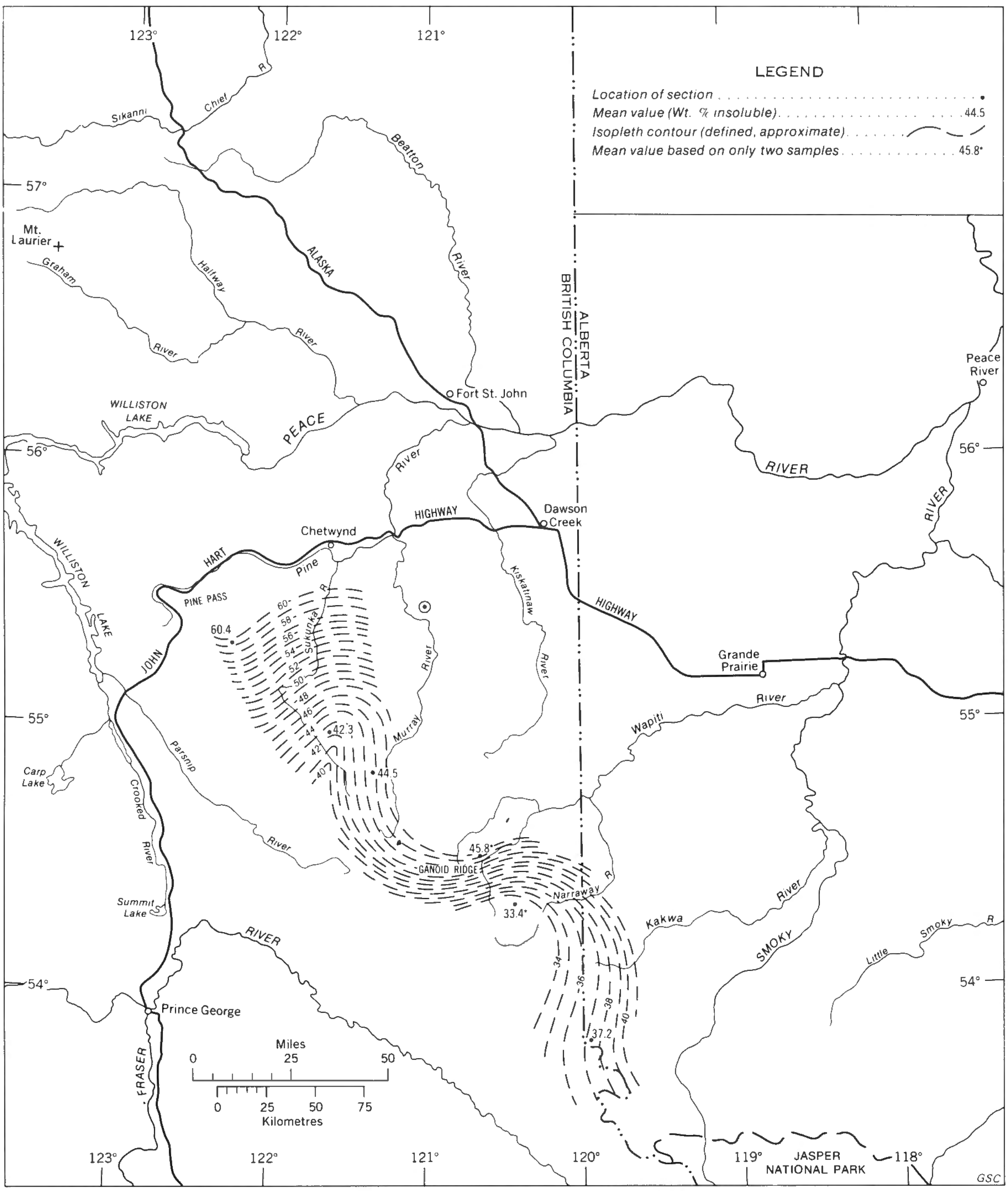

FIGURE 16. Isopleth map of the acid insoluble fraction in the Whistler Member.

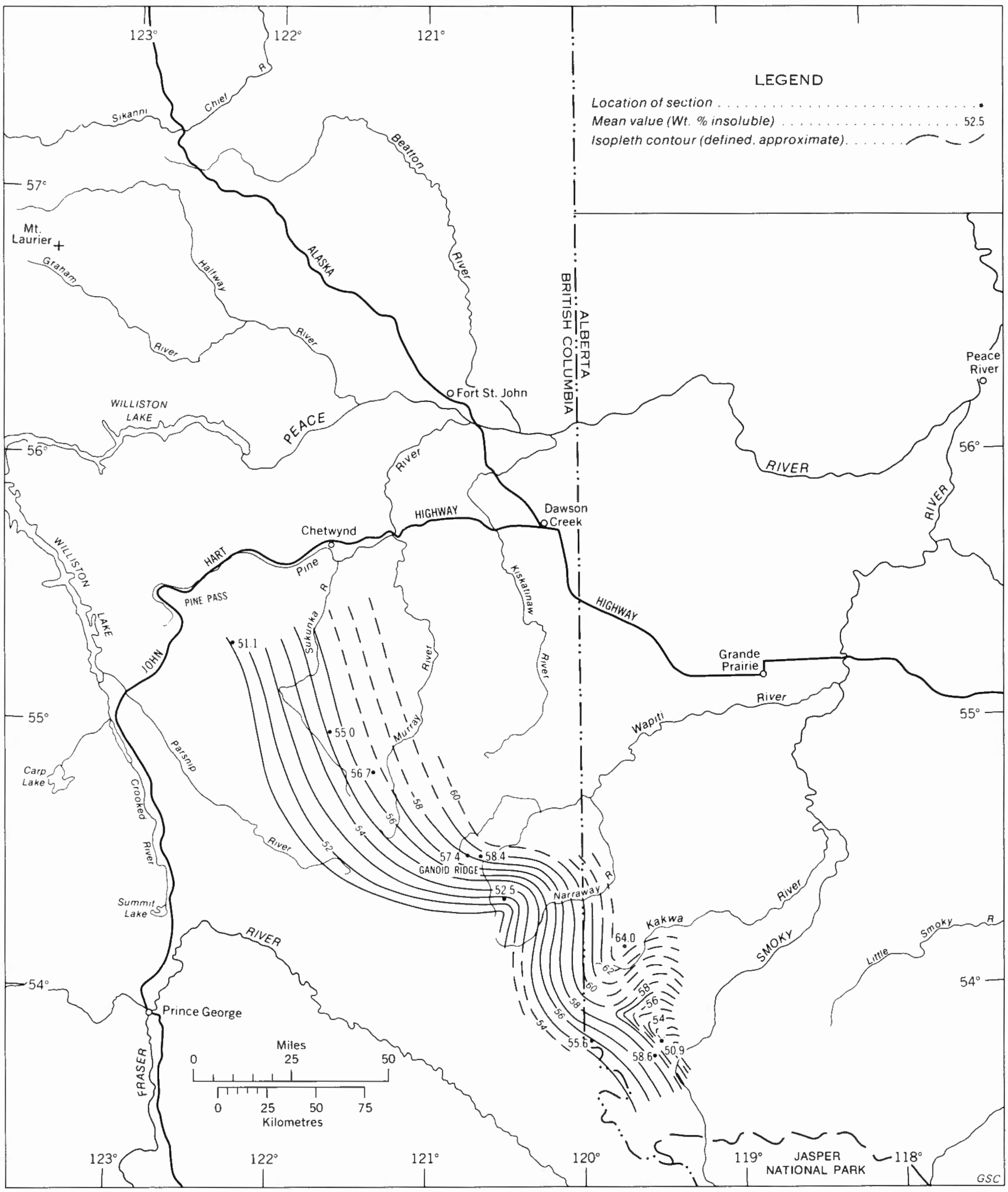

FIGURE 17. Isopleth map of the acid insoluble fraction in the Llama Member.

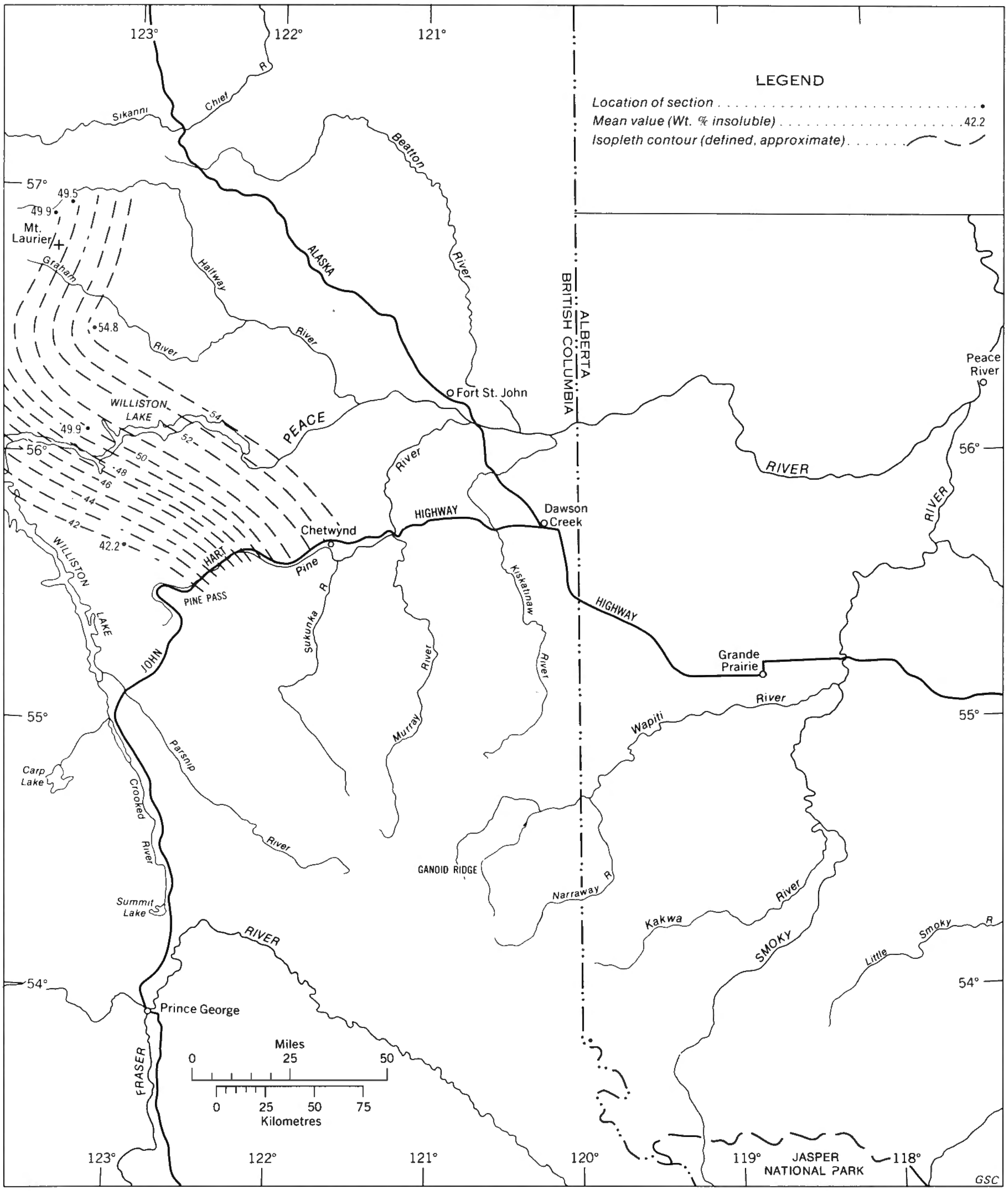

FIGURE 18. Isopleth map of the acid insoluble fraction in the Toad Formation.

DEPOSITIONAL HISTORY OF TRIASSIC SEDIMENTATION

The depositional history of Triassic rocks in the Rocky Mountains and Foothills of Western Canada is complex. Interpretation is difficult, owing, in part, to lack of specific modern depositional environments with which to compare most of the Triassic rocks in the region, especially facies of the Sulphur Mountain, Toad, and Grayling Formations. Hunt and Ratcliffe (1959), Colquhoun (1960), Clark (1961), Armitage (1962), Barss *et al.* (1964), Pelletier (1965), Sharma (1968), Mothersill (1968), Nelson (1970), and Roy (1972) have studied and/or provided various interpretations for part of the report-area and adjacent eastern Peace River Plains. Many of these interpretations concern only specific formations or lithofacies of the subsurface.

The writer previously outlined the Triassic depositional history of the Sikanni Chief River – Pine Pass area of the Rocky Mountain Foothills (Gibson, 1971b). This interpretation was of a preliminary nature and was based mainly on lithology, fauna, and stratigraphic relationships observed in the field. With petrological studies now complete, no major revisions of the original interpretation are deemed necessary. The following discussion deals mainly with the depositional history of Triassic strata in the Pine Pass – Smoky River part of the report-area, south of Peace River. To illustrate interpreted depositional events throughout the report-area, however, a brief outline of depositional events for the Triassic rocks to the north is included.

Depositional Basin

Triassic strata in the Sikanni Chief – Smoky River area were deposited in part of what commonly is referred to as the Cordilleran Miogeoclinal–Platform wedge of the Western Canada Sedimentary Basin. The eastern margin of the basin generally is well defined. Barss *et al.* (1964) suggested that the erosional edge of Triassic strata as now preserved represents a close approximation of the original Triassic shoreline. In contrast, the configuration and extent of the western margin, because of major tectonic complications, are speculative, especially for sediments of Early and early Middle Triassic age. Nelson (1970) depicted two possible basin configurations within which Triassic sediments in Western Canada may have accumulated. The first, favoured by Nelson, consists of a relatively narrow Triassic seaway bounded on the west by extensive areas of land throughout much of the present British Columbia interior and on the east by the craton. The second configuration depicts a broader, shallow basin extending much farther to the west, with considerably less extensive land areas. Recently, Wheeler *et al.* (1972) have provided evidence to suggest that lower Mesozoic sediments of the Cordilleran Structural Province were deposited in a marginal basin or platform between the continent or craton and volcanic arcs, the latter forming part of the eugeosynclinal facies of the Western Cordillera. From Triassic studies (Gibson, 1971a, b; 1974) in other areas of the miogeocline–platform of Western Canada, the writer favours this interpretation and, to a certain degree, the second interpretation of Nelson. If the hypothesis of a narrow marine basin bounded on the west by an extensive landmass is accepted, some lithologic or compositional evidence of a westerly sediment source should be evident and preserved in the Triassic rocks of the report-area and of other areas of Western Canada. To date, no convincing evidence has been documented to substantiate or support this hypothesis.

Paleocurrents

Paleoccurent studies by Pelletier (1965) indicate a sediment source area to the east or northeast for all clastic sediments in the present report-area. However, stratigraphic and sedimentological investigations by Colquhoun (1960), Clark (1961), Mothersill (1968), Sharma (1968), and others favour sediment transport from the north or northwest of the report-area for some clastic rocks of the Halfway and probable younger Middle and Upper Triassic formations. On the basis of a few paleocurrent determinations from sandstones of the Liard and lower Charlie Lake Formations in the Sikanni Chief – Pine Pass area, the writer also favours a current transport direction from the north or northwest. The actual detrital sediment source area, however, is still uncertain because movement may have been by longshore drift or currents paralleling the eastern basin margin. The postulated unconformity and related uplift between the Toad and Ludington Formations in the western Foothills north of Peace River, discussed earlier in this report, may provide some evidence of a western sediment source area for some of the sandstone and siltstone of the Liard and laterally equivalent subsurface Halfway Formations.

Early Triassic Sedimentation

Vega–Phroso Siltstone Member, Grayling and Lower Toad Formations

Uplift, erosion, and/or non-deposition probably preceded deposition of most Triassic rocks in the report-area. In the eastern Foothills south of Peace River, the base of the Triassic succession is characterized by a conspicuous phosphatic pebble conglomerate; in the Foothills north of Peace River, the conglomerate has not been observed. The contrast in lithology and the absence of Early Triassic and Late Permian fossil index zones between the two systems, however, indicate a hiatus in the region.

Lower Triassic strata of the Vega–Phroso Siltstone Member and the Grayling and lower Toad Formations probably were deposited in an easterly to southeasterly transgressing sea along the western margin of a relatively deep water, open shelf, marine environment, similar in some respects to that now existing off the east coast of the United States. The shallower water sediments were deposited to the east, near the erosional edge of Triassic strata, a locality suggested by Barss *et al.* (1964) as being a close approximation of the original Triassic shoreline. Recent studies by Milliman (1972) indicate that the textural and compositional properties of siltstones and carbonates of the Atlantic continental shelf between Cape Hatteras and northern Florida are similar to those of Lower Triassic rocks of the northern Rocky Mountain Foothills described in this report. Van Straaten (1959) also outlined sedimentary criteria of recent open shelf environments, and again many of these are found in Lower Triassic rocks of the report-area. However, the relative water depths—whether shallow or deep—into which the Lower Triassic sediments were deposited are somewhat speculative, because of evidence supporting both a shallow or deep water depositional environment. Most of the Lower Triassic strata appear to have been deposited in a restricted, relatively deep water environment, although at times, during later minor regressive stages, deposition may have been close to or above the lower limit of active wave base.

The rocks consist mainly of siltstone and shale containing relatively high concentrations of clay and mica, and are characterized by thin, regular to lenticular laminations showing little evidence of any wave or current activity. The common occurrence of dark grey to black organic carbonaceous-ferruginous matter throughout most siltstone and silty shale of the Vega–Phroso and laterally equivalent strata north of Pine Pass suggests depostion in a restricted, possibly euxinic, environment, where the iron and organic matter could be preserved readily before complete oxidation. Berner (1970) described sedimentary iron sulphate and carbonaceous organic matter in recent tidal flat and adjacent subtidal sediment areas along parts of the east coast of the United States. The texture, stratigraphic configuration, thickness trends, and occurrence of very fine, regular to lenticular laminations, however, do not support a tidal flat environmental interpretation for the ferruginous and organic carbonaceous matter in the sediments of the Pine Pass – Smoky River area. Moreover, the common occurrence of intercalated limestone beds and relatively high concentrations of calcite and dolomite as cement and/or matrix in much of the siltstone of the succession, particularly in the vicinity of, and north of Pine Pass would favour deposition in a subtidal environment, although with sedimentation taking place some distance offshore from the eastern basin margin.

Much of the limestone and some of the calcareous siltstone contain variable concentrations of both whole and fragmented pelecypod shells. The shell fragments are angular, very thin, and generally are aligned parallel to the stratification, resembling in some strata fine, crenulated algal laminations. The fragmentation of the shells is difficult to explain because of the postulated deep water depositional environment. Investigations by Swinchatt (1969) and Gatrall and Golubic (1970) on the boring or destructive action of blue-green algae and endolithic fungi, respectively, have shown or demonstrated the importance of these mechanisms in the fragmentation of shells in both Recent and ancient carbonate sediments. Algae, however, depend on light for their survival and, consequently, are restricted to the photic zone. Swinchatt (1969) suggests that most algal boring occurs in water less than 120 feet deep, and commonly less than 60 feet. In contrast, fungi can exist in total darkness and, consequently, in a much deeper water environment. Much of the shell material in the Lower Triassic rocks of the report-area has been recrystallized and subjected to pressure solution, thus obliterating or removing any evidence of algal or fungal boring. The fragmentation of shells also may be accomplished by a lowering of sea level. In the Pine Pass – Sikanni Chief River area to the north, stratigraphic evidence suggests that sea level began to fluctuate periodically following deposition of Grayling sediments (Gibson, 1971b). This fluctuation may have been reflected in the strata of the Vega–Phroso Siltstone Member. Sea level may have been lowered, at times, to such an extent that sediments were being deposited close to or above normal wave base (30 feet as defined by Embry and Klovan, 1972, p. 685), resulting in energy conditions sufficiently strong to break or comminute many of the pelecypod shells. Upon return to more normal deeper water conditions, the finely fragmented shell material would be incorporated into the limestone and siltstone, and deposited parallel to the stratification. The occurrence of ripple-marks and micro-cross-laminations in some of the siltstone and bioclastic limestone of the member also may provide additional evidence of periodic relatively high energy conditions in the area. The frequency of these directional structures, although low, does show an obvious increase toward the postulated shoreline area to the east.

Small, spherical, recrystallized carbonate grains up to 0.25 mm in diameter are found throughout many of the fossiliferous limestone beds, and some of the calcareous siltstone of the Vega–Phroso Member and the Toad Formation (Pl. 8A–E). These spherical grains, if correctly interpreted as calcispheres of probable algal origin, indicate deposition in a restricted, shallow water environment (Stanton, 1967; Rupp, 1966; Wray, 1972). Most calcispheres described in the literature are associated with limestone and/or dolostone and are generally considered to be products of a back reef lagoonal facies (Wray, 1972). In a study of Cretaceous limestones in northeast Mexico, Bishop (1972) described the occurrence of small calcispheres that he thought represented deposition in a relatively deep water environment, in which the depositional interface was below wave base throughout deposition. The Triassic spheres, interpreted as calcispheres in the limestone and siltstone of the Sikanni Chief – Smoky River area, are considered by the writer to have been deposited in a depositional environment similar to that postulated by Bishop for the Cretaceous calcispheres, although with deposition generally occurring under relatively shallower water, higher energy conditions (i.e., probably close to or above normal wave base).

The fine detrital grain sizes, high quartz concentrations, and lack of ferromagnesian and other common heavy minerals suggest that most sediments of the Vega–Phroso, Grayling, and lower Toad lithologic units were derived from sedimentary rocks from a low-lying, eastern source area.

Middle Triassic Sedimentation

Whistler Member and Middle Toad Formation

Lower Triassic sedimentation terminated in a shallowing, regressing sea, the regression having begun after deposition of the Grayling and laterally equivalent Phroso facies of the Vega–Phroso Siltstone Member. After deposition of the Vega–Phroso Siltstone Member, the Pine Pass – Smoky River, Jasper–Banff and Peace River Plains areas may have been subjected to a short interval of non-deposition or erosion. At many localities, basal strata of the Middle Triassic Whistler Member contain a thin zone of granular and oolitic phosphate and phosphatic pebble conglomerate (Pl. 5D). Triassic index fossil zones (Tozer, 1967) appear to be complete between the Lower and Middle Triassic rocks, so that the magnitude of the depositional break or hiatus, if it does exist, is probably small. The well-rounded phosphate grains, lithoclasts, and oolites (Pl. 5A, B, C) suggest that the initial stages of early Middle Triassic sedimentation took place under very shallow water, high energy conditions, above normal wave base. Conditions changed following deposition of the granular phosphates and phosphatic conglomerate, and the seas began to transgress and deepen, returning the region to a depositional environment similar in some ways to that of Early Triassic times. Fine, regular to lenticular laminations, a high concentration of organic carbonaceous-ferruginous matter, and the occurrence of thin bioclastic limestone beds in the silty limestone and calcareous siltstone of the Whistler Member again suggest deposition in a restricted environment, below normal wave base, along the outer margin of the shelf. Periodically, sedimentation may have taken place close to or above wave base, or possibly below normal wave base during periods of storm activity, thus comminuting the pelecypod shells of the bioclastic limestone (Pl. 7C). In contrast, however, shell fragmentation may have resulted from boring by algae and/or fungi. The high carbonaceous-ferruginous concentration, dark coloration, and general thin-bedded nature of the strata suggest that the Whistler Member may have been deposited during a period of slow sedimentation and low clastic input. The decrease in clastic concentration (Table 2) may reflect the beginning of climatic changes in the cratonic and source area to the east, a feature suggested by a compositional and textural change in overlying and younger strata of the succession. In the Pine Pass – Sikanni Chief River area to the northwest, the Whistler Member is not recognizable, and the laterally equivalent middle Toad Formation consists of more thickly bedded, less carbonaceous limestone, silty limestone, and calcareous and dolomitic siltstone. Strata of the Toad Formation thus indicate deposition in a deeper water, less restricted, open marine environment.

Llama Member, Liard and Halfway Formations

During deposition of the Llama Member and laterally equivalent Liard and subsurface Halfway Formations, the seas began to shallow and withdraw westward, resulting in a lowering of sea level along the eastern margin of the miogeocline–platform. Shallowing water conditions are suggested by a noticeable increase in clastic grain diameters compared to those in strata of the underlying Whistler and Vega–Phroso Siltstone Members. Well-rounded, silt- and sand-sized detrital carbonate grains were observed in concentrations much greater than in underlying strata. Furthermore, cross-laminations, lack of micaceous and other clay minerals, and a high concentration of fragmented pelecypod and/or brachiopod shell material suggest that deposition took place in a shallow water, high energy environment. Well-preserved *Lingula* shells and lingulid and orbiculid shell fragments were found throughout the Llama Member, particularly in the vicinity of Smoky River. Investigations by Rhodes and Bloxam (1969), Craig (1952), Ferguson (1963), Paine (1970), and Detterman (1970) have shown that inarticulate brachiopods, including lingulids, are characteristic of shallow water, intertidal, depositional environments. Recent lingulids are found at water depths rarely greater than 25 feet. Coleman *et al.* (1970) described and illustrated lingulid brachiopod mounds on the tidal flats of the Klang Delta of Malaysia. At many Triassic localities, particularly in the western Foothills, upper Llama Member strata contain lenses and thin beds replete with terebratulid brachiopods. Logan and Noble (1971) recorded Recent terebratulid specimens in the Bay of Fundy at depths ranging from 4 to 45 feet. The occurrence of terebratulids in the Triassic strata of the report-area may provide evidence of a similar shallow water depositional environment. Bioturbate structures are common in many of the thicker bedded Llama strata (Pl. 3D). The origin of the bioturbation is uncertain; it may have resulted in part from sediment-ingesting annelids. The organism(s) responsible for the bioturbation apparently was not preserved.

The depositional history of the Llama-equivalent Liard and Halfway sediments in Pine Pass – Sikanni Chief River area to the north is complex and has been discussed in variable detail by Armitage (1962), Hunt and Ratcliffe (1959), Clark (1961), Pelletier (1965), Barss *et al.* (1964), Colquhoun (1960), Mothersill (1968), Sharma (1969), and by the writer (Gibson, 1971b), and is not discussed in detail here. Depositional conditions were similar to those postulated for Llama sediments in the south, except that most Liard and equivalent subsurface Halfway strata probably were deposited under more agitated, shallower water, near-shore conditions. The Liard Formation in the Pine Pass – Peace River area contains numerous intercalated dense limestone beds, lesser amounts of clastic quartz and feldspar than in equivalent strata to the north and south, and a minor amount of carbonaceous-ferruginous matter, suggesting sediment deposition in deeper waters farther offshore.

During later stages of Llama sedimentation, the climate appears to have changed from temperate to tropical, to arid to semi-arid. This suggestion is supported by the nature of the upper Llama and overlying sediments, which become progressively less carbonaceous, less silty and sandy, and more dolomitic and calcareous toward the top of the member. Immediately overlying the Llama Member are strata characteristic of an arid to semi-arid, shallow water, evaporitic environment.

Late Triassic Sedimentation

Starlight Evaporite Member, and Charlie Lake and Ludington Formations

Following deposition of the Llama Member and the laterally equivalent Liard and Halfway strata north of Pine Pass, Late Triassic seas continued to regress and shallow, possibly in part a result of plate tectonic movements and related volcanism, and plutonic intrusive activity in the eugeosynclinal region to the west (Wheeler *et al.*, 1972). The shallowing seas formed restricted lagoons, extensive tidal flat areas, barrier bars, and barrier islands, randomly distributed throughout the report-area. The depositional environment resembles in some ways depositional environments and processes existing today along the south Texas Gulf Coast (Kwon, 1969; Shepard and Moore, 1955), Baja California (Phleger and Ewing, 1962; Thompson, 1968), and the Trucial Coast (Evans, 1966; Evans *et al.*, 1969) of the United States, Mexico, and Persian Gulf, respectively. All areas contain sediments with textural and compositional characteristics found in the Starlight Evaporite and Charlie Lake strata of the report-area.

Whitehorse Formation rocks are poorly exposed in the Pine Pass – Smoky River area; however, widely scattered outcrops and partial sections indicate the general nature of the strata. Near Casket Mountain (Sec. 37, Fig. 2), white gypsum occurs as wavy contorted beds comprising a relatively thick stratigraphic interval, and as interbeds in the limestone and dolostone of the member. Much of the limestone and some of the dolostone contain well-rounded grains, pellets, ooliths and bioclasts in variable concentrations, with the dolostone surrounded in part by thin micritic algal rims (Pl. 6E). Some of the siltstone and sandstone associated with the intraformational breccia and conglomerate of the member form prominent "red-bed" intervals. The occurrence of breccias, conglomerates, "red beds," oolitic, pelletal, and granular carbonates suggests that Starlight deposition took place under very shallow water, probably evaporitic conditions, in a broad intertidal to tidal flat environment.

The Charlie Lake Formation in the vicinity of Pine Pass and to the north contains strata similar to the Starlight Evaporite Member, although gypsum does not outcrop in the Foothills. It is, however, present in the lower Charlie Lake Formation of the Peace River Plains. "Red beds" and intraformational and/or collapse breccia are common in the vicinity of Peace River. In the extreme western Foothills north of Peace River, sediments of the Ludington Formation were deposited at the same time as those of the Charlie Lake Formation to the east, although under less restricted and slightly deeper water conditions. Much of the Ludington sandstone contains crossbedding, whereas most of the limestone is bioclastic with the pelecypod and/or brachiopod bioclasts being well rounded, suggesting strong wave or current activity (Pl. 6F). The large shell "bank" previously described in the Ludington Formation near Mount Laurier represents the probable western margin of a tidal flat-intertidal shelf environment. This bioclastic deposit may have formed a barrier that was responsible in part for hypersaline conditions developing in the shallow water area to the east, and the formation of the evaporite deposits of the Peace River Plains subsurface. Ripple-marks, crossbedding, and extensive fragmentation and rounding of bioclasts in some of the calcareous sandstone and limestone suggest that deposition took place close to normal wave base or above.

Brewster Limestone and Winnifred Members, and Baldonnel Formation

Following deposition of the Starlight Evaporite Member in the Pine Pass – Smoky River area, the seas began to deepen slightly resulting in deposition of the Brewster Limestone Member. The Brewster strata consist of limestone and dolomitic limestone commonly composed of, or containing, well-rounded bioclasts of pelecypod and/or brachiopod shells, crinoid-echinoid fragments, and well-rounded detrital grains (Pl. 6E). The fragmented and well-rounded nature of the bioclasts suggest deposition in a shallow water, high energy environment. Some bioclasts contain micritic coatings which may be of algal or fungal origin, again implying deposition in a shallow water environment. In the Pine Pass – Sikanni Chief River area to the north, part of the laterally equivalent Baldonnel Formation consists of a similar lithology (Pl. 6D); in the eastern subsurface, it consists of porous bioclastic dolostone. Toward the western Foothills Baldonnel strata contain increasing concentrations of organic carbonaceous matter and less bioclastic material, indicating deposition in a relatively deeper water, less oxygenated environment, probably close to normal wave base level. The transgressing and deepening seas during Brewster and Baldonnel time may have been influenced similarly or caused by middle Late Triassic plutonism and volcanism taking place in the west along the eugeosynclinal regions of the Triassic sea (Wheeler, 1966; Wheeler *et al.*, 1972; Monger *et al.*, 1972) as suggested earlier for depositional events at the beginning of Starlight, Charlie Lake, and Ludington time. The occurrence of intraformational and/or solution breccia, intraformational conglomerate, "red beds," and granular carbonate strata in the lower Winnifred strata of the Jasper–Banff area to the south (Gibson, 1971a), coupled with the thinning and termination of the Brewster Member toward the east and southeast, suggests that the transgression and sea level rise did not have as much influence in this southern area and, consequently, restricted shallow water, evaporitic, tidal flat-intertidal conditions prevailed in the Jasper–Banff area during early Winnifred time.

Following deposition of the Brewster Member in the Pine Pass – Smoky River area, the seas again receded, returning part of the area to an environment similar to that postulated for much of Starlight time. The lower part of the Winnifred Member, where observed, is characterized mainly by carbonate rocks, many containing well-rounded shell fragments, as well as minor ooliths and pellets. Some of the carbonate is characterized by fine, wavy, crenulated laminations which resemble those produced in stromatolites and these, along with the above textures and predominant carbonate rock types, suggest deposition in an intertidal environment. During middle and late Winnifred time, however, the seas again deepened, onlapping the area toward the southeast and east, depositing carbonaceous limestone, silty to sandy dolostone, and siltstone more characteristic of an open marine, deeper water environment. Granular phosphate and well-rounded quartz and feldspar grains are common in carbonate strata of the upper Winnifred Member.

In the Pine Pass – Sikanni Chief River area to the north, similar depositional events were taking place; there, water depths were greater than those to the south. However, upper Baldonnel strata show little change in composition from the base to the top of the member.

Pardonet Formation

At the end of Baldonnel time, the seas again began to shallow, returning the area to a partly restricted, euxinic depositional environment. The cause of the marine withdrawal and development of restricted conditions is not known, although it probably is related to tectonic events in the west that occurred during Late Triassic time. Large, well-preserved, calcareous ooliths and pisoliths were observed in basal strata of the Pardonet Formation, in a coquinoid mass of thin, fragmented pelecypod shells (Pl. 9A, B). The extremely fragmented condition of many pelecypod shells, in addition to the concentrically banded ooliths, suggests shallow water depositional conditions, probably in an active wave environment. Shell fragmentation, however, may occur also through the action of boring algae and fungi as previously discussed. During deposition of middle and upper Pardonet strata, sea level appears to have been raised, with depths approaching those prevailing during earlier Toad and Vega–Phroso times. Upper Pardonet strata are generally very finely laminated, shaly weathering, and contain intercalated medium to thin bedded, very carbonaceous, calcareous siltstone beds that form, in places, the predominant lithology. The intact preservation of many of the thin pelecypod shells and the relatively high concentration of black to brown organic carbonaceous matter suggest that upper Pardonet sedimentation took place in waters considerably deeper than those postulated for lower Pardonet sediments, probably in an oxygen-free environment. The water may have been replete at times with pelagic pelecypods, which may have been subjected periodically to deeper toxic waters, as a result of upwellings and water inversions, thereby resulting in their death. The occurrence of ammonites throughout many of the limestones of the Pardonet Formation may be interpreted by some as evidence of deep water depositional conditions. Along some shoreline, intertidal and subtidal areas of the South Pacific Ocean, particularly in northern Australia, whole and fragmented shells of *Nautilus* occur in great abundance (G. R. Davies, pers. com.). In the Pardonet Formation, nautiloid shells sometimes are found along with ammonites. Consequently, the Triassic ammonites by association may have floated to, and indeed lived, near their final place of burial in a shallow water setting.

Bocock Formation

Following deposition of the Pardonet Formation, the seas again regressed to the west and northwest, most of the report-area being subject to uplift and pre-Jurassic erosion. Between Peace River and Pine Pass, however, a shallow marine embayment remained, and limestone of the Bocock Formation was deposited. The well-rounded, fragmented pelecypod shells, crinoid columnal and other fossil fragments, and well-rounded carbonate grains of the formation suggest very shallow water, high wave-energy conditions. The Triassic period terminated with further uplift, regression, and probable erosion, as indicated by a surface relief up to 25 feet on the upper surface of the Bocock Formation and a marked contrast in lithology between Triassic and overlying Jurassic sediments.

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APPENDIX

Chemical and mineralogical data from 33 selected field samples (mainly siltstone and silty shale) of the Sulphur Mountain, Grayling, and Toad Formations follow. These data were used to supplement and/or substantiate some of the microscope observations during the petrological phase of the investigation. Analyses were undertaken and tables prepared by A. E. Foscolos and R. R. Barefoot of the Geological Survey.

TABLE 4. *Data chart illustrating the results of total chemical analyses of 33 selected samples of the Sulphur Mountain, Grayling, and Toad Formations in the Sikanni Chief – Smoky River region of British Columbia and Alberta. For analytical methods see Foscolos and Barefoot (1970).*

SAMPLE AND UNIT	$\%SiO_2$	$\%Al_2O_3$	%Fe	%CaO	%MgO	$\%Na_2O$	$\%K_2O$	%S	$\%P_2O_5$	$\%CO_2$	% Organic Matter	Total
SECTION 35 MEOSIN MOUNTAIN												
GK-70-12-1-V-P	50.45	7.17	2.85	10.33	5.31	.89	4.37	2.25	.40	10.05	1.72	96.69
GK-70-12-8A-V-P	61.10	5.10	1.40	7.93	4.32	1.44	3.30	.20	4.50	9.38	.61	99.98
GK-70-12-21B-V-P	53.45	6.80	2.30	11.92	4.64	.98	4.87	1.13	.00	9.93	3.04	99.06
GK-70-12-32B-W	12.75	2.65	.80	41.60	2.99	.30	1.18	.78	.75	32.84	3.58	100.12
GK-70-12-60A-L	53.50	3.21	.95	12.47	8.67	.50	1.42	.10	1.60	15.25	.50	98.17
SECTION 36 LICK CREEK												
GK-70-9-1A-V-P	54.60	7.17	2.00	7.83	5.64	1.13	3.25	.94	1.90	12.00	1.60	98.01
GK-70-9-18A-L	65.20	3.59	.75	7.41	5.13	.98	2.41	.22	1.65	11.00	.70	99.00
SECTION 32 MOUNT BECKER												
GK-70-4-8B-V-P	49.25	6.05	2.50	12.30	6.63	.80	3.09	.61	.35	16.75	1.31	99.64
GK-70-4-44A-W	6.64	.57	.35	49.55	.83	.51	.67	.45	30.50	7.98	1.72	99.77
SECTION 31 GANOID RIDGE												
GK-70-5-2B-V-P	47.10	6.89	2.70	13.45	3.82	.70	3.25	2.00	.15	15.83	1.04	96.93
GK-70-5-20A-V-P	53.50	7.74	2.70	8.73	4.14	1.04	4.19	1.26	.65	10.63	3.15	97.83
GK-70-5-26B-V-P	66.35	7.37	2.30	5.44	2.16	1.27	4.53	.43	.40	5.09	1.82	97.16
GK-70-5-40A-W	16.25	1.70	.90	42.68	1.00	.63	.90	.41	27.50	6.66	1.11	99.74
SECTION 29 HOOK-MURRAY												
GK-70-6-51A-V-P	22.25	3.78	1.90	27.90	5.31	.59	2.29	1.86	8.60	18.01	6.55	99.03
GK-70-6-46A-W	47.10	5.48	1.40	15.95	3.15	1.10	3.02	1.40	.15	16.85	4.27	99.84
SECTION 27 WOLVERINE-SUKUNKA												
GK-70-7-19A-W	8.77	1.32	.40	45.76	1.33	.30	1.10	.58	24.55	12.38	2.67	99.07
SECTION 26 LEAN-TO CREEK												
GK-69-8-17B-V-P	66.35	6.80	1.70	5.50	2.65	1.23	4.37	.88	.40	7.05	1.53	98.46
GK-69-8-22A-W	28.90	5.48	1.90	22.70	4.47	.58	3.09	1.75	4.00	18.62	7.12	99.27
GK-69-8-13A-V-P	64.20	6.62	1.90	5.01	1.83	1.07	5.37	1.14	.45	5.57	3.64	96.80
SECTION 24 WATSON PEAK												
GK-69-10-31A-L	45.90	5.48	1.60	15.25	3.82	1.04	3.47	1.10	.40	15.77	3.68	97.40
GK-69-10-25A-W	26.60	3.21	1.00	32.30	2.82	.61	1.57	.38	.60	27.84	1.77	97.70
GK-69-10-10A-V-P	56.60	6.05	1.40	11.97	1.66	.95	3.53	.85	5.90	5.23	2.65	96.79
GK-69-10-7A-V-P	25.10	3.59	1.00	34.21	2.16	.66	1.74	.79	.40	28.73	1.06	99.44
SECTION 25 WEST BURNT RIVER												
GK-69-9-2B-V-P	51.35	7.17	3.00	11.00	5.31	.85	3.02	1.98	.40	14.03	1.96	100.02
GK-69-9-9A-V-P	67.35	6.23	1.80	6.75	1.49	1.35	3.09	.96	.40	6.33	1.71	97.71
GK-69-9-21B-W	25.90	4.53	1.15	28.70	2.32	.62	2.01	1.06	1.70	23.56	6.72	98.27
GK-69-9-22A-W	23.30	3.40	1.05	26.85	2.16	.50	1.51	1.19	.65	23.05	15.58	99.24
SECTION 19 CLEARWATER CREEK												
GK-69-3-87-T	8.98	1.32	.40	44.46	1.49	.23	.78	.16	.40	36.11	1.96	96.29
GK-69-3-113A-T	31.60	3.97	.95	29.50	2.49	.55	1.34	.68	.60	25.16	3.18	99.92
GK-69-3-136A-G	61.40	6.98	1.60	7.89	3.48	1.17	2.80	.86	.50	9.53	1.89	98.20
GK-69-3-88A-T	10.50	1.51	.40	44.84	1.66	.23	.90	.16	.50	36.58	1.03	98.76
SECTION 12 MOUNT LUDINGTON												
GK-68-10-7-T	59.75	6.62	1.90	9.80	2.84	1.70	2.69	.54	1.30	8.48	2.46	96.08
GK-68-10-10-T	49.25	4.16	1.20	18.73	3.48	.88	1.62	.78	.65	17.22	2.31	100.26

GSC

1. Iron was not reported as an oxide since most of it is tied up with sulphur in the form of pyrite

2. Not all calcium present is actually calcium oxide (as a part of calcite, etc.), but some is calcium fluorite. Fluorine was not determined

3. Water content of minerals also was not determined

4. For the reasons mentioned above, the total of each sample analyzed is not always 100.00, but relatively close

Vega-Phroso Siltstone Member .... V-P
Whistler Member .... W
Llama Member L
Toad Formation .... T
Grayling Formation .... G
Section localities (see Figure 2) 12

SAMPLE AND UNIT	%SiO2	% Al2O3	%Fe	%CaO	%MgO	%Na2O	%K2O	%Total
SECTION 35 MEOSIN MOUNTAIN								
GK-70-12-1-V-P	43.90	1.51	.10	.00	.00	.89	2.01	48.41
GK-70-12-8A-V-P	47.10	1.51	.10	.11	.02	1.02	2.01	51.87
GK-70-12-21B-V-P	47.10	1.80	.10	.00	.02	.98	2.46	52.46
GK-70-12-32B-W	10.92	.95	.10	.00	.00	.31	.78	13.06
GK-70-12-60A-L	49.25	.76	.10	.00	.00	.29	1.14	51.54
SECTION 36 LICK CREEK								
GK-70-9-1A-V-P	50.20	2.08	.20	.00	.07	1.13	2.46	56.14
GK-70-9-18A-L	62.10	1.13	.10	.00	.02	.77	1.68	65.89
SECTION 32 MOUNT BECKER								
GK-70-4-8B-V-P	43.85	1.51	.15	.00	.03	.80	1.70	47.89
GK-70-4-44A-W	4.71	.00	.10	.00	.00	.15	.12	5.08
SECTION 31 GANOID RIDGE								
GK-70-5-2B-V-P	42.75	1.13	.10	.00	.00	.70	1.23	45.91
GK-70-5-20A-V-P	48.15	1.89	.15	.00	.03	1.04	2.58	53.84
GK-70-5-26B-V-P	58.90	2.08	.20	.00	.05	1.27	2.58	68.08
GK-70-5-40A-W	13.30	.57	.10	.06	.00	.63	.34	15.00
SECTION 29 HOOK-MURRAY								
GK-70-6-51A-V-P	19.30	1.13	.10	.01	.00	.59	1.01	22.30
GK-70-6-46A-W	42.75	1.89	.15	.00	.02	1.10	1.85	47.76
SECTION 27 WOLVERINE-SUKUNKA								
GK-70-7-19A-W	5.99	.19	.10	.04	.02	.14	.22	6.70
SECTION 26 LEAN-TO CREEK								
GK-69-8-17B-V-P	59.90	1.70	.15	.01	.02	1.13	2.35	65.26
GK-69-8-22A-W	25.10	1.70	.10	.10	.02	.58	1.57	29.17
GK-69-8-13A-V-P	57.75	2.27	.30	.01	.07	1.07	2.91	64.38
SECTION 24 WATSON PEAK								
GK-69-10-31A-L	41.65	1.70	.10	.00	.02	1.04	1.96	46.47
GK-69-10-25A-W	23.05	1.13	.10	.01	.00	.61	.95	25.84
GK-69-10-10A-V-P	52.35	1.51	.10	.04	.03	.74	2.46	57.23
GK-69-10-7A-V-P	18.40	1.32	.10	.00	.02	.61	.95	21.40
SECTION 25 WEST BURNT RIVER								
GK-69-9-2B-V-P	46.00	1.13	.10	.01	.03	.85	.95	49.07
GK-69-9-9A-V-P	60.90	1.32	.10	.04	.00	1.35	1.40	65.11
GK-69-9-21B-W	19.50	1.13	.10	.03	.00	1.50	.78	22.04
GK-69-9-22A-W	18.65	1.13	.10	.01	.03	.46	.62	21.00
SECTION 19 CLEARWATER CREEK								
GK-69-3-87B-T	8.56	.38	.10	.21	.02	.23	.12	9.62
GK-69-3-113A-T	25.90	.76	.10	.07	.02	.54	.45	27.84
GK-69-3-136A-G	48.70	1.51	.10	.06	.03	1.05	1.18	52.63
GK-69-3-88A-T	6.85	.38	.10	.04	.00	.23	.22	7.82
SECTION 12 MOUNT LUDINGTON								
GK-68-10-7-T	54.40	1.51	.10	.01	.00	1.70	1.40	59.12
GK-68-10-10-T	34.30	.76	.10	.10	.00	.74	.90	36.90

GSC

NOTE Differential dissolution was done by sodium bisulphate fusion which dissolves every mineral except for quartz and feldspar. The percentages shown are given as per cent of the original sample.

Vega-Phroso Siltstone Member.......V-P
Whistler Member........................W
Llama Member...........................L
Toad Formation..........................T
Grayling Formation......................G
Section localities (see Figure 2)........12

TABLE 5

Data chart illustrating the results of chemical analyses of the quartz-feldspar portion of 33 selected samples of the Sulphur Mountain, Toad, and Grayling Formations in the Sikanni Chief – Smoky River region of British Columbia and Alberta.

TABLE 6. *Data chart illustrating the results of the mineralogical composition, by geochemical methods, for 33 selected samples of the Sulphur Mountain, Toad, and Grayling Formations in the Sikanni Chief – Smoky River region of British Columbia and Alberta.*

SAMPLE AND UNIT	% QUARTZ	% SiO_2	%TOTAL FELDSPAR	% MICA	% PYRITE	% CALCITE	% DOLOMITE	% APATITE	%Kaolinite and/or Chlorite	%ORGANIC MATTER	% TOTAL	*** pH
SECTION 35 MEOSIN MOUNTAIN												
GK-70-12-1-V-P	27.0	.0	22.5	17.0	4.2	3.9	22.0**	.9	.0	1.7	100.2	8.6
GK-70-12-8A-V-P	27.5	10.0	24.4	8.9	.3	.0	18.7**	10.2	.0	.6	100.5	9.1
GK-70-12-21B-V-P	31.7	.0	26.5	16.0	2.1	6.7	14.5**	.0	.0	3.0	100.5	8.8
GK-70-12-32B-W	6.0	.0	8.4	2.1	1.5	64.0	13.0	1.7	.0	3.5	100.2	8.8
GK-70-12-60A-L	40.4	3.0	12.1	1.6	.2	.0	38.6	3.7	.0	.5	100.1	9.2
SECTION 36 LICK CREEK												
GK-70-9-1A-V-P	31.6	.0	27.7	3.8	1.8	.0	25.8**	4.4	3.3	1.6	100.0	8.8
GK-70-9-18A-L	46.6	.0	19.1	4.7	.3	.0	23.5	3.8	1.2	.7	99.9	9.2
SECTION 32 MOUNT BECKER												
GK-70-4-8B-V-P	29.8	.0	19.8	11.9	1.1	4.8	30.3**	.8	.0	1.3	99.8	8.5
GK-70-4-44A-W	4.0	.0	.8	4.7	.8	15.0	3.8	71.0	.0	1.7	99.8	8.8
SECTION 31 GANOID RIDGE												
GK-70-5-2B-V-P	31.9	.0	15.3	15.6	3.8	14.5	17.5**	.4	.0	1.0	100.0	8.1
GK-70-5-20A-V-P	27.4	.0	27.9	11.1	2.4	3.8	18.9**	1.5	3.8	3.2	100.0	8.9
GK-70-5-26B-V-P	36.8	.0	30 1	13.6	.8	3.5	7.9**	.7	3.8	1.8	100.0	8.4
GK-70-5-40A-W	6.7	.0	8.7	4.0	.8	10.0	4.6**	64.2	.0	1.1	100.1	8.8
SECTION 29 HOOK-MURRAY												
GK-70-6-51A-V-P	10.8	.0	12.7	5.5	3.5	16.7	24.3	20.1	.0	6.6	100.2	8.8
GK-70-6-46A-W	26.5	.0	23.4	7.4	2.6	20.5	14.5	.4	.0	4.3	99.6	8.6
SECTION 27 WOLVERINE-SUKUNKA												
GK-70-7-19A-W	4.0	.0	3.1	6.3	1.1	18.9	6.1	57.3	.0	2.7	99.5	9.3
SECTION 26 LEAN-TO CREEK												
GK-69-8-17B-V-P	39.3	.0	27.2	14.6	1.7	2.9	12.0**	.9	.0	1.5	100.1	8.9
GK-69-8-22A-W	13.1	.0	17.1	9.5	3.3	20.0	20.2	9.3	.0	7.1	100.3	8.8
GK-69-8-13A-V-P	35.9	.0	30.6	15.0	2.1	3.2	8.5**	1.1	.0	3.6	100.0	8.9
SECTION 24 WATSON PEAK												
GK-69-10-31A-L	24.6	.0	23.6	10.4	1.9	16.8	17.5	.9	.0	3.7	99.4	8.9
GK-69-10-25A-W	14.8	1.8	12.5	4.0	.7	49.6	13.0	1.1	.0	1.8	99.3	8.8
GK-69-10-10A-V-P	33.7	.0	24.5	11.7	1.6	3.8	7.6	13.8	.0	2.7	99.4	9.2
GK-69-10-7A-V-P	10.9	3.7	12.4	4.9	1.5	54.7	9.9	.9	.0	1.1	100.0	8.7
SECTION 25 WEST BURNT RIVER												
GK-69-9-2B-V-P	36.0	.0	14.7	12.8	3.7	5.6	24.3**	.9	.0	2.0	100.0	9.0
GK-69-9-9A-V-P	43.3	.0	22.9	14.3	1.8	7.6	6.8**	.9	.0	1.7	99.3	8.8
GK-69-9-21B-W	13.3	2.4	10.4	8.9	2.0	41.6	10.6	4.0	.0	6.7	99.9	9.2
GK-69-9-22A-W	14.1	2.0	8.8	6.0	2.3	40.0	9.8	1.5	.0	15.6	100.2	8.9
SECTION 19 CLEARWATER CREEK												
GK-69-3-87B-T	5.9	.0	4.2	5.1	.3	73.7	6.8	.9	.0	2.0	99.9	8.8
GK-69-3-113A-T	10.1	3.0	8.7	5.7	1.3	45.2	11.4	1.4	.0	3.2	100.1	8.9
GK-69-3-136A-G	35.8	8.0	18.6	11.9	1.6	4.3	16.4**	1.2	.0	1.9	99.7	8.8
GK-69-3-88A-T	4.4	1.5	4.0	5.2	.3	74.8	7.6**	1.2	.0	1.0	100.0	8.9
SECTION 12 MOUNT LUDINGTON												
GK-68-10-7-T	42.4	.0	19.0	13.0	1.0	11.9	7.0**	3.0	.0	2.5	99.8	8.5
GK-68-10-10-T	23.5	12.6	13.9	5.3	1.5	23.5	15.9	1.5	.0	2.3	100.0	8.9

GSC

*SiO_2 is amorphous silica and/or microcrystalline quartz and/or poorly crystalline quartz which is soluble in sodium bisulphate fusion.

** Fe-rich dolomite

***The pH was measured by shaking 2.5 grams of sample with 5 ml of distilled water for 5 minutes and then measuring immediately.

Vega-Phroso Siltstone Member .... V-P
Whistler Member .... W
Llama Member L
Toad Formation .... T
Grayling Formation .... G
Section localities (see Figure 2) 12

TABLE 7

Data chart illustrating the mineralogical composition of the feldspar and quartz components, by geochemical methods, for 33 selected samples of the Sulphur Mountain, Toad, and Grayling Formations, in the Sikanni Chief – Smoky River region of British Columbia and Alberta.

SAMPLE AND UNIT	%MICROCLINE	%ALBITE	%ANORTHITE	%TOTAL FELDSPAR	%QUARTZ
SECTION 35 MEOSIN MOUNTAIN					
GK-70-12-1-V-P	14.1	8.5	.0	22.5	27.0
GK-70-12-8A-V-P	14.1	9.7	.6	24.4	27.5
GK-70-12-21B-V-P	17.2	9.3	.0	26.5	31.7
GK-70-12-32B-W	5.5	3.0	.0	8.4	6.0
GK-70-12-60A-L	9.4	2.8	.0	12.1	40.4
SECTION 36 LICK CREEK					
GK-70-9-1A-V-P	17.2	10.7	.0	27.7	31.6
GK-70-9-18A-L	11.6	7.3	.0	19.1	46.6
SECTION 32 MOUNT BECKER					
GK-70-4-8B-V-P	12.2	7.6	.0	19.8	29.8
GK-70-4-44A-W	.8	.0	.0	.8	4.0
SECTION 31 GANOID RIDGE					
GK-70-5-2B-V-P	8.6	6.7	.0	15.3	31.9
GK-70-5-20A-V-P	18.1	9.9	.0	27.9	27.4
GK-70-5-26B-V-P	18.1	12.1	.0	30.1	36.8
GK-70-5-40A-W	2.4	6.0	.3	8.7	6.7
SECTION 29 HOOK-MURRAY					
GK-70-6-51A-V-P	7.1	5.6	1.0	12.7	10.8
GK-70-6-46A-W	13.0	10.5	.0	23.5	26.5
SECTION 27 WOLVERINE-SUKUNKA					
GK-70-7-19A-W	1.5	1.4	.2	3.1	4.0
SECTION 26 LEAN-TO CREEK					
GK-69-8-17B-V-P	16.5	10.7	.1	27.3	39.3
GK-69-8-22A-W	11.0	5.5	.6	17.1	13.1
GK-69-8-13A-V-P	20.4	10.2	.1	30.7	35.9
SECTION 24 WATSON PEAK					
GK-69-10-31-L	13.7	9.9	.0	23.6	24.6
GK-69-10-25A-W	6.7	5.8	.1	12.6	14.8
GK-69-10-10A-V-P	17.2	7.0	.2	24.4	33.7
GK-69-10-7A-V-P	6.6	5.8	.0	12.4	10.9
SECTION 25 WEST BURNT RIVER					
GK-69-9-2B-V-P	6.6	8.1	.1	14.8	36.0
GK-69-9-9A-V-P	9.8	12.8	.2	22.8	43.3
GK-69-9-21B-W	5.5	4.8	.2	10.5	13.3
GK-69-9-22A-W	4.3	4.4	.1	8.8	14.1
SECTION 19 CLEARWATER CREEK					
GK-69-3-87B-T	.8	2.2	1.2	4.2	5.9
GK-69-3-113A-T	3.2	5.1	.4	8.7	10.1
GK-69-3-136A-G	8.3	10.0	.3	18.6	35.8
GK-69-3-88A-T	1.5	2.2	.2	3.9	4.4
SECTION 12 MOUNT LUDINGTON					
GK-68-10-7-T	2.8	16.2	.1	19.1	42.4
GK-68-10-10-T	6.3	7.0	.6	13.9	23.5

GSC

Vega-Phroso Siltstone Member .... V-P
Whistler Member .... W
Llama Member L
Toad Formation .... T
Grayling Formation .... G
Section localities (see Figure 2) 12

TABLE 8

Data chart illustrating relationship between organic matter, pyrite and colour value for 33 selected samples of the Sulphur Mountain, Toad, and Grayling Formations in the Sikanni Chief – Smoky River region of British Columbia and Alberta.

SAMPLE AND UNIT	COLOUR VALUE	ORGANIC MATTER	PYRITE
GK-70-12-1-V-P	0	.61	.34
GK-70-12-60A-L	0	.50	.19
		*.56	*.26
GK-70-9-18A-L	1	.66	.34
GK-70-4-8B-V-P	1	1.31	1.14
GK-70-4-44A-W	1	1.72	.82
GK-70-5-2B-V-P	1	1.04	3.75
GK-70-5-26B-V-P	1	1.82	.81
GK-70-5-40A-W	1	1.11	.77
GK-69-8-17B-V-P	1	1.53	1.65
GK-69-10-7A-V-P	1	1.06	1.48
GK-69-9-2B-V-P	1	1.98	3.70
GK-69-9-9A-V-P	1	1.71	1.80
		*1.39	*1.63
GK-70-12-8A-V-P	2	1.72	.34
GK-70-9-1A-V-P	2	1.55	1.14
GK-70-5-20A-V-P	2	3.15	.82
GK-70-7-19A-W	2	2.65	3.75
GK-69-10-31A-L	2	1.77	.81
GK-69-10-10A-V-P	2	2.65	.77
GK-69-3-87B-T	2	1.96	1.65
GK-69-3-136A-G	2	1.89	1.48
GK-69-3-88A-T	2	1.03	3.70
GK-68-10-7-T	2	2.46	1.80
		*2.06	*1.63
GK-70-12-21B-V-P	3	3.04	2.12
GK-70-12-32B-W	3	3.48	1.48
GK-69-8-13A-V-P	3	3.64	2.13
GK-69-10-25A-W	3	3.68	1.89
GK-68-10-10-T	3	2.31	1.46
		*3.23	*1.82
GK-70-6-51A-V-P	4	6.55	3.48
GK-70-6-46A-W	4	4.27	2.62
GK-69-8-22A-W	4	7.12	3.27
GK-69-9-21B-W	4	6.72	1.98
GK-69-9-22A-W	4	15.58	2.34
GK-69-3-113A-T	4	3.81	1.27
		*8.05	*2.49

* Average value

GSC

The colour value was measured by visual observation

0. Very light grey — *3. Dark grey*
1. Light grey — *4. Black*
2. Medium grey

Vega-Phroso Siltstone Member .... V-P
Whistler Member .... W
Llama Member L
Toad Formation .... T
Grayling Formation .... G

Geochemical Calculations

Because most elements in a total chemical analysis of a clastic rock may come from many sources, i.e., 1) SiO_2 from feldspar, quartz, mica, clays, and amorphous silica; 2) CaO from apatite, calcite, dolomite, etc.; 3) K_2O from mica, feldspar, etc.; and 4) Al_2O_3 from feldspar, clays, etc., the chemical analysis data must be used in conjunction with X-ray diffraction in order to assign, within limits, elemental values to the minerals in which particular elements are believed to occur. Geochemical calculation examples, prepared by R. R. Barefoot, were derived from the chemical analysis of sample GK-70-4-8B.

1. Organic matter – Calculated by multiplying organic carbon by a suitable conversion factor, 1.2 (Forsman and Hunt, 1958; Gehman, 1962).
   % organic matter = organic carbon × 1.2
   = 1.07 × 1.2
   = 1.3%

2. Pyrite – Calculated on the basis of sulphur content (X-ray diffraction shows pyrite as the only sulphur-bearing mineral).
   $FeS_2 \rightarrow Fe + S_2$
   Thus % pyrite = mol. wt. pyrite × % S/mol. wt. sulphur
   = 119.97 × 0.61/64.12
   = 1.14%

3. Apatite – Calculated on the basis of P_2O_5 content.
   $2Ca_5F(PO_4)_3 \rightarrow 3P_2O_5 + 9CaO + CaF_2$
   Thus % apatite = 2 × mol. wt. apatite × % P_2O_5/3 × mol. wt. P_2O_5
   = 2 × 504.3 × 0.35/3 × 141.9
   = 0.77%

4. Dolomite – Calculated on the basis of MgO content.
   $CaMg(CO_3)_2 \rightarrow MgO + CaO = 2CO_2$
   Thus % dolomite = mol. wt. dolomite × % MgO/mol. wt. MgO
   = 184.4 × 6.63/40.3
   = 30.3%

   NOTE:
   X-ray diffraction shows a peak shift which indicates iron substitution (towards ankerite). 1.14% pyrite contains 0.53% iron, but the sample contains 2.50% iron. Thus the excess iron is (2.50 – 0.53)% iron. This means that 30.3% dolomite contains 1.97% iron or the iron content in the dolomite is 6.5%. Thus it can be called an iron-rich dolomite.

5. Calcite – Calculated from either the remaining Ca or CO_2.
   $CaCO_3 \rightarrow CaO + CO_2$
   Remaining Ca = total (Ca) – apatite (Ca) – feldspar (Ca) – dolomite (Ca)
   = 8.78 – 0.24 – 0.00 – 6.57
   = 1.97%

   Per cent calcite = mol. wt. calcite × % Ca/mol. wt. Ca
   = 100.1 × 1.97/40.1
   = 4.8%

   Remaining CO_2 = total (CO_2) – dolomite (CO_2)
   = 16.75 – 14.65
   = 2.10%

   Per cent calcite = mol. wt. calcite × % CO_2/mol. wt. CO_2
   = 184.4 × 2.10/44
   = 4.8%

   Thus calcite is 4.8% in sample GK-70-4-8B.

The remaining components of the sample required further analysis to determine their percentages. This was accomplished by fusing the sample with sodium bisulphate ($NaHSO_4H_2O$), which removes all components except for quartz and feldspars, and then washing and analyzing the residue, according to the method of Jackson (1965), to give the following components in GK-70-4-8B:

6. Microcline – Calculated on the basis of K_2O content of the bisulphate residue.
   $2KAlSi_3O_8 \rightarrow Al_2O_3 + K_2O + 6SiO_2$
   % microcline = % K_2O × 7.0
   = (1.74 × 7.0)%
   = 12.18%

   NOTE:
   The factor 7.0 was determined by mole ratio calculations and using tables to determine the small amount of microcline that would dissolve because of particle size.

7. Albite – Determined on the basis of Na_2O content of the bisulphate residue, taking into account the small amount of albite dissolved during the fusion (using particle size factors).
   $2NaAlSi_3O_8 \rightarrow Al_2O_3 + Na_2O + 6SiO_2$
   % albite = % Na_2O × 9.5
   = (0.80 × 9.5)%
   = 7.60%

8. Anorthite – Determined on the basis of CaO content of the bisulphate residue, taking into account the small amount of anorthite dissolved during the fusion (using particle size factors).
   $CaAl_2Si_2O_8 \rightarrow Al_2O_3 + CaO + 2SiO_2$
   % anorthite = % CaO × 5.5
   = (0.0 × 5.5)%
   = 0%

9. Total feldspars – Determined by adding the percentages of microcline, albite, and anorthite.
   Total feldspar = 12.18 + 7.60 + 0
   = 19.78%

10. Mica – Determined on the basis of K_2O.
    Total K_2O – K_2O of orthoclase is K_2O of micas.
    Thus: 3.08 — 1.70 = 1.39 K_2O of mica
    $2KAl_2(Si_3AlO_{10})(OH)_2 \rightarrow K_2O + 3Al_2O_3 + 6SiO_2 + 2H_2O$
    % mica = % K_2O (mica) × 8.6
    = 1.39 × 8.46
    = 11.9%

11. Quartz – Calculated by subtracting the feldspars from the total residue and multiplying by a factor to account for the portion of quartz which dissolved during fusion.
    % quartz = 1.009[% total – (0.936 × microcline) – (0.927 × albite) – (0.991 × anorthite)]
    = 1.009(47.93 – 0.936 × 12.2 – 0.927 × 7.60 – 0.991 × 0)
    = 29.8%

12. SiO_2 – Calculated as the difference between the SiO_2 which dissolved and the SiO_2 of mica plus clays. This SiO_2 is amorphous silica and/or microcrystalline quartz and/or poorly crystalline quartz.
    % SiO_2 = SiO_2 of mica and clays
    Total SiO_2 dissolved in this specific example SiO_2 = 0%
    = 0%

13. Kaolinite/chlorite – Calculated as the difference between 100% and the sum of the remaining components in those samples in which X-ray diffraction showed the minerals to be present.

PLATE 1

A. Contact and lithologic relationships between the Permian Fantasque Formation and the Triassic Grayling and Toad Formations, Pine Pass – Peace River area. Note recessive weathering and covered nature of Grayling Formation. Permian Fantasque Fm. (Fn); Grayling Fm. (Gr); Toad Fm. (Td).

B. Toad Formation, illustrating resistant-recessive alternation of strata, Graham River area. Note shaly to flaggy weathering nature of Toad Formation strata.

C. Contact and lithologic relationships between the Toad, Liard, and Charlie Lake Formations, Mount Stearns, Halfway River area. Note resistant, cliff-forming appearance of Liard Formation. Toad Fm. (Td); Liard Fm. (Ld); Charlie Lake Fm. (Cl).

D. Contact and lithologic relationships between the Liard and Charlie Lake Formations, and the Ducette Member of the Baldonnel Formation, Clearwater Lake, Pine Pass – Peace River area. Note abrupt colour contrast between the Charlie Lake Formation and the Ducette Member. Liard Fm. (Ld); Charlie Lake Fm. (Cl); Ducette Mbr. (Dc).

E. Contact and lithologic relationships between Toad and Ludington Formations, Mount Ludington. Toad Fm. (Td); Ludington Fm. (Lt).

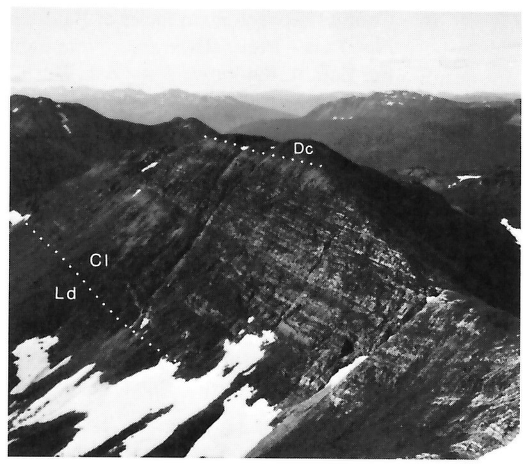
F. Conglomeratic zone at base of Ludington Formation at Calnan Creek. Note well-rounded cobble near hammer head. Conglomerate zone extends from base to top of Jacobs staff. Toad Fm. (Td); Ludington Fm. (Lt).

PLATE 1

A

B

C



D

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F

PLATE 2

A. Contact and lithologic relationships between Charlie Lake, Baldonnel, and Pardonet Formations. Note dark weathering and contrasting colour of Ducette Member of Baldonnel Formation. Headwaters of Carbon Creek. Charlie Lake Fm. (Cl); Baldonnel Fm. (Bd); Ducette Mbr. (Dc).

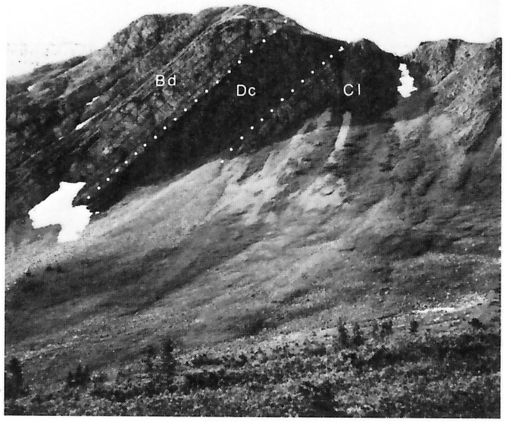
B. Contact between main facies of Baldonnel and Pardonet Formations, headwaters Carbon Creek, Pine Pass – Peace River area. Note light weathering, resistant, cliff-forming nature of Baldonnel Formation. Baldonnel Fm. (Bd); Ducette Mbr. (Dc); Pardonet Fm. (Pd).

C. Contact and lithologic relationships between Pardonet and Bocock Formations and Jurassic Fernie Formation, Pine Pass – Peace River area. Pardonet Fm. (Pd); Bocock Fm. (Bc); Jurassic Fernie Fm. (Fm).

D. Contact and lithologic relationships of Sulphur Mountain Formation illustrating Vega–Phroso Siltstone, Whistler, and Llama Members. Note resistant sandstone band near base of Vega–Phroso Siltstone Member. Meosin Mountain. Vega–Phroso Siltstone Mbr. (Vp); Whistler Mbr. (Wh); Llama Mbr. (Lm); Mississippian Rundle Gp. (Rg).

E. Typical lithology of basal Vega–Phroso Siltstone Member in contact with Mississippian Rundle Group, Ganoid Ridge. Note alternating resistant-recessive, light and dark weathering character of strata. Vega–Phroso Siltstone Mbr. (Vp); Mississippian Rundle Gp. (Rg).

F. Unconformity between Triassic Vega–Phroso Siltstone Member and Mississippian Rundle Group, Hook Lake area. Note finely laminated character of Vega–Phroso Siltstone Member, and texture of phosphatic pebble conglomerate. Vega–Phroso Siltstone Mbr. (Vp); Mississippian Rundle Gp. (Rg).

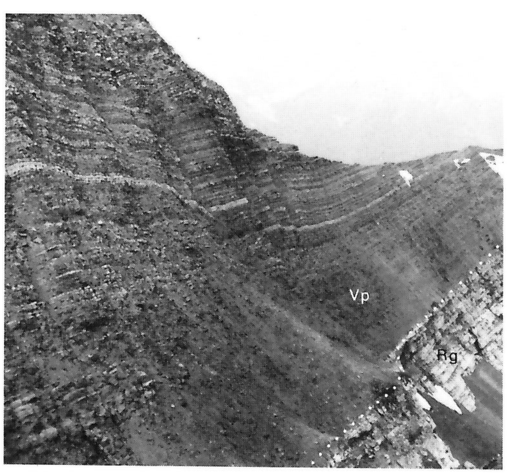


A

B

C

D



E

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Plate 3

A. Llama Member showing physical similarity to strata of Vega–Phroso Siltstone Member (Pl. 2E). Light weathering strata, mainly limestone, Watson Peak, Sukunka River area. Whistler Mbr. (Wh); Llama Mbr. (Lm).

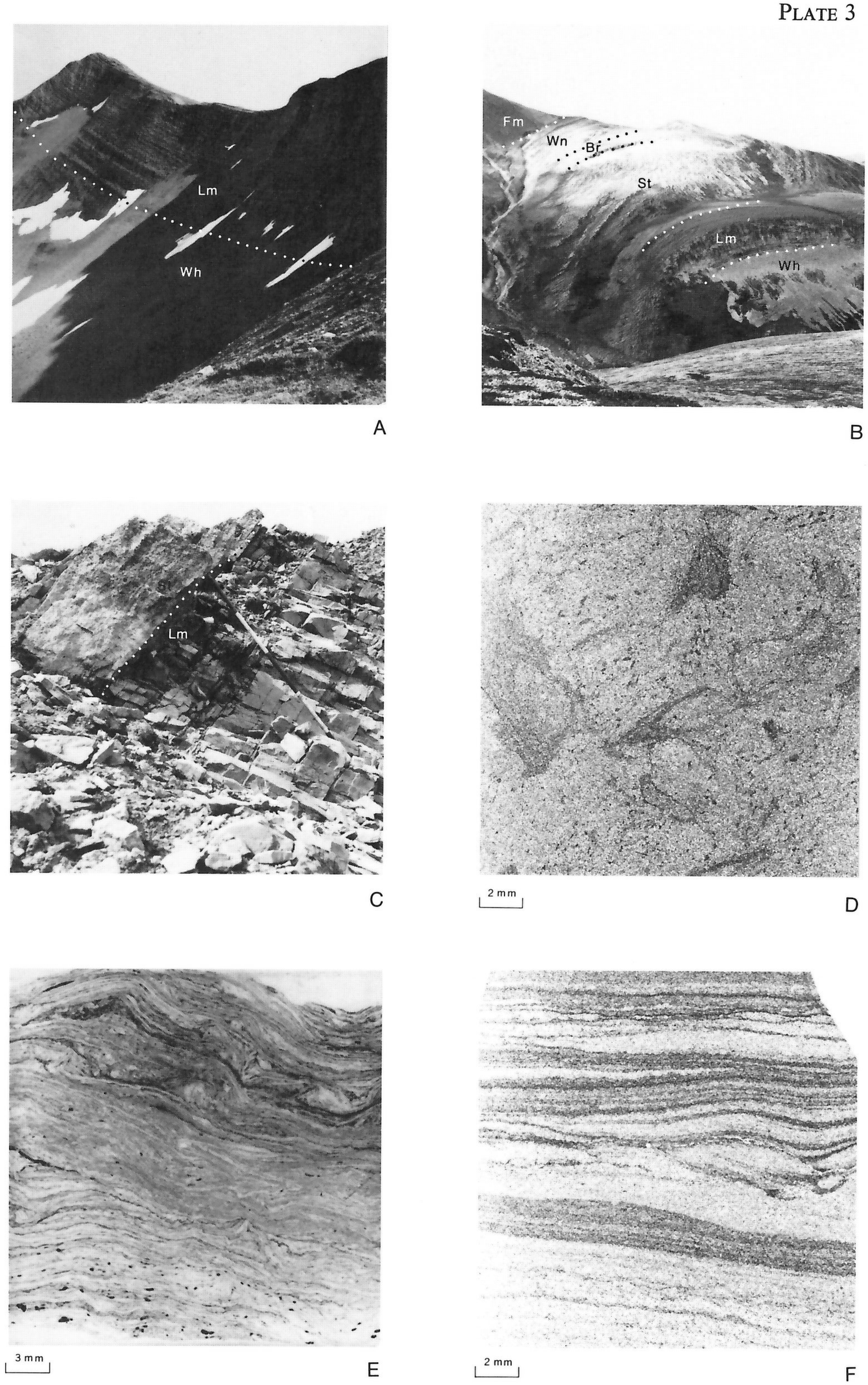
B. Whitehorse and Sulphur Mountain Formations illustrating colour contrasts and members of the formations, Lick Creek. Whistler Mbr. (Wh); Llama Mbr. (Lm); Starlight Evaporite Mbr. (St); Brewster Limestone Mbr. (Br); Winnifred Mbr. (Wn); Jurassic Fernie Fm. (Fm).

C. Contact between Sulphur Mountain Llama Member and Whitehorse Starlight Evaporite Member, Meosin Mountain. Llama Mbr. (Lm); Starlight Evaporite Mbr. (St).

D. Bioturbate mottling in dolomitic siltstone, Llama Member, Ganoid Ridge.

E. Pelecypod shell coquina, Pardonet Formation, Pink Mountain. Note physical similarity to stromatolitic laminations.

F. Typical carbonaceous-ferruginous laminations in calcareous siltstone of Vega–Phroso Siltstone Member, Lick Creek.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Wh
A
Fm
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D
3 mm
E
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F

Plate 4

A. Quartzitic texture showing "welded" nature of grain contacts; note angularity and recrystallized nature of grains and cement. Toad Formation.

B. Same thin section as A; crossed nicols.

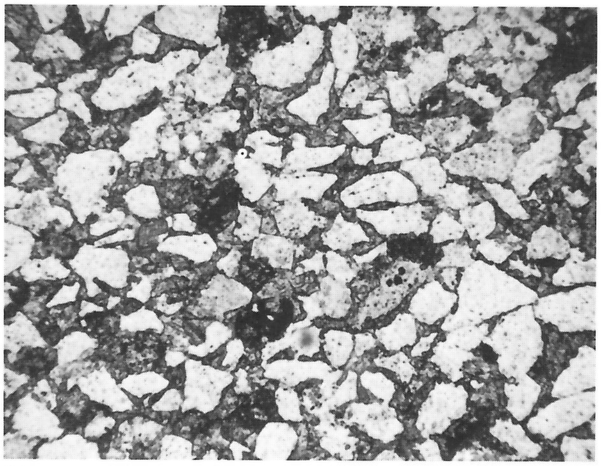
C. "Floating" or carbonate-supported quartz and feldspar grains in a recrystallized carbonaceous-ferruginous dolomite. Dark opaque grains are phosphatic pellets. Ludington Formation.

D. Same thin section as C; crossed nicols.

E. Rounded to subrounded quartz and feldspar grains in a fine to medium crystalline recrystallized cement of calcite. Note corroded nature of detrital grain boundaries.

F. Same thin section as E; crossed nicols. Note large grain of microcrystalline quartz centre right.

PLATE 4



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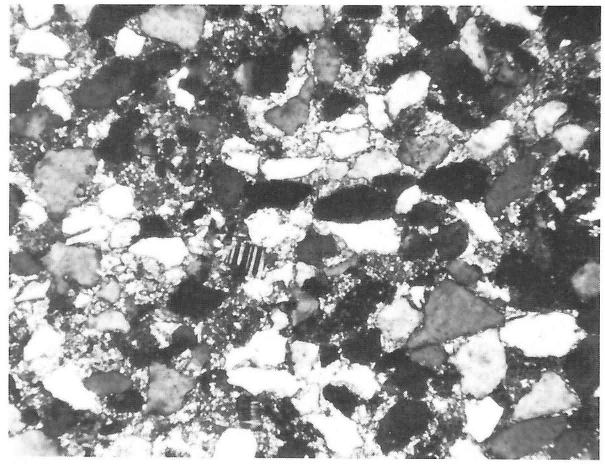

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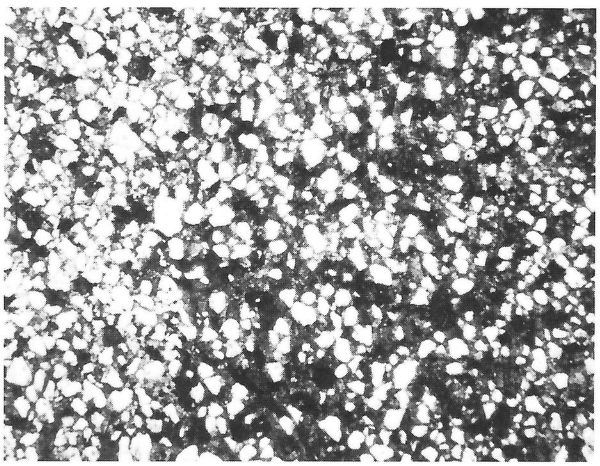

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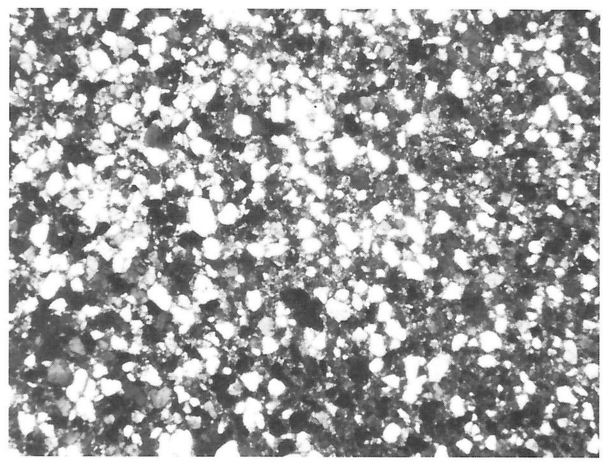

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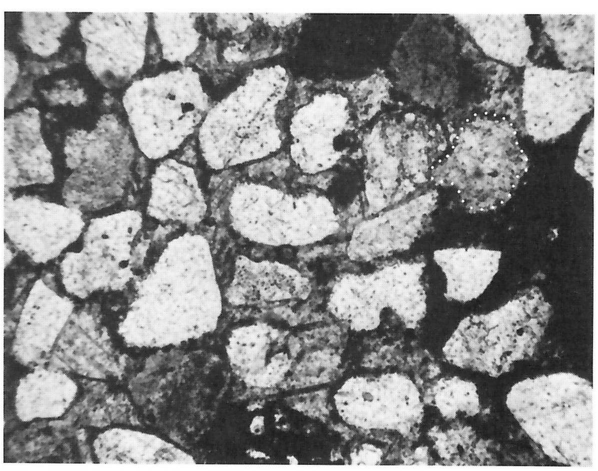

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E

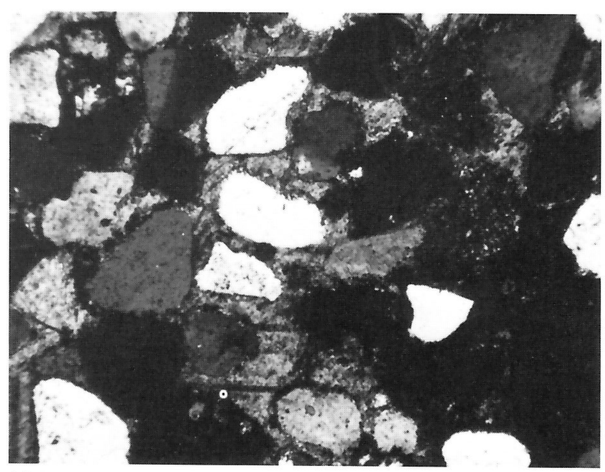

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PLATE 5

A. Granular phosphate in cement and matrix of calcite and collophane, Whistler Member, Mount Becker. Note ooliths, pellets, and well-rounded nature of component grains.

B. Large ooliths and well-rounded grains of collophane, Whistler Member, Mount Becker. Clear grains secondary quartz. Note ferruginous inclusions.

C. Well-rounded grains, pellets, and ooliths of collophane, Whistler Member, Ganoid Ridge. Note core of detrital quartz in large oolith.

D. Phosphatic conglomerate, base of Whistler Member, Casket Mountain.

E. Subhedral to euhedral dolomite crystals in medium to coarsely crystalline recrystallized calcite. Note "floating" or carbonate-supported quartz and feldspar grains. Llama Member, Ganoid Ridge.

F. Same thin section as E; crossed nicols.

PLATE 5

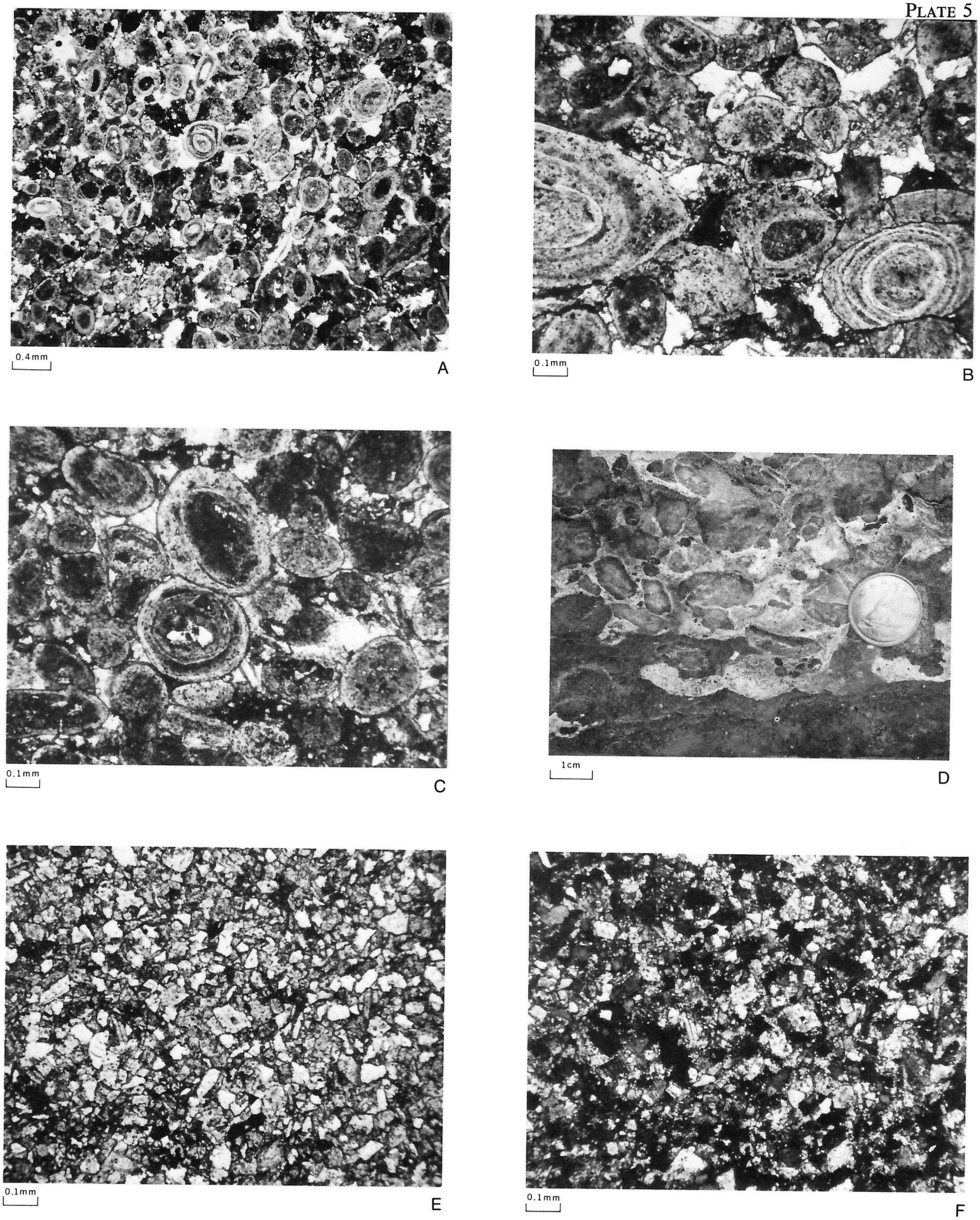


Plate 6

A. Euhedral dolomite rhombs in recrystallized medium crystalline dolomite cement.

B. Euhedral dolomite overgrowth on well-rounded grain of dolomite in medium crystalline calcite cement. Brewster Limestone Member, West Burnt River.

C. Well-rounded relict grains or pseudo-oolites of dolomite in finely crystalline cement of dolomite. Small clear grains of quartz and minor feldspar, Charlie Lake Formation, Clearwater Lake area.

D. Crinoid columnal bioclasts in very finely crystalline dolomite cement. Note carbonate-supported quartz and feldspar grains. Baldonnel Formation, Halfway River area.

E. Bioclastic limestone of Brewster Limestone Member showing probable algal-coated bioclast. Cement is finely crystalline carbonaceous-ferruginous calcite.

F. Well-rounded bioclasts composed of crinoid-echinoid and pelecypod shell fragments in recrystallized calcite cement and matrix. Note well-rounded grains of quartz. Ludington Formation, Mount Ludington.

Plate 6

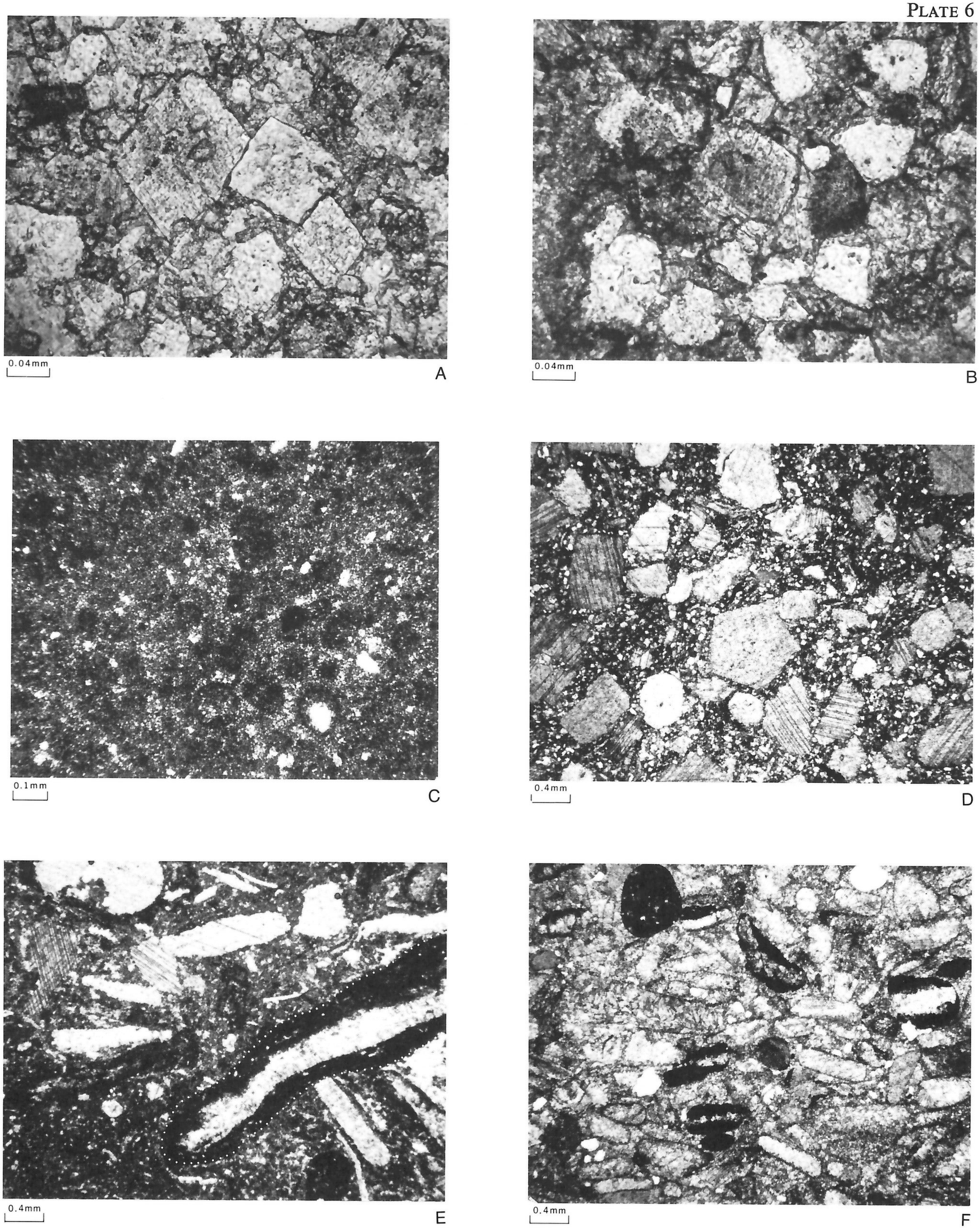


PLATE 7

A. "Ghost" outlines of well-rounded recrystallized pelecypod? shell bioclasts in medium crystalline calcite cement. Note large semi-opaque grain of collophane and scattered angular grains of quartz and feldspar. Starlight Evaporite Member, Ganoid Ridge.

B. Bioclastic limestone composed of fragmented pelecypod shells (*Monotis*) cemented by carbonaceous calcite. Interstices filled with coarsely crystalline calcite. Pardonet Formation, Pink Mountain.

C. Bioclastic limestone composed of thin-shelled pelecypod fragments in finely crystalline, very carbonaceous-ferruginous limestone. Note wavy silt laminae between some shell layers. Whistler Member, Wolverine – Sukunka River area.

D. Fragmented pelecypod shell bioclasts in silty, very carbonaceous-ferruginous limestone. Note angular fragmented character of bioclasts. Toad Formation, Clearwater Lake, Pine Pass – Peace River area.

E. Fibrous calcite bounded above and below by granular calcite (calcarenite). Opaque material is carbonaceous-ferruginous matter, Bocock Formation, Pine Pass – Peace River area.

F. Fibrous calcite lens in carbonaceous-ferruginous calcareous siltstone of Vega–Phroso Siltstone Member, Pine Pass – Sukunka River area. Note opaque carbonaceous laminations above and below fibrous calcite.

PLATE 7

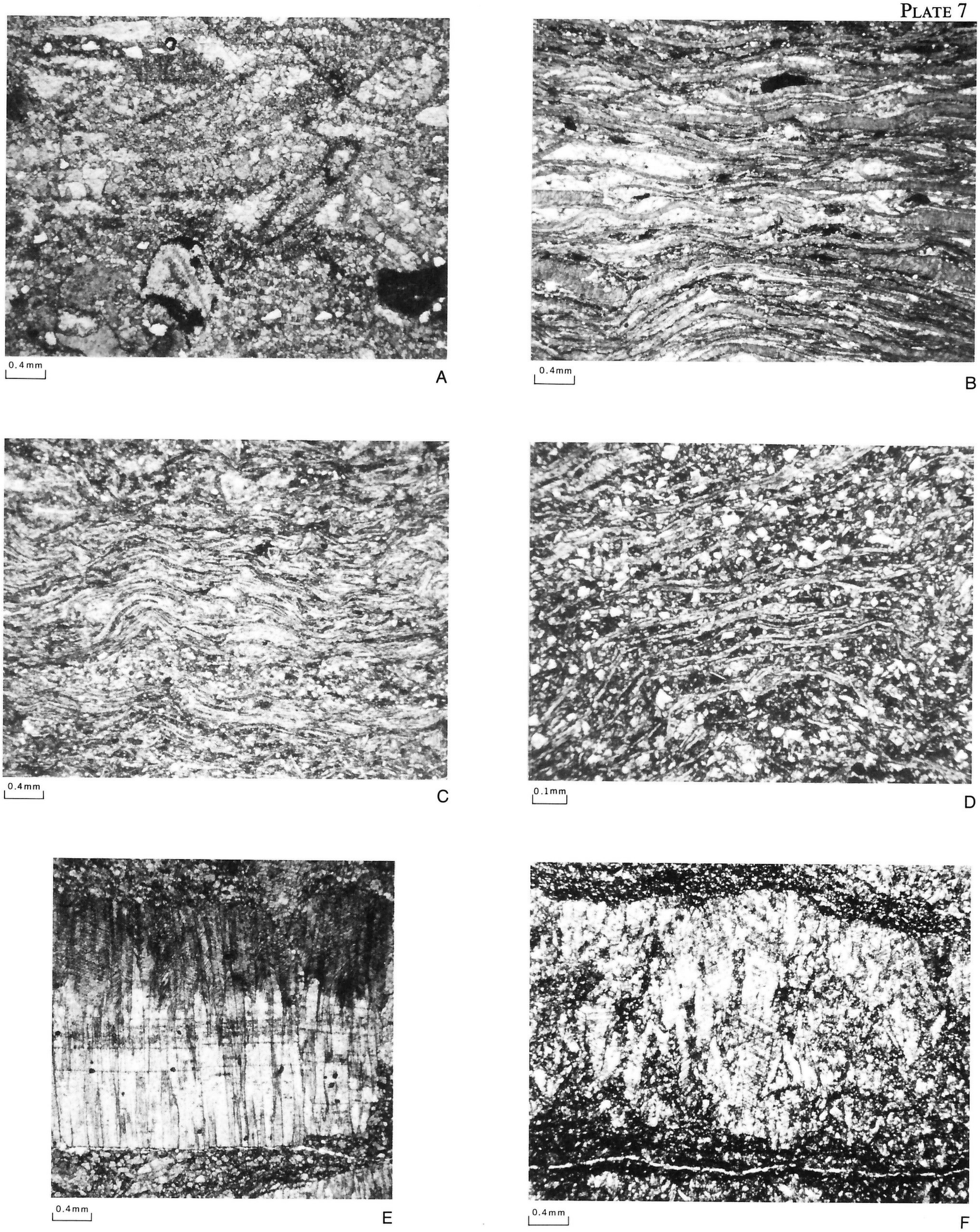


Plate 8

A. Well-rounded spheres interpreted as calcispheres in carbonaceous-ferruginous limestone of Toad Formation, Mount Ludington.

B. Well-rounded spheres or calcispheres in very carbonaceous limestone of Vega–Phroso Siltstone Member. Note concentric banding in calcisphere in centre right of photo.

C. Enlarged photomicrograph of B showing relict pillars between and extending through concentric bands.

D. Well-rounded spheres or calcispheres showing their recrystallized character obliterating all original structure. Note "floating" quartz and feldspar grains and scattered elongate flakes of muscovite. Toad Formation, Pine Pass – Sukunka River area.

E. Dolomitized spheres or calcispheres illustrating recrystallized nature of the dolomite. Note stained (alizarin red S) calcite core of large sphere in centre of photograph.

F. Pelecypod shell coquina with large oolith-pisolith, Pardonet Formation, Carbon Creek – Pine Pass – Peace River area.

PLATE 8

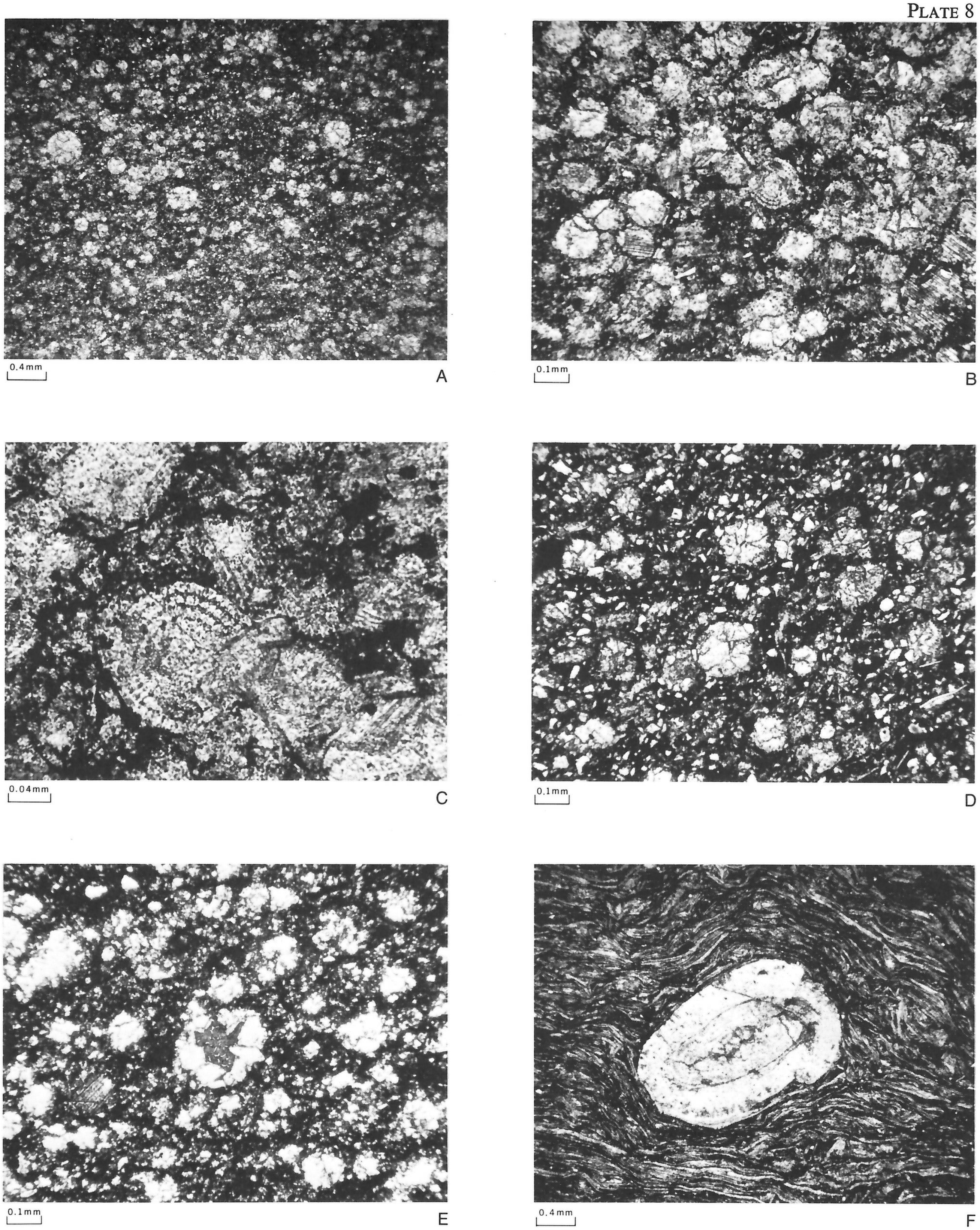


PLATE 9

A. Ooliths-pisoliths in pelecypod shell coquina. Note clear calcite-filled concentric and radiating fractures in ooliths-pisoliths, which do not extend beyond rim of sphere. Pardonet Formation, Pine Pass – Peace River area.

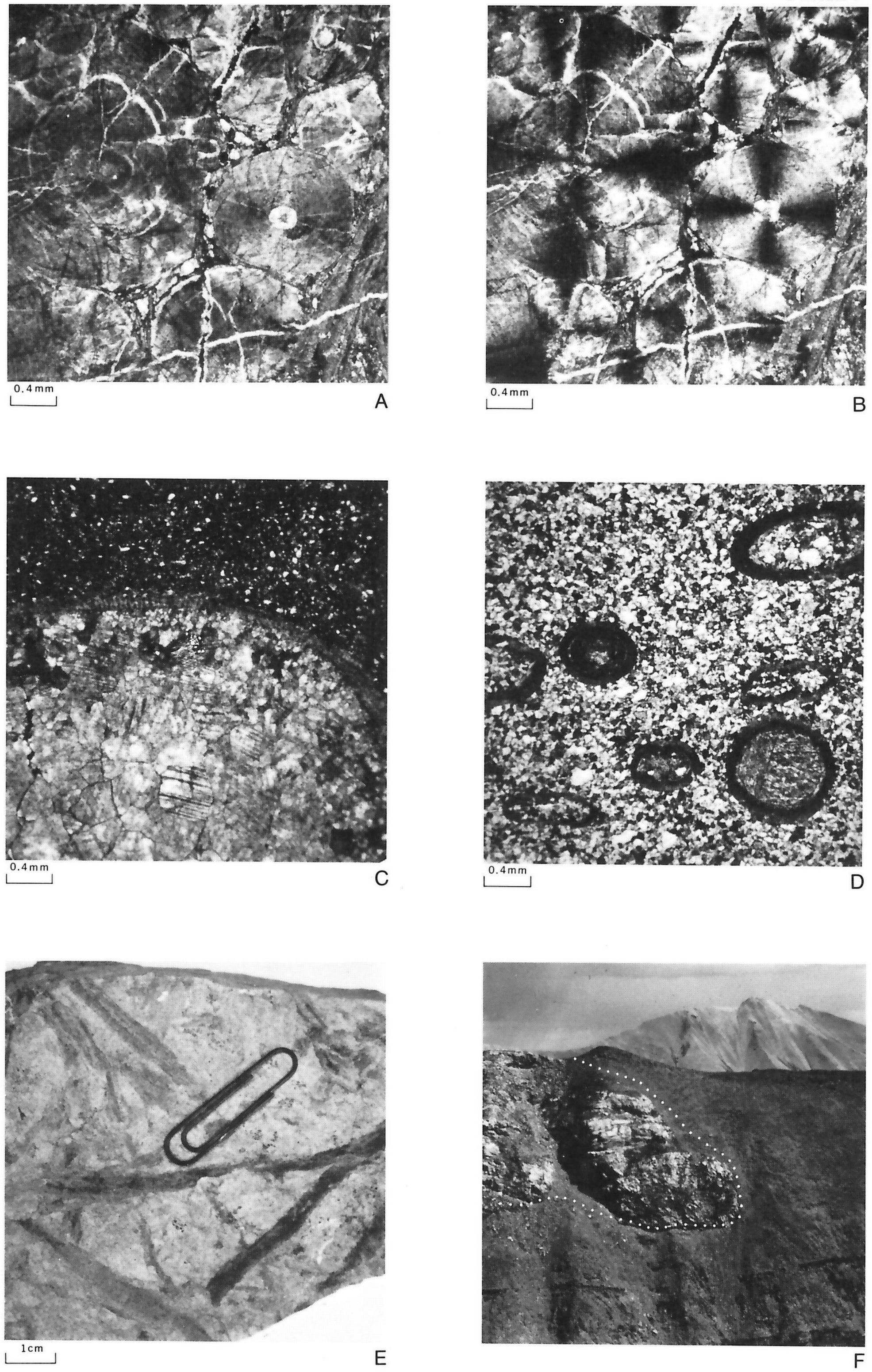
B. Same thin section as A; crossed nicols.

C. Large spherical grain of coarsely crystalline dolomite with concentric rim, displaying in part relict pillar structures of probable algal origin. Pardonet Formation, West Burnt River.

D. Annelid? tests in cross-section, dolomitic siltstone of Llama Member, Lick Creek.

E. Probable aquatic plant stems and stem fragments preserved as dark grey carbonaceous films, upper Llama Member.

F. Bioclastic shell bank, Ludington Formation, Mount Laurier area.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A
0.4mm
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C
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1cm
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F